

SCHOOL LAUNCH • GEOGRAPHY K-12

GRADE 8 GEOGRAPHY: RIVERS, PORTS AND STRAITS

A year of true stories about where cities and trade begin, from the fords of Oxford and Frankfurt and the fall-line mills of Richmond to the flooding Nile, the mud banks of Venice, Malcom McLean's first container ship, the narrow seas of Gibraltar and Malacca, the locks of Panama and the satellites of GPS, each one taken apart to see why the place mattered and then tried at the kitchen table with string, bottles, blocks and a map notebook, ending with a study of the student's own city.

First edition

"And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;" (Acts 17:26, KJV)

COURSE GUIDE

Why do cities stand where they do? This course answers that question across one school year in eight units: the ford, the confluence, the fall line and the harbor; the river civilizations of the Nile, the Tigris and Euphrates, the Indus and the Yellow River; the great port cities of Venice, Amsterdam, London and New York; the modern container ports of Rotterdam, Singapore and Hong Kong; the straits and choke points of the sea, from Gibraltar and the Bosphorus to Malacca, Hormuz and the English Channel; the canals that cut through continents; the map skills of real life; and a capstone study of the student's own city.

Every lesson follows the same path. First comes **the story**: a real place at a real moment, such as the Franks crossing the Main at Frankfurt, the yearly flood rising along the Nile, the *Ideal X* sailing from Newark in 1956, or the Suez Canal opening in 1869. Then **how they figured it out**: what the land and water offered, what stood in the way, and what people tried. Then **the big idea** underneath, explained for an eighth grader: site and situation, the head of navigation, the natural harbor, the choke point, the lock, the bearing, trilateration and the map layer. Last, the student does it with his or her own hands and records it in the map notebook.

A thread runs through the whole year: **technology overcoming geography**. Good geography gives a city its start, but people make it great. The shaduf lifts the river onto the fields, canals and locks lift ships over mountains and between seas, the steel box and the giant crane change every port on earth, and satellites put a blue dot on every phone. The course also shows what technology has not overcome: a narrow strait is still narrow, and a shallow harbor still needs dredging.

The course is taught from a Christian view of the world. God made the seas and the dry land, and He set the rivers in their courses: "For he hath founded it upon the seas, and established it upon the floods" (Psalm 24:2). The series verse reminds us that the peoples who built cities along these rivers and coasts are one family under one Creator: "And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;" (Acts 17:26). Along the way the student follows Abraham out of Ur and the apostle Paul along the sea lanes of Rome to his shipwreck on Malta (Acts 27).

WHO IT IS FOR

Written for students in grade 8 (about ages 13–14) who read on their own, can work with ratios, percentages and simple measurements, and are ready to use a compass and a ruler with care. A parent or teacher reads along, discusses the stories, helps with the larger projects and goes along for any orienteering outside the home. Nothing needs to be bought beyond ordinary household items, a world atlas and an inexpensive baseplate compass; the GIS lessons use free public map websites.

HOW TO USE THIS COURSE

The weekly rhythm. The year has 32 lessons, one a week, in eight units of four. Session 1 (about 45 minutes) is the warm-up, the video, the teaching, the worked examples and the picture study. Session 2 (about 45 minutes) is the project, the practice and the map notebook. In the last week of each unit, add a third session for the unit review and the unit project. The capstone, Unit 8, can stretch across a month if the city study needs more time. The optional **Map Lab** adds four lessons of games and puzzles: an orienteering race, a trade-route board game called Port Tycoon, an old-map detective puzzle and a GIS treasure hunt. Use it at the end of the year, over the summer or as a reward between units.

The ★ and ⚙ marks. Ten lessons are marked ★. Together they make the *quarter path*, a one-quarter version of the course for families who want a shorter study; it keeps at least one lesson from every unit along with the core skills and the technology thread. Lessons marked ⚙ carry the thread of technology overcoming geography: the shaduf, canals and locks, the container and the crane, GPS and GIS. Units 4, 6 and 7 carry the thread from start to finish.

The map notebook. Use one graph-paper composition book for the whole year. Each unit asks for one careful map: fall-line cities and river confluences, the four river valleys, four harbors compared, the world's twenty busiest ports, the eight great straits, the four canals and the voyages they shorten, a layered map of the county and finally the capstone map of the student's own city. Every map gets a title, a date, a north arrow, a scale and a key. Date every page and write one sentence about what the map shows.

Worked examples and practice. Each lesson includes worked examples that show the reasoning step by step, such as measuring how many miles the Panama Canal saves on a voyage from New York to San Francisco, converting a compass bearing, or reading the scale on an old map. Practice questions follow, with answers given in the lesson so the student can check his or her own work. When an answer is wrong, find the step where the thinking went off course before moving on.

Unit reviews and unit projects. Each unit ends with a short review (50 points) and a unit project that pulls the unit together: a site-and-situation game, a working shaduf, a harbor model, a container-ship loading puzzle, a choke-point traffic game, a working model lock, an orienteering course and, at the end, the city study with a poster, a map and a short talk for the family. Keep the unit projects and their notebook pages in one folder for the year.

How it fits the series. This is the eighth year of the School Launch Geography series, which runs from first maps in kindergarten to the high school electives on borders, sea lanes and trade. It pairs well with the School Launch Engineering courses, which build the same locks, levers and bridges from the builder's side, and the Business and Finance courses, which follow the merchants, ports and trade routes from the trader's side. A student taking all three will meet the Erie Canal, the container and the great ports from three angles.

SCOPE AND SEQUENCE

Unit 1: Why Cities Stand Where They Do (1–4)

Site and situation: the ford and the bridge at Oxford, Frankfurt and London; the confluence at Pittsburgh; the fall-line cities where boats stopped and mills began; and the hills and harbors chosen for defense and trade.

Unit 2: The River Civilizations (5–8)

The Nile and its yearly flood, “the gift of the river”; the canals of Mesopotamia and Abraham’s Ur; the planned streets of Mohenjo-daro on the Indus; and the Yellow River, “China’s sorrow,” with the flood control of Yu the Great.

Unit 3: Great Port Cities, Old and New (9–12)

Venice, a republic built on mud banks and trade; Amsterdam’s canals, ships and shares in the Dutch East India Company; London’s docks on the Thames; and New York, where a deep harbor and the Erie Canal made America’s greatest port.

Unit 4: Modern Ports and the Container (13–16)

Rotterdam, Europe’s gateway on the Rhine; Singapore and Hong Kong at the crossroads of Asia; Malcom McLean and the *Ideal X* in 1956; and a working day at a container port with its cranes, stacks and trucks.

Unit 5: Straits and Choke Points (17–20)

What makes a strait a choke point; Gibraltar and the Bosphorus, the doors of the Mediterranean and the Black Sea; the Strait of Malacca and the Strait of Hormuz, taught as facts of geography; and the English Channel, twenty miles of water that protected Britain.

Unit 6: Canals Through Continents (21–24)

The Grand Canal of China and its rice barges; Ferdinand de Lesseps and the sea-level Suez Canal (1869); Goethals, Gorgas and the locks of the Panama Canal (1904–1914); and the St. Lawrence Seaway that brought ocean ships to the Great Lakes (1959).

Unit 7: Map Skills for Real Life (25–28)

Taking and following a bearing with a baseplate compass; finding control points on an orienteering map; how GPS satellites find a position by trilateration; and layered GIS maps, from John Snow’s cholera map of 1854 to a free online map of the student’s own county.

Unit 8: Capstone: The Geography of My City (29–32)

The student studies his or her own city or nearest town: why it was founded where it was, how roads, rails and rivers connect it to the world, how an old map compares with today’s, and a poster, map and short talk presented to the family.

Unit 9: Bonus: Map Lab (Optional)

Four lessons of map games and puzzles: an orienteering race, a trade-route board game, dating an old map by its clues and a GIS treasure hunt.

MATERIALS

- **Map notebook (a graph-paper composition book):** One for the whole year: every unit map, the worked examples, practice answers and project records.
- **A world atlas and a road map or printed map of your county:** Any recent atlas will do. Free printable maps from the U.S. Geological Survey or your state transportation department work well for Units 7 and 8.
- **A baseplate (orienteering) compass:** An inexpensive one is fine. Used in Unit 7, the capstone and the Map Lab orienteering race.
- **A ruler, protractor, string, colored pencils and fine-tip markers:** For measuring distances by scale, plotting bearings and drawing distance circles in the GPS lesson.
- **Sticks, string, tape and a small weight for the shaduf:** Unit 2. A paper cup makes the bucket and a lump of clay or a bag of coins makes the counterweight.
- **Two or three clean plastic bottles, a craft knife (used by a parent), and waterproof tape:** For the working model lock in Unit 6. Do this one at the kitchen sink or outdoors.
- **Building blocks or small boxes, coins or washers for weights, and a shallow tray or tub of water:** For the harbor model, the container-ship loading puzzle and the choke-point traffic game with toy boats.
- **Clear plastic sheets or tracing paper:** For layering maps in the GIS lesson and for comparing an old map of your city with a new one.
- **A computer or tablet with internet access:** For the lesson videos, a free online GIS map of your county and the Library of Congress map collections.
- **Optional: one of the books or resources listed in a unit:** Never required. See the list in each unit.

GRADING

Grades come mostly from the projects and the map notebook, because geography is learned by looking, measuring and drawing. A project that did not work the first time but is honestly recorded, explained and improved earns full credit.

- Projects (effort, careful measuring and the improve-it step): 30%
- Map notebook (titled, dated maps with north arrow, scale and key; practice checked): 20%
- Unit reviews: 20%
- Unit projects, including the capstone city study: 30%

A 90–100, B 80–89, C 70–79, D 60–69. Below 60: redo the project or review with help.

- Grade the reasoning, not just the answer. Can the student explain why a city grew where it did, what the land offered and what people built to overcome what it lacked?
- A notebook map earns full marks when it has a title, a date, a north arrow, a scale, a key and one sentence about what the map shows.

- Unit reviews may be done orally for a student who writes slowly; the parent writes down the answers.
- The capstone city study counts as the Unit 8 project. Grade the poster, the map and the short talk together, and give credit for good questions asked of librarians, older relatives or the local historical society.

A NOTE TO PARENTS

You do not need to be a geographer to teach this course. Read the story together, look at the picture and the map, and then ask three questions: “Why here and not somewhere else?”, “What did the land and water give these people, and what did they have to build?” and “How do you know? Show me on the map.” Those three questions are most of what a good geography teacher does.

The course tells history and present-day facts honestly and plainly. Straits such as Hormuz and Malacca, and cities such as Hong Kong and Singapore, are taught as matters of geography and trade, not of present-day politics, and nothing in the course asks you or your child to take a side in current public debates. Builders and explorers are shown with their real achievements and their real failings.

The orienteering lessons and the capstone take the student out into your town. Go along, or choose a safe park you know well, and help your child find the old maps, the historical marker and the oldest bridge or road. By the end of the year, the hope is that your child will never look at a river, a harbor or a highway in quite the same way again, and will see in the shape of the land the hand of the One who “hath determined the times before appointed, and the bounds of their habitation.”

CONTENTS

Unit 1: Why Cities Stand Where They Do

- 1.1 The Ford and the Bridge ★
- 1.2 The Confluence
- 1.3 The Fall Line
- 1.4 The Hill and the Harbor

Unit 2: The River Civilizations

- 2.1 The Nile: The Gift of the River ★
- 2.2 The Tigris and Euphrates: Canals, Cities and Abraham's Ur
- 2.3 The Indus: Mohenjo-daro's Planned Streets
- 2.4 The Yellow River: China's Sorrow and Yu the Great

Unit 3: Great Port Cities, Old and New

- 3.1 Venice: A Republic Built on Mud Banks and Trade ★
- 3.2 Amsterdam and the Dutch Golden Age
- 3.3 London and the Thames: Docks for an Empire
- 3.4 New York: A Deep Harbor and the Erie Canal ⚙

Unit 4: Modern Ports and the Container

- 4.1 Rotterdam: Europe's Gateway on the Rhine ★
- 4.2 Singapore and Hong Kong: Ports at the Crossroads of Asia
- 4.3 Malcom McLean's Box ★ ⚙
- 4.4 A Day at a Container Port ⚙

Unit 5: Straits and Choke Points

- 5.1 What Is a Strait? ★
- 5.2 Gibraltar and the Bosphorus
- 5.3 Malacca and Hormuz
- 5.4 The English Channel

Unit 6: Canals Through Continents

- 6.1 The Grand Canal of China ★ ⚙
- 6.2 The Suez Canal ⚙
- 6.3 The Panama Canal ⚙
- 6.4 The St. Lawrence Seaway ⚙

Unit 7: Map Skills for Real Life

- 7.1 Bearings and the Compass ★
- 7.2 Orienteering
- 7.3 GPS: How Satellites Tell a Phone Where It Is ★ ⚙
- 7.4 GIS: Maps in Layers ⚙

Unit 8: Capstone: The Geography of My City

- 8.1 Site and Situation of My City ★
- 8.2 Roads, Rails and Rivers ⚙
- 8.3 Old Maps and New
- 8.4 Presenting My City

Unit 9: Bonus: Map Lab (optional)

9.1 Orienteering Race

9.2 Port Tycoon

9.3 Old Map Detective

9.4 GIS Treasure Hunt

★ quarter path · ⚙ technology overcoming geography

WHY CITIES STAND WHERE THEY DO

No great city stands where it does by accident. Long before there were city planners, travelers and traders found the places where a river could be waded, where two rivers met, where boats had to stop, or where a steep rock rose beside safe water. People gathered at those places, and towns grew. Geographers explain every town with two words: its **site**, the ground it stands on, and its **situation**, the way it connects to the world around it. Scripture calls Mount Zion “beautiful for situation” (Psalm 48:2), and the Apostle Paul told the Athenians that God “hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;” (Acts 17:26).

In this unit you will stand with Peter of Colechurch as he begins the stone London Bridge in 1176, and read how Oxford and Frankfurt were named for their fords. You will follow twenty-one-year-old George Washington to the Forks of the Ohio in 1753, where he judged the point “extremely well situated for a Fort.” You will row up the James with Captain Newport in 1607 until the falls stop the boat, and see how the fall line raised Richmond, Washington and Philadelphia. Finally you will climb the Acropolis of Athens, the hills of Rome and the castle rock of Edinburgh, and learn how each city joined a safe hill to a busy harbor.

All through the unit you will build a **Site-and-Situation Game** board, settling an imaginary land one town at a time, and you will map the fall-line cities and the great river confluences. By the end you should be able to look at any map and predict where the cities ought to be.

BEFORE YOU BEGIN

- Can read latitude and longitude in degrees and use a map scale
- Knows the cardinal and intermediate directions (N, NE, E, SE and so on)
- Can multiply and divide decimals and convert between kilometers and miles
- Can find the major rivers of the eastern United States and of Europe on a map

MASTERY CHECKLIST

- I can explain the difference between a town’s site and its situation and give an example of each.
- I can explain why fords, the lowest bridging point and confluences attract towns, using Oxford, Frankfurt, London and Pittsburgh.
- I can explain what the fall line is, why it formed, and why Richmond, Washington and Philadelphia grew on it.
- I can explain the trade-off between defense and trade and how Athens, Rome and Edinburgh each joined a hill to a harbor.
- I can use map scales, latitude and longitude, and bearings to find distances and directions between real cities.
- I can predict good town sites on a blank landscape and defend my choices.

OPTIONAL BOOKS AND RESOURCES

- **Library of Congress: Maps Collection** (<https://www.loc.gov/maps/>): Free. Search for Lewis Evans's 1755 map of the middle colonies, L'Enfant's 1791 plan of Washington, and old maps of Pittsburgh and Richmond. Zoom in to find fords, falls and confluences.
- **Great Falls Park (National Park Service)** (<https://www.nps.gov/grfa/>): Free information and maps. See the Great Falls of the Potomac and the remains of George Washington's Patowmack Canal locks. Worth a visit for families near Washington, D.C.
- **USGS TopoView (historical topographic maps)** (<https://ngmdb.usgs.gov/topoview/>): Free. Browse old and new U.S. topographic maps. Find your own nearest river and look for the fords, falls and confluences where towns began.

1.1 THE FORD AND THE BRIDGE ★

OBJECTIVES

- Define site and situation and explain why a ford or the lowest bridging point on a river drew travelers, markets and towns.
- Tell the stories of Oxford, Frankfurt and London Bridge and locate each on a map.
- Use latitude, longitude and a map scale to find the distance between real river towns in kilometers and miles.

Warm-up. Lay a long bath towel across the floor as a river. Put three or four books under it in different places so the towel is “shallow” in some spots and “deep” (flat on the floor) in others. You are leading a cart loaded with wool and two oxen. Walk along the bank and choose the one place you would cross. Then ask: if a hundred travelers a day crossed there, what would soon be built beside that spot? Where would an innkeeper set up? Where would a lord build a tower to collect a toll?

Watch. *What happened to Old London Bridge?* (Map Men, 9:36).

<https://www.youtube.com/watch?v=u5CguqywlBk>

After the story: the old London Bridge with houses built on it, and why the crossing made London.

Note: Map Men is a comedy-history channel: jokes, songs and silly voices, but the facts check out. It ends with a sponsor message, so stop when the history ends.

Backup video. *The 1014 Viking Attack on London Bridge* (The History Guy: History Deserves to Be Remembered, 10:39). <https://www.youtube.com/watch?v=bckAgAGAglo>
With the history note: the story behind “London Bridge is falling down,” and the river crossing in 1014.

KEY TERMS

site

The actual ground a town stands on: its soil, slope, water supply, river crossing, hill or harbor.

situation

Where a town lies in relation to the places and routes around it: the roads, rivers, coasts and neighbors that connect it to the wider world.

ford

A shallow place with a firm bottom where people, animals and carts can wade across a river.

lowest bridging point

The point farthest downstream (nearest the sea) where a river could be bridged; often also the highest point that seagoing ships could reach.

route center

A place where several roads or waterways meet, so that travelers from many directions pass through it. Geographers also call it a nodal point.

tidal river

The lower part of a river where the sea's tide rises and falls twice a day, carrying ships upstream on the flood tide and back down on the ebb.

CORE IDEAS

The story. In the year 1176 a London priest named Peter, chaplain of the little church of St. Mary Colechurch, began a task no one in England had attempted: a bridge of stone across the tidal Thames. Wooden bridges had stood near the spot since Roman times, but they rotted, burned and were battered by ice and floods. Peter's workmen drove elm piles into the riverbed and built boat-shaped platforms of rubble around them, called **starlings**. On these they raised nineteen pointed stone arches. The work took thirty-three years. Peter died in 1205 and was buried in the chapel built on the middle of the bridge; the bridge was finished in 1209. Old London Bridge then stood for more than six hundred years, lined with houses and shops, and for most of that time it was the only bridge across the Thames in London.

How they figured it out. Why build there and nowhere else? The Romans, who invaded Britain in AD 43, had already answered that question. Within a few years they bridged the Thames at almost the same place and founded the town of Londinium beside it. On the north bank, two low hills of gravel (today called Cornhill and Ludgate Hill) stood firm and dry above the marshes. The river here was narrow enough to bridge, yet the tide still pushed far enough up to carry seagoing ships. So the bridge marked the meeting of two worlds: ships from the sea unloaded below it, and roads fanned out from it across the land. That made London the **lowest bridging point** on the Thames, and every road from the south coast to the north of England had a reason to pass through it.

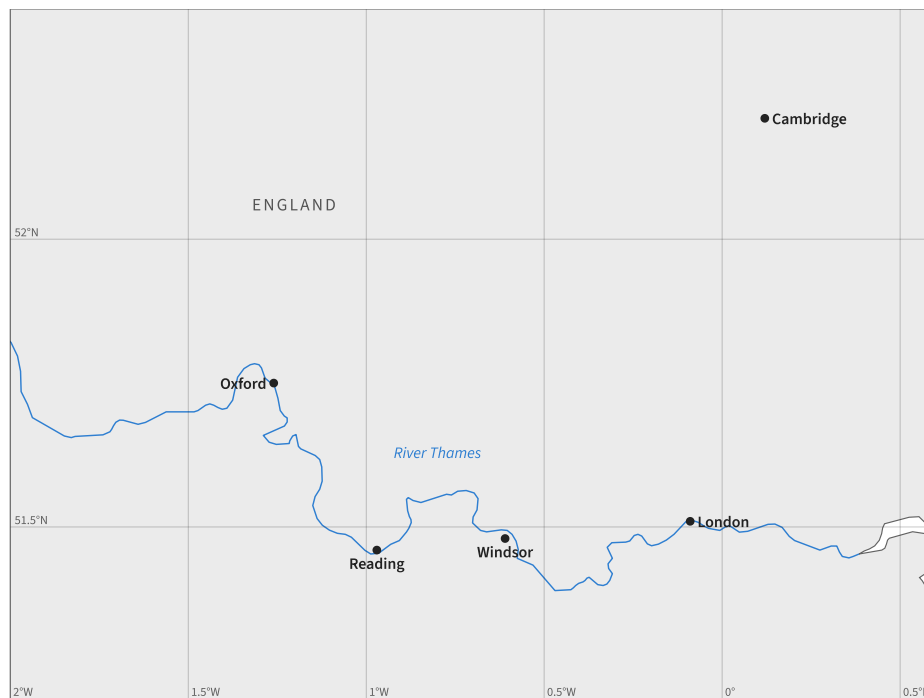
Before the bridge, the ford. Long before stone bridges, people crossed rivers at **fords**: shallow places with a hard gravel bottom and gentle banks. Some fifty miles west of London, far up the Thames, the Anglo-Saxon Chronicle names *Oxnaforða*, "the ford of the oxen," in its entry for 911 (912 in some copies), when King Edward the Elder took control of London and Oxford. The town grew on a dry gravel tongue of land between the Thames and its tributary the Cherwell, and its coat of arms still shows an ox crossing water. On the river Main in Germany, a charter of Charlemagne from 794 names *Franconofurd*, "the ford of the Franks." A legend says a white deer showed Charlemagne's army the shallow crossing while they fled from the Saxons. The real reason is plainer: a low hill on the north bank stayed above floods, and the Main was easy to wade there. Frankfurt grew into a great market and fair town, and in 1356 the Golden Bull named it the place where German kings were to be elected.

The big idea. Geographers ask two questions about every town. The first is its **site**: the ground itself. Is it dry, firm and above the floods? Is there fresh water? Can it be defended? The second is its **situation**: how it connects to everything around it. Which roads and rivers lead to it? What lies upstream and downstream? A ford or a bridge gives a town both. The site is good because the river is crossable there. The situation is good because roads from

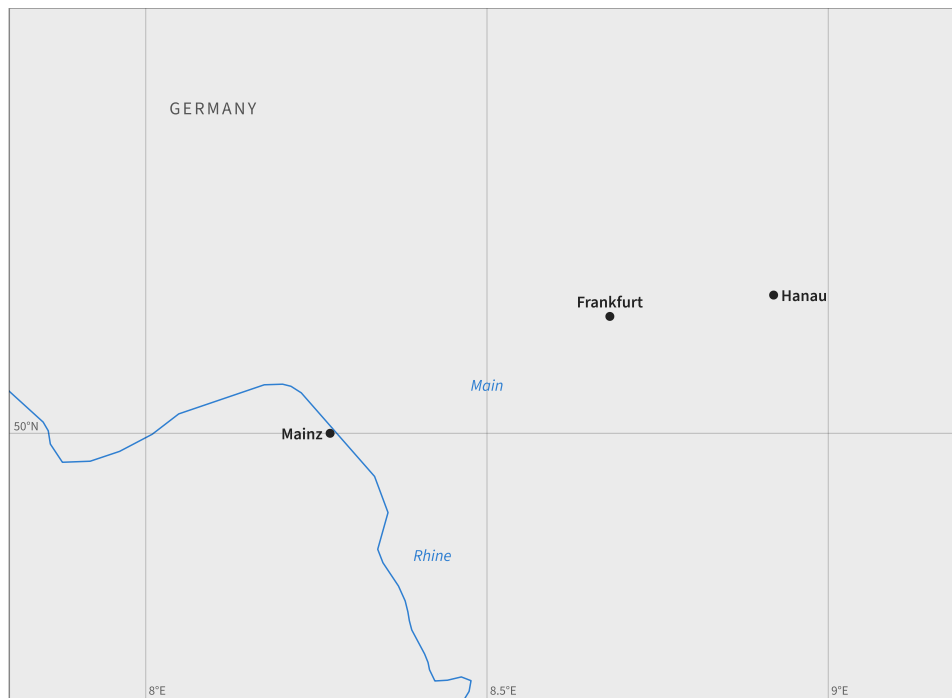
many directions must bend toward the crossing, turning the town into a **route center**. Wherever travelers are forced to gather, people follow them to sell food, rent beds, trade goods, collect tolls and build castles to guard the crossing. The Normans built Oxford Castle in 1071 for exactly that reason.

On the map. Old place names are fossils of geography. English towns ending in *-ford* (Oxford, Stratford, Bradford) and German towns ending in *-furt* or *-furth* (Frankfurt, Erfurt, Schweinfurt) began at fords. Names with *-bridge* or the German *-brück* began at bridges: Cambridge on the river Cam, Innsbruck (“Inn bridge”) on the river Inn. Maastricht in the Netherlands comes from the Latin *Mosae Trajectum*, “the crossing of the Meuse.” Hartford, Connecticut, took its name from Hertford in England, another ford town. When you find one of these names on a map, look for the river.

Technology overcoming geography. A ford works only when the river is low; a flood can close it for weeks. A bridge conquers the river in every season, but it costs a fortune and needs skilled engineers, so for centuries a great river might have only one or two. In the heart of London, London Bridge stood alone until Westminster Bridge opened in 1750. As engineering improved, bridges multiplied, and today the Thames is crossed far downstream by the Queen Elizabeth II Bridge at Dartford, opened in 1991. Yet London still stands where the Romans first bridged the river. Technology can add new crossings, but the first good crossing usually keeps its city.



The Thames from the ford of Oxford to the bridge of London. Both towns stand where the river could be crossed.



Frankfurt, “the ford of the Franks,” on the river Main about 30 km (20 miles) above its meeting with the Rhine at Mainz.

PICTURE STUDY



London: The Thames from Somerset House Terrace towards the City, Canaletto (Giovanni Antonio Canal), about 1750–51 · Oil on canvas · Royal Collection, United Kingdom

Canaletto was a Venetian painter famous for *vedute*, careful and sunny views of cities. In 1746, when war made it hard for English travelers to reach Venice, he came to London and stayed for about nine years. From the riverside terrace of old Somerset House he painted a

pair of views: one looking upstream toward Westminster and this one looking downstream toward the City of London and the dome of St. Paul's Cathedral.

Both pictures were painted for Joseph Smith, the British consul in Venice and Canaletto's great patron. King George III bought Smith's collection in 1762, and the paintings have belonged to the royal family ever since. Look at the river as Canaletto saw it: not a barrier, but London's busiest street.

Look closely

- Find the dome of St. Paul's Cathedral. Christopher Wren finished it in 1710 after the Great Fire of 1666. Count the church spires around it.
- Find the small rowing boats. These were wherries, water taxis rowed by licensed watermen who carried people across and along the river. Why were there so many?
- Find the larger boats with sails. What might they be carrying, and where are they going?
- Look for a bridge. In 1750 there was none between Westminster and London Bridge, which lies downstream, around the bend beyond the far end of this view.

Talk about it

1. If you lived on the south bank in 1750 and wanted to reach St. Paul's, how would you get there? What would it cost you in time and money?
2. How does this painting show both the Thames as a highway and the Thames as a barrier?
3. Blackfriars Bridge opened in 1769 a short distance downstream from where Canaletto stood. Who would have been glad of it, and who might have lost business?

PROJECT: THE SITE-AND-SITUATION GAME

You will draw an imaginary, empty landscape and then settle it, one town at a time, like the first people who came to a new land. Every town must be placed for a reason, and the game's scoring rules reward the same things that made Oxford, Frankfurt and London grow. Keep the board: you will add to it in Lessons 1.2 to 1.4, and it becomes part of your unit portfolio.

You will need

- A large sheet of poster board or butcher paper (at least 55 × 70 cm, or 22 × 28 inches)
- Pencil, eraser, ruler, colored pencils (blue, green, brown, gray)
- One six-sided die
- About 10 small tokens per player (beans, buttons or coins) and a few slips of paper
- 2 to 4 players (a parent or sibling makes a fine rival)

Steps

1. Draw a coastline along one short edge of the paper. Give it one sheltered bay (a curve protected by a headland) and one stretch of open beach.
2. Draw a main river from hills on the far edge winding to the sea. Add one tributary that joins it about halfway down. Shade deep stretches dark blue and shallow stretches light blue.
3. Mark three fords with small gray dots where the river is shallow and has firm gravel banks. Mark one rocky falls, where hills end and lowland begins, about two thirds of the way upstream. Mark the tide's limit with a dotted line a short way up from the mouth.
4. Add a marsh along part of the lower river, one steep rocky hill near the coast, forest in the uplands, and a pass through the hills. Rule a light grid of 5 cm (2-inch) squares so towns can be named by square.
5. Take turns. On your turn, place a token as a new town and write a slip that names one advantage of its *site* and one of its *situation*. Score it from this table: ford or bridge point +3; meeting of two rivers +3; at the falls or tide limit +3; sheltered harbor +3; steep hill beside water +2; each road or river route passing through +1; in the marsh -3; on low floodplain with no high ground -2.
6. After each full round, roll the die for an event. 1: great flood (every floodplain town loses 2). 2: raiders (every town without a hill or water on two sides loses 2). 3: trade fair (every town on two or more routes gains 2). 4: hard winter, fords freeze (no change). 5: a king builds a bridge at any one ford town (that town gains 2). 6: a road is built (the roller draws a road linking two towns; both gain 1).
7. Play four rounds. Then draw roads linking every town to its nearest neighbor. The town with the most routes meeting in it is the capital. Write two sentences explaining why it won.

Tips

- Do not cluster all the towns in one corner. Real settlers spread out to claim each good crossing before a rival does.
- A town can have a strong site and a weak situation (a fine hill with no roads) or the reverse. Notice which kind scores better over time.
- Photograph the board after each lesson so you can show how your country grew.

Check your work

- I can explain the difference between a town's site and its situation.
- I can explain why a ford or the lowest bridging point becomes a route center.
- My board shows at least one ford town and one bridge town, each with a written reason.

MAP NOTEBOOK

1. Draw a cross section of a ford: the riverbed, the gravel bar, the water line in summer and the water line in a flood. Label where a cart could cross and when it could not.

2. Sketch Old London Bridge as a strip of nineteen arches with houses on top. Mark north and south, upstream and downstream, and where seagoing ships had to stop.
3. Make a two-column list titled "Fords and Bridges in Names." Find at least six real place names on a map of Britain, Germany or the United States and write the river each one crosses.

From history. When John Rennie's new London Bridge of 1831 began sinking under the weight of modern traffic, the City of London sold it in 1968 to an American businessman, Robert McCulloch. The granite facing was numbered block by block, shipped across the Atlantic and rebuilt over a channel at Lake Havasu City, Arizona, where it was dedicated in 1971. A bridge that once marked the lowest crossing of the Thames now spans water in the desert.

WORKED EXAMPLES

Example 1. Oxford lies at about 51.75° N, 1.26° W. London Bridge lies at about 51.51° N, 0.09° W. Estimate the straight-line distance between them in kilometers and miles. (Use 1° of latitude ≈ 111 km, and 1° of longitude ≈ 111 km $\times$ the cosine of the latitude.)

(Use the map or drawing "Check your answer against the map: London lies east-southeast of Oxford." shown earlier in this lesson.)

1. Difference in latitude: $51.75^\circ - 51.51^\circ = 0.24^\circ$. North-south distance $\approx 0.24 \times 111 = 26.6$ km.
2. Difference in longitude: $1.26^\circ - 0.09^\circ = 1.17^\circ$. At about 51.6° N, $\cos 51.6^\circ \approx 0.62$, so 1° of longitude $\approx 111 \times 0.62 \approx 69$ km. East-west distance $\approx 1.17 \times 69 \approx 80.7$ km.
3. The two distances form the legs of a right triangle. Distance $\approx \sqrt{(26.6^2 + 80.7^2)} = \sqrt{(708 + 6,512)} = \sqrt{7,220} \approx 85$ km.
4. Convert: $85 \text{ km} \div 1.609 \approx 53$ miles.

Answer: About 85 km (about 53 miles), mostly east and a little south from Oxford.

Example 2. On a map with a scale of 1:250,000, the distance from the center of Frankfurt to the center of Mainz measures 12.8 cm. How far apart are they in kilometers and miles?

(Use the map or drawing “Frankfurt and Mainz on the Main and the Rhine.” shown earlier in this lesson.)

1. A scale of 1:250,000 means 1 cm on the map stands for 250,000 cm on the ground.
2. $12.8 \text{ cm} \times 250,000 = 3,200,000 \text{ cm}$ on the ground.
3. $100,000 \text{ cm} = 1 \text{ km}$, so $3,200,000 \text{ cm} = 32 \text{ km}$.
4. $32 \text{ km} \div 1.609 \approx 20 \text{ miles}$.

Answer: About 32 km (about 20 miles).

Example 3. A drover walks his cattle at 3 km/h (about 2 mph). His road meets a river that is too deep to wade, and the nearest ford is 6 km upstream. He must walk up his own bank to the ford, cross, and walk 6 km back down the far bank to rejoin his road. How much time does the detour add? If a bridge is later built where his road meets the river, how much time does he save on each trip? (These numbers are an example, not a real road.)

1. Extra distance = 6 km up to the ford + 6 km back down = 12 km.
2. Extra time = distance $\div$ speed = $12 \text{ km} \div 3 \text{ km/h} = 4 \text{ hours}$.
3. A bridge on his road removes the whole detour, saving 4 hours every time he crosses.
4. Over 50 trips a year that is $50 \times 4 = 200 \text{ hours}$, about 25 working days of 8 hours.

Answer: The detour adds 4 hours (12 km, about 7.5 miles). A bridge on his road saves 4 hours per trip, about 200 hours in 50 trips. This is why towns grew at crossings: every traveler’s time was at stake.

PRACTICE

1. **EASY** Define site and situation. Give one example of each for London.
2. **EASY** What does the name Frankfurt mean, on what river does it stand, and in what year is it first named in writing?
3. **EASY** What does the name Oxford mean, and where does the town stand in relation to the Thames and the Cherwell?
4. **EASY** Peter of Colechurch began Old London Bridge in 1176, and it was finished in 1209. A new London Bridge opened beside it in 1831. How many years did the stone bridge take to build, and how many years did it serve before the new bridge opened?
5. **MEDIUM** On a 1:50,000 map, two fords on the same river are 7.5 cm apart. How far apart are they on the ground in kilometers and miles?

6. **MEDIUM** Cambridge lies at about 52.21° N, 0.12° E, and London Bridge at about 51.51° N, 0.09° W. Estimate the straight-line distance using 1° latitude ≈ 111 km and 1° longitude ≈ 69 km at this latitude.
7. **MEDIUM** Sort these names into “ford” or “bridge” and name the river where you can: Stratford, Innsbruck, Erfurt, Cambridge, Maastricht.
8. **HARD** Using the map g8-thames-crossings, give the compass direction you would travel from Oxford to reach London, and name two towns on the Thames between them.
(Use the map or drawing “Use this map for Problem 8.” shown earlier in this lesson.)
9. **HARD** Explain in three or four sentences why the lowest bridging point on a tidal river is often the place where a great port city grows.
10. **CHALLENGE** In 1750 London had only two bridges across the Thames in the city, and thousands of watermen earned their living rowing passengers across. Write a short paragraph explaining who would gain and who would lose when a new bridge was built, and why a city government might still choose to build it.

COMMON MISTAKES

- Mixing up site and situation. Site is the ground itself; situation is the connections around it. A hill is a site feature; the roads leading to it are part of its situation.
- Thinking a ford is any narrow place in a river. A narrow place is often the deepest and fastest. A ford is a wide, shallow place with a firm bottom.
- Forgetting the cosine when measuring east-west distance by longitude. A degree of longitude shrinks as you go north; at London’s latitude it is only about 69 km, not 111 km.

Make it a game • Ford, Bridge or Neither?. A parent reads out place names one at a time: Oxford, Cambridge, Frankfurt, Innsbruck, Hartford, Stratford, Maastricht, Saarbrücken, Erfurt, Paris, Rome, Bradford. Shout “Ford!”, “Bridge!” or “Neither!” within five seconds. Score a point for each right answer and a bonus point if you can also name the river. Play to ten points, then swap and make the parent play with new names you find on a map.

Scripture. “And he rose up that night, and took his two wives, and his two womenservants, and his eleven sons, and passed over the ford Jabbok.” (Genesis 32:22, KJV)

The Bible names fords because travelers’ lives depended on them. Jacob brought his whole household to the one place the Jabbok could be crossed, and that night at the ford he met God. Crossings are places of meeting, in Scripture and in geography.

Practice answers

1. Site is the ground a town stands on; situation is its location relative to surrounding places and routes. London’s site: dry gravel hills on the north bank of the Thames where the river could

be bridged. London's situation: at the lowest bridging point, where seagoing ships met the roads to the rest of England.

2. "The ford of the Franks." It stands on the river Main and is named (as Franconofurd) in a charter of Charlemagne from 794.
3. "The ford of the oxen" (Old English Oxnaforda). It stands on a dry gravel tongue of land where the Cherwell joins the Thames.
4. Building: $1209 - 1176 = 33$ years. Service: $1831 - 1209 = 622$ years.
5. $7.5 \times 50,000 = 375,000$ cm = 3.75 km $\approx$ 2.3 miles.
6. Latitude difference $0.70^\circ \times 111 \approx 77.7$ km. Longitude difference $0.12 + 0.09 = 0.21^\circ \times 69 \approx 14.5$ km. Distance $\approx \sqrt{(77.7^2 + 14.5^2)} \approx \sqrt{6,248} \approx 79$ km, about 49 miles.
7. Ford: Stratford (Stratford-upon-Avon is on the Avon), Erfurt (on the Gera). Bridge or crossing: Innsbruck (bridge over the Inn), Cambridge (bridge over the Cam), Maastricht (Latin Mosae Trajectum, crossing of the Meuse).
8. East-southeast (roughly east). Reading and Windsor lie on the Thames between them.
9. Ships coming in from the sea can sail up the river on the tide until a bridge (or shallow water) stops them, so they unload there. Roads from the land side also gather at the bridge, because it is the only dry crossing near the sea. Goods must change from ship to cart at this one spot, which brings merchants, warehouses, workers and markets. London grew in exactly this way at London Bridge.
10. Answers will vary. A strong answer notes that travelers, carters and shopkeepers gain because crossing becomes faster, cheaper and possible in any weather, and land near the bridge rises in value. Watermen and ferry owners lose much of their trade. A city might still build the bridge because the time saved by thousands of people every day is worth far more than the business of one trade, and it might help the watermen with compensation or new work.

1.2 THE CONFLUENCE

OBJECTIVES

- Define confluence, tributary and drainage basin, and explain why a confluence gathers trade, armies and towns.
- Retell how George Washington judged the Forks of the Ohio in 1753 and how Fort Duquesne became Fort Pitt and Pittsburgh.
- Read compass bearings of rivers and compare the distance along a river with the straight-line distance.

Warm-up. Fold a sheet of aluminum foil into a shallow letter Y, with two arms and a stem, and prop the arms up on a book so the stem slopes down into a bowl. Put a drop of blue food coloring in one cup of water and a drop of yellow in another. Pour both cups at the same moment, one into each arm. Watch where the colors meet and how far down the stem they stay apart. Then ask: if each arm were a valley full of farms, where would their people meet to trade?

Watch. *George Washington's Defeat: the Battle of Fort Necessity* (The History Guy: History Deserves to Be Remembered, 8:49). <https://www.youtube.com/watch?v=Dh2d2uQ6gps>

After the story: how the fight for the Forks of the Ohio began the French and Indian War.

Backup video. *Why Pittsburgh Exists / Unboxing The Point* (Pittsburgh Unboxed, 8:21). <https://www.youtube.com/watch?v=fzRvyDBE4fE>

With On the map: why Pittsburgh stands where the three rivers meet.

KEY TERMS

confluence

The place where two or more rivers meet and flow on as one.

tributary

A stream or river that flows into a larger river rather than into the sea.

main stem

The principal river of a river system, which receives the tributaries.

drainage basin

All the land that drains into one river and its tributaries; also called a watershed. Rain falling anywhere in the basin eventually flows past the river's mouth.

gateway city

A city that controls the entrance to a large region, so that people and goods going into or out of that region pass through it.

bearing

A direction measured in degrees clockwise from north: north is 0° (or 360°), east 90°, south 180°, west 270°.

CORE IDEAS

The story. In late November 1753 a tall, twenty-one-year-old major of the Virginia militia named George Washington reached the place where two rivers meet in the forests of western Pennsylvania. Governor Robert Dinwiddie of Virginia had sent him to carry a letter to the French commander in the Ohio country, warning the French to leave land that Britain claimed. Washington arrived ahead of the canoe carrying his baggage and used the time to study the spot. In the journal he published the next year, he wrote that the land in the fork was “extremely well situated for a Fort, as it has the absolute Command of both Rivers.” He noted that the point stood twenty or twenty-five feet above the water, that each river was a quarter of a mile or more across, and that they met very nearly at right angles: the Allegheny coming from the northeast and the Monongahela from the southeast. Together they form the Ohio.

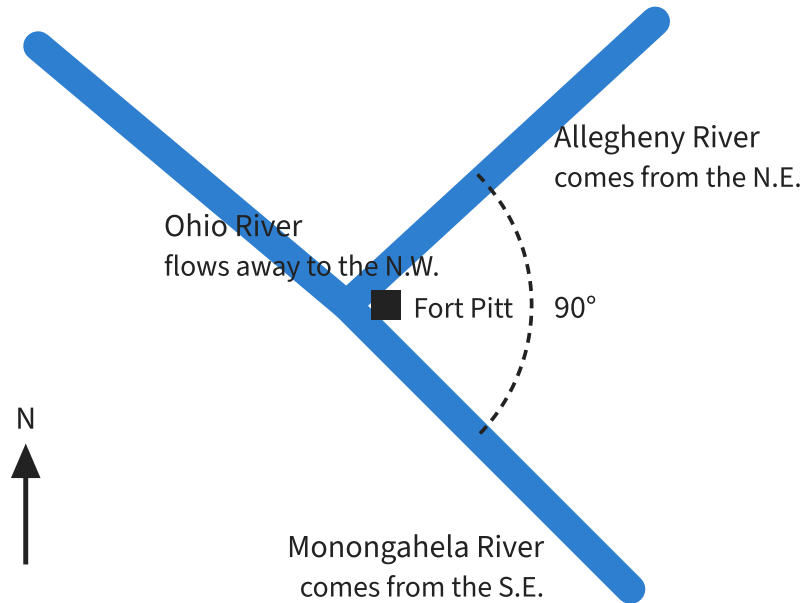
What happened next. Both empires saw what Washington saw. In early 1754 a small party of Virginians began a fort at the point. In April a much larger French force came down the Allegheny with cannon, and the Virginians had to surrender and march away. The French built Fort Duquesne on the spot, and the contest for the forks helped start the French and Indian War. In July 1755 General Edward Braddock’s British army was destroyed on the Monongahela a few miles short of the fort. Only in November 1758, when General John Forbes approached with a new army, did the French blow up the fort and withdraw. Forbes named the place for William Pitt, the British statesman, and the British built the great Fort Pitt beside the ruins.

The big idea. A **confluence** is where a **tributary** joins a river or where two rivers join to make a new one. Before railroads, rivers were the best highways in the world, because a boat could carry many times the load of a wagon. A confluence gathers the traffic of two valleys and sends it down a third, so whoever holds it holds the door to a whole **drainage basin**. The site is strong as well: water guards the point on two sides, and an enemy can approach easily from only one. The danger is flooding, because a confluence collects the floods of both rivers. On March 17 and 18, 1936, the water at the Point rose to 46 feet on the river gauge, and much of downtown Pittsburgh stood under water.

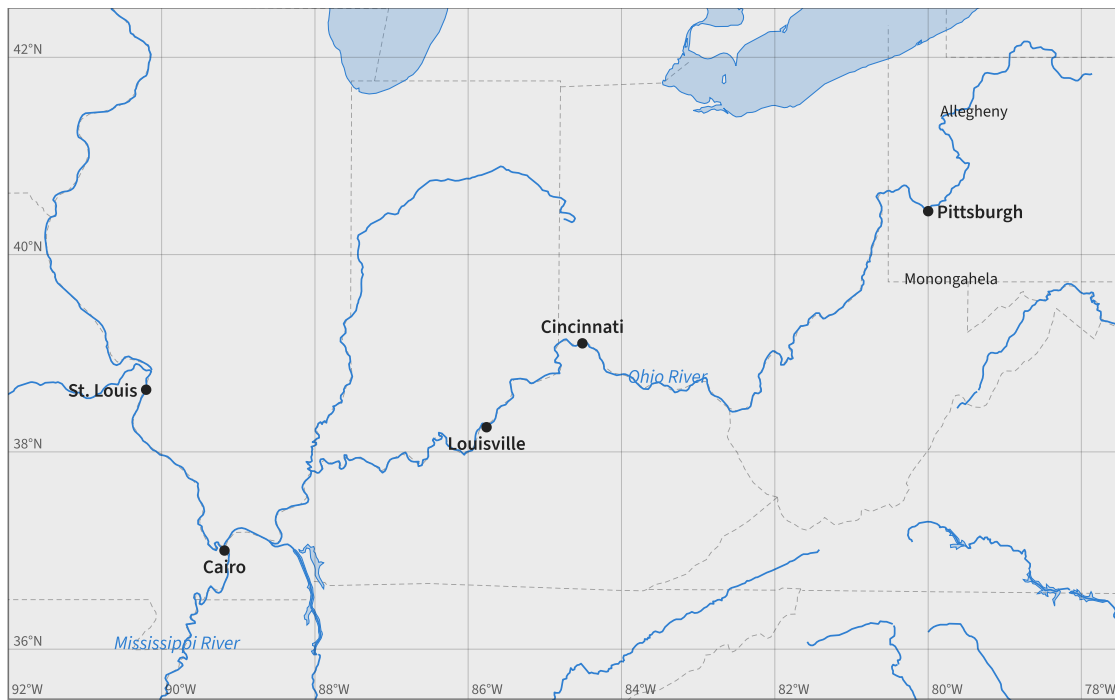
Gateway to the West. After the Revolution, Pittsburgh became the jumping-off place for the Ohio valley. Settlers bought flatboats there and floated down the Ohio, which runs about 981 miles (1,579 km) to meet the Mississippi at Cairo, Illinois. On August 31, 1803, Meriwether Lewis set off from Pittsburgh in a keelboat built there to begin the journey of Lewis and Clark. In 1811 the steamboat *New Orleans*, built at Pittsburgh, steamed down the Ohio and Mississippi, the first steamboat on those rivers. The hills around the city held thick seams of coal, and the rivers carried coal, iron, glass and later steel. In 1875 Andrew Carnegie opened his Edgar Thomson steel works on the Monongahela, on the very field where Braddock had been defeated.

On the map. Look for confluence cities everywhere. Koblenz in Germany takes its name from the Latin *Confluentes*, for it stands where the Moselle meets the Rhine. Lyon, France, stands where the Saône meets the Rhône. Belgrade guards the meeting of the Sava and the Danube. Khartoum, in Sudan, stands where the White Nile and the Blue Nile become one Nile. In America, St. Louis grew just below the meeting of the Missouri and the Mississippi, and Harpers Ferry sits where the Shenandoah meets the Potomac.

Technology overcoming geography. A river helps you downstream and fights you upstream. Flatboats from Pittsburgh were usually broken up for lumber at the end of the trip, because poling them back against the current was too slow. The steamboat changed that: for the first time, heavy cargo could go up the Ohio as well as down. Later, engineers built locks and dams on the Monongahela, the Allegheny and the Ohio, turning them into a stairway of deep pools that barges still use. In the 1850s the Pennsylvania Railroad crossed the mountains to Pittsburgh. Yet every new road, rail line and bridge still converged on the same forks Washington studied in 1753.

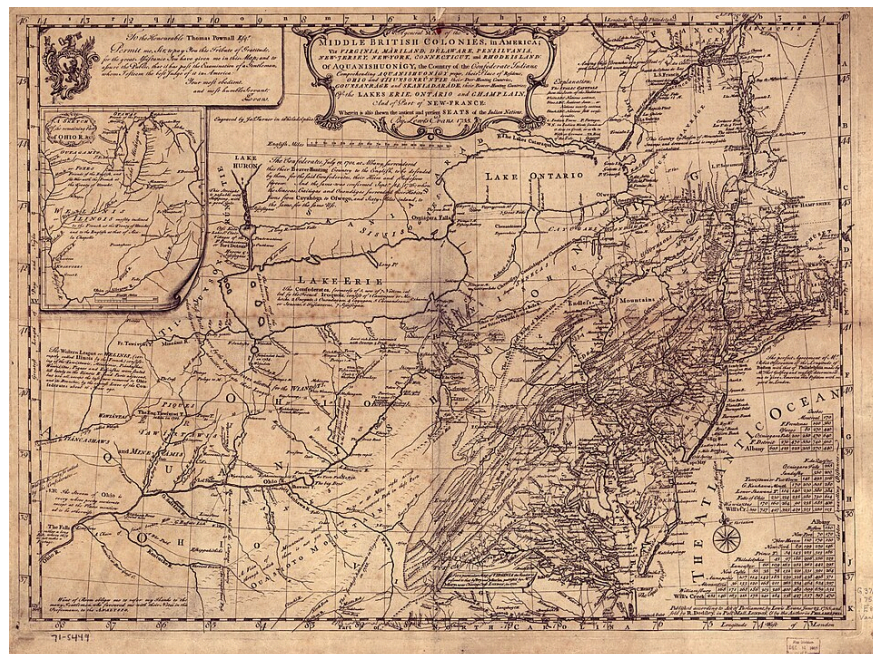


The Forks of the Ohio as Washington described them: two rivers meeting very nearly at right angles to form the Ohio.



The Ohio River from its source at the Pittsburgh confluence to its own confluence with the Mississippi at Cairo.

PICTURE STUDY



A General Map of the Middle British Colonies, in America, Lewis Evans (engraved by James Turner), 1755 · Copperplate engraving on paper (some copies hand-colored) · Library of Congress, Geography and Map Division (one of several surviving copies)

Lewis Evans was a surveyor and mapmaker in Philadelphia who traveled the backcountry and gathered reports from traders and travelers. In 1755, the year after the French seized the Forks of the Ohio, he published this map of the middle colonies and the Ohio country,

with a printed essay explaining it. It was the best map of the region in its day and was copied and reissued by other mapmakers for many years.

Evans filled his map with small written notes about the land, the rivers and the routes. To an army officer, a land company or a settler in 1755, the most important question on it was simple: how do the rivers connect?

Look closely

- Find the Ohio River and follow it upstream until it splits into two rivers. That is the Forks of the Ohio, where Pittsburgh now stands.
- Find the long ridges of the Allegheny Mountains running from southwest to northeast. Which way do the rivers on each side of them flow?
- Find Philadelphia, where Evans made the map. Trace a route a trader might take from Philadelphia to the forks.
- Look at the small notes printed across the land. Choose one and read it aloud if you can.

Talk about it

1. Why would British and French officers in 1755 both want an accurate map of where the Ohio began?
2. How could a mapmaker who had not walked every mile still make a useful map? What might he get wrong?
3. If you were choosing one spot on this map for a trading post, where would you put it and why?

PROJECT: A CONFLUENCE IN A TRAY

You will build two river valleys that meet, run real water down them, and watch how a confluence behaves: where the water speeds up and slows down, where sand piles, and where floods spread. Then you will choose the best spot for a fort and a market, just as Washington did.

You will need

- A large shallow baking pan, plastic storage-box lid or boot tray
- Damp sand or garden soil, enough to fill the tray about 3 cm (1 inch) deep
- Two cups or small pitchers, water, blue and yellow food coloring
- A protractor, a ruler, toothpicks and small paper flags
- A book or block to tilt the tray, and a towel

Steps

1. Spread the damp sand evenly and tilt the tray by setting one end on a book.
2. With a finger, carve two river channels starting at the high corners and meeting in the middle of the tray, then one channel running from the meeting point to the low end.

Shape a raised point of land between the two incoming rivers.

3. Use the protractor to measure the angle between your two incoming rivers. Try to make it close to 90° , as Washington described the Allegheny and Monongahela.
4. Color one cup of water blue and the other yellow. Pour both slowly at the same time, one at the head of each river. Watch and record: where do the colors mix? Does sand wash away or pile up at the point?
5. Now make a flood: pour both cups quickly. Mark with toothpicks how far the water spreads over the low ground. Is the tip of the point safe?
6. Place three flags: a fort, a market and a boatyard. Write one sentence for each explaining why you put it there.
7. Add a confluence town to your Site-and-Situation Game board from Lesson 1.1 and score it.

Tips

- Pour slowly at first; a gentle stream shows the meeting of the currents better than a rush.
- If the sand is too dry, the channels collapse. Mist it with a spray bottle.
- Take a photo from above after each pour so you can compare the normal flow with the flood.

Check your work

- I can point to the confluence, the tributaries and the main stem on my model.
- I measured the angle between my incoming rivers.
- I can explain where my fort, market and boatyard stand and why, including the flood risk.

MAP NOTEBOOK

1. Copy the Forks diagram into your notebook. Add a compass rose and write the bearing each river comes from or flows toward.
2. Draw a simple map of the Ohio drainage basin: shade the land that drains to the Ohio and mark Pittsburgh at the top and Cairo at the bottom.
3. Make a timeline from 1753 to 1811 with five events at the Forks of the Ohio: Washington's visit, Fort Duquesne, Forbes and Fort Pitt, Lewis's departure, and the steamboat *New Orleans*.

From history. The St. Patrick's Day flood of March 1936 was the worst in Pittsburgh's history. Snowmelt and heavy rain upstream on both the Allegheny and the Monongahela arrived at the Point together, and the water reached 46 feet on the gauge, about 21 feet above flood stage. That year Congress passed the Flood Control Act of 1936, and in the following years the Army Corps of Engineers built dams and reservoirs on the rivers above Pittsburgh to hold back the floods of the tributaries before they reached the confluence.

WORKED EXAMPLES

Example 1. Washington wrote that from the Point the Allegheny bears northeast and the Monongahela southeast. Write each direction as a bearing in degrees and find the angle between the two rivers. Was he right that they meet very nearly at right angles?

(Use the map or drawing “The two incoming rivers meet at about 90° .” shown earlier in this lesson.)

1. Bearings are measured clockwise from north. Northeast is halfway between north (0°) and east (90°), so NE = 45° .
2. Southeast is halfway between east (90°) and south (180°), so SE = 135° .
3. Angle between them = $135^\circ - 45^\circ = 90^\circ$.
4. A 90° angle is a right angle, which matches Washington’s description.

Answer: Allegheny 045° , Monongahela 135° ; the angle between them is 90° , a right angle.

Example 2. Pittsburgh (40.44° N, 80.00° W) and Cairo, Illinois (37.00° N, 89.18° W) stand at the two ends of the Ohio River. Estimate the straight-line distance between them, then compare it with the river’s length of about 981 miles (1,579 km). Use 1° latitude $\approx$ 69 miles and 1° longitude $\approx$ 54 miles at this latitude.

(Use the map or drawing “Compare the winding river with a straight line from Pittsburgh to Cairo.” shown earlier in this lesson.)

1. Latitude difference: $40.44 - 37.00 = 3.44^\circ$. $3.44 \times 69 \approx 237$ miles.
2. Longitude difference: $89.18 - 80.00 = 9.18^\circ$. $9.18 \times 54 \approx 496$ miles.
3. Straight-line distance $\approx \sqrt{(237^2 + 496^2)} = \sqrt{(56,169 + 246,016)} = \sqrt{302,185} \approx 550$ miles. In kilometers: $550 \times 1.609 \approx 885$ km.
4. Ratio of river length to straight line: $981 \div 550 \approx 1.8$.

Answer: About 550 miles (885 km) in a straight line. The river is about 1.8 times as long, because it winds through its valley.

Example 3. Suppose a flatboat drifting with the current makes about 50 miles (80 km) a day, and a later steamboat going upstream against the current makes about 100 miles (160 km) a day. How long would each take to cover the Ohio's 981 miles? (The daily speeds are example figures.)

1. Flatboat downstream: $981 \div 50 \approx 19.6$, so about 20 days.
2. Steamboat upstream: $981 \div 100 \approx 9.8$, so about 10 days.
3. Before steam, a crew going back upstream usually walked or rode home overland and left the flatboat to be sold for lumber.

Answer: About 20 days for the flatboat downstream; about 10 days for the steamboat upstream. Steam made two-way river trade practical.

PRACTICE

1. **EASY** Which two rivers meet at Pittsburgh, and what river do they form?
2. **EASY** Define tributary and drainage basin.
3. **EASY** Washington was born on February 22, 1732. How old was he when he visited the Forks of the Ohio in November 1753?
4. **EASY** Put these in order: Fort Pitt is built; Washington views the forks; the French build Fort Duquesne; Forbes names the place Pittsburgh.
5. **MEDIUM** From the Point, the Ohio flows away toward the northwest at first. Write that direction as a bearing. What is the back bearing (the direction you would look to face back toward the Point from downstream)?
6. **MEDIUM** Using the map g8-ohio-system, name the city at the confluence of the Ohio and the Mississippi, and the city on the Mississippi just below the mouth of the Missouri. *(Use the map or drawing "Use this map for Problem 6." shown earlier in this lesson.)*
7. **MEDIUM** Match each confluence city to its rivers: Koblenz, Lyon, Khartoum, Belgrade. Rivers: (a) Sava and Danube, (b) White Nile and Blue Nile, (c) Moselle and Rhine, (d) Saône and Rhône.
8. **MEDIUM** The Ohio is about 981 miles long. Convert this to kilometers (1 mile = 1.609 km).
9. **HARD** On a map at 1:100,000, the Allegheny River from the Point to a dam upstream measures 6.5 cm along its winding course. How far is that on the ground in kilometers and miles?
10. **CHALLENGE** Explain in a short paragraph why a confluence is both a strong site and a strong situation, and name one danger of building there.

COMMON MISTAKES

- Saying the "three rivers" of Pittsburgh all flow into the city. Two rivers flow in; the third, the Ohio, flows out.
- Confusing where a river comes from with where it flows to. When Washington wrote that the Allegheny bears northeast, he meant the direction you look upstream along it

from the Point, not the direction the water flows.

- Measuring a river's length with a straight ruler. A river winds, so its true length is much longer than the straight line between its ends; use a string laid along the curves.

Make it a game • Name That Confluence. Write pairs of rivers on cards: Allegheny + Monongahela, Moselle + Rhine, Saône + Rhône, White Nile + Blue Nile, Sava + Danube, Missouri + Mississippi, Ohio + Mississippi, Shenandoah + Potomac. Shuffle. A player draws a card and has ten seconds to name the city at that confluence and point to it on a world map or globe. Two points for the city, one more for finding it on the map. The highest score after two rounds wins.

Scripture. "There is a river, the streams whereof shall make glad the city of God, the holy place of the tabernacles of the most High." (Psalm 46:4, KJV)

The psalmist pictures a city made glad by a river and its many streams. Cities at confluences know that gladness in a plain, earthly way: water, food and trade arrive from many valleys at once. The psalm points beyond them to the city God Himself sustains.

Practice answers

1. The Allegheny and the Monongahela meet to form the Ohio.
2. A tributary is a stream or river that flows into a larger river. A drainage basin is all the land that drains into one river and its tributaries.
3. 21 years old.
4. Washington views the forks (1753); the French build Fort Duquesne (1754); Forbes names the place Pittsburgh (1758); Fort Pitt is built (begun 1759).
5. Northwest is 315° . The back bearing is $315^\circ - 180^\circ = 135^\circ$ (southeast).
6. Cairo, Illinois, at the Ohio-Mississippi confluence; St. Louis, just below the Missouri-Mississippi confluence.
7. Koblenz (c), Lyon (d), Khartoum (b), Belgrade (a).
8. $981 \times 1.609 \approx 1,578$ km, about 1,580 km.
9. $6.5 \times 100,000 = 650,000$ cm = 6.5 km $\approx$ 4.0 miles.
10. Site: water guards the point on two sides, so it is easy to defend, and the rivers supply water and transport right at the town's edge. Situation: the confluence collects the traffic of two valleys and controls the river below, so goods and travelers from a whole drainage basin pass through it. Danger: floods from both rivers meet there, as in Pittsburgh's 1936 flood, when the river reached 46 feet at the Point.

1.3 THE FALL LINE

OBJECTIVES

- Explain what the fall line is and why it formed where the hard rock of the Piedmont meets the soft sediments of the Atlantic Coastal Plain.
- Use the ideas of head of navigation, break of bulk and water power to explain why Richmond, Washington and Philadelphia grew where they did.
- Locate the chain of fall-line cities on a map and calculate distances, river gradients and the number of canal locks needed to pass the falls.

Warm-up. Make a ramp from a long board or a cookie sheet and set it on the floor. At the high end, stand two thick books on end to make a sudden step. Push a toy car or boat up the ramp from the low end. It rolls easily until it reaches the step, and then someone must lift it. Ask: if every boat on a river had to stop at the same step, what jobs would people do there? Who would carry the cargo up? Where would they store it overnight?

Watch. *America's String of Cities - How the Fall Line Determines Where People Live* (That Is Interesting, 9:48). <https://www.youtube.com/watch?v=yc1uFb3Va4o>
After the big idea: the string of fall-line cities from Trenton to Columbus.

Backup video. *History of the C&O Canal* (Chesapeake and Ohio Canal NHP, 12:48). <https://www.youtube.com/watch?v=5Uc4wNPCjpY>
With On the map: the C&O Canal and the falls of the Potomac, from the National Park Service.

KEY TERMS

fall line

The boundary between the hard rock of the Piedmont and the soft sediments of the Atlantic Coastal Plain, where rivers drop over falls and rapids. It runs from New Jersey to Alabama.

Piedmont

The rolling upland of hard, old rock between the Appalachian Mountains and the Coastal Plain. The name means “foot of the mountain.”

Atlantic Coastal Plain

The low, flat land of sand, gravel and clay along the Atlantic coast, where rivers are wide, slow and often tidal.

head of navigation

The farthest point upstream that ships or boats can travel on a river.

break of bulk

A place where cargo must be unloaded from one kind of transport and loaded onto another, such as from ship to wagon.

water power

Energy taken from falling or flowing water, usually by a waterwheel or turbine, to grind grain, saw wood, run looms or make electricity.

CORE IDEAS

The story. In May 1607, only days after the first English settlers landed at Jamestown, Captain Christopher Newport took a small boat and a party of men, among them John Smith, up the broad James River to see how far it led into the continent. For days they rowed easily on deep, tidal water. Then the river changed. Rocks, rapids and white water blocked the way, and no boat could go farther. On May 24, near the falls, Newport's men set up a wooden cross to claim the land for King James. They had found the end of the easy water, the place where the coastal lowland ends and the hard upland begins. More than a century later, in 1737, William Byrd II laid out a town at the falls and named it Richmond, because the view of the river reminded him of Richmond on the Thames in England.

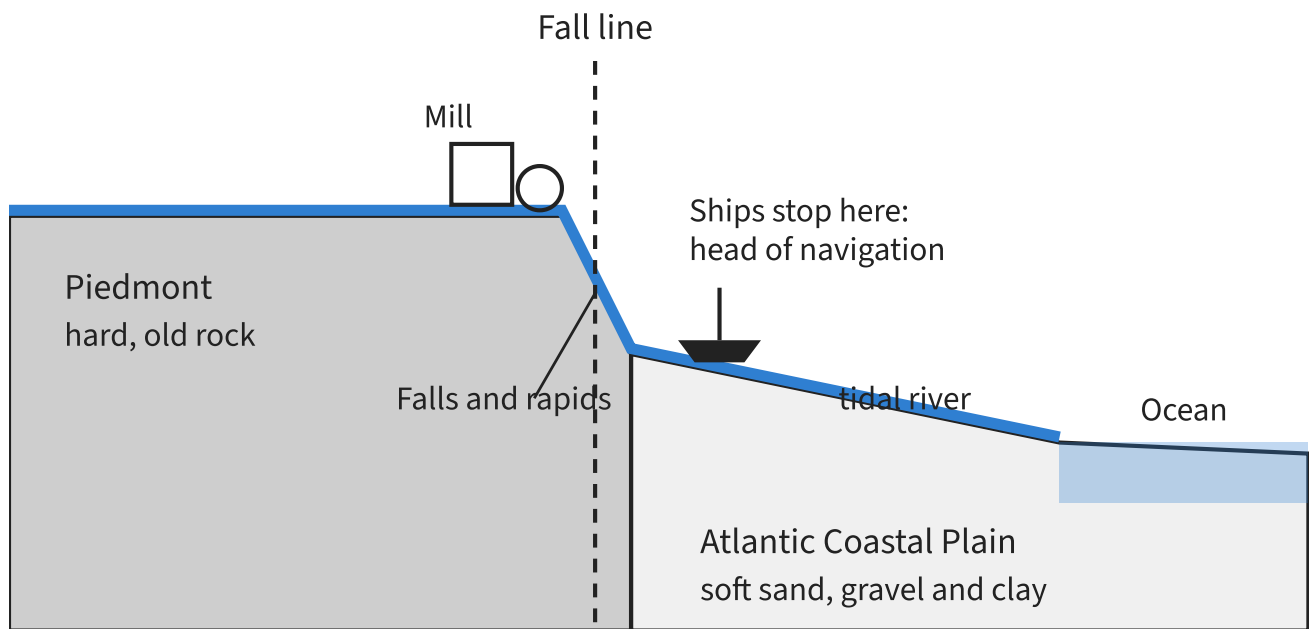
How it works. East of the Appalachians lie two very different kinds of land. The **Piedmont** is made of hard crystalline rock, such as granite and gneiss. Between it and the sea lies the **Atlantic Coastal Plain**, built of layers of soft sand, gravel and clay. A river crossing from the hard rock onto the soft sediments cuts down much faster into the soft layers, so a step forms where the two meet. Along that step the rivers tumble over falls and rapids. At Richmond the James drops roughly 100 feet (30 m) in about 7 miles (11 km). At the Great Falls of the Potomac, about 15 miles above Washington, the river drops about 76 feet (23 m) through a rocky gorge. Join these falls on a map and they make a line from Trenton, New Jersey, to Georgia and Alabama. Geographers call it the **fall line**.

The big idea. The fall line gave towns three gifts at once. First, it was the **head of navigation**: ships from the ocean could sail up the tidal rivers until the falls stopped them. Second, it was a **break of bulk**: tobacco, wheat and furs coming down from the farms of the Piedmont by wagon had to be loaded onto boats here, and cloth, tools and sugar coming up from the sea had to be unloaded onto wagons. Merchants, warehouses, inns and roads gathered at that change. Third, the falls offered **water power**. Millers dug channels called races to lead water onto their wheels, and the river ground their grain and sawed their logs for free. A fourth, smaller gift: rocky shallows near the falls often made good fords.

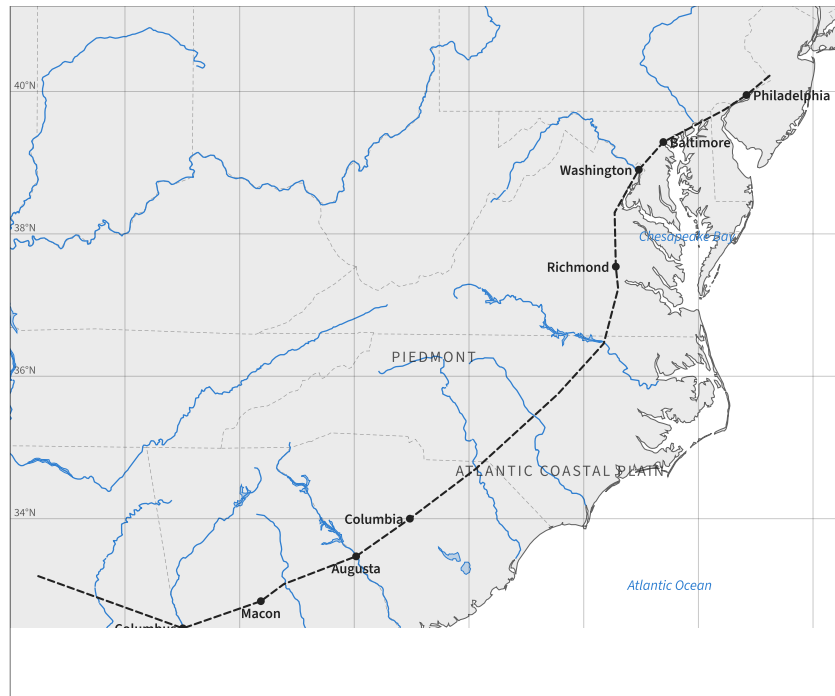
Three capitals of the fall line. Richmond became the capital of Virginia in 1780. Its riverside filled with tobacco warehouses, and by the 1800s it had some of the largest flour mills in America and the Tredegar Iron Works, founded in 1837 and driven by water from the canal around the falls. Washington, D.C., was laid out in 1791 where the tidal Potomac meets the falls. The old tobacco port of Georgetown, founded in 1751 just below the Little Falls, already stood at the head of navigation, and President Washington himself chose the site for the new federal city. Philadelphia, founded by William Penn in 1682, lies on the tidal Delaware near the falls of its tributary, the Schuylkill. From 1822 the Fairmount Water Works used waterwheels turned by the Schuylkill to pump drinking water for the city, and textile mills rose upstream at Manayunk.

On the map. Trace the fall line south and the cities appear like beads on a string: Trenton, Philadelphia, Wilmington, Baltimore, Washington, Fredericksburg, Richmond, Petersburg, Columbia, Augusta, Macon and Columbus. Old U.S. Route 1 and much of Interstate 95 follow this chain, because the roads were built to link the towns that already stood there. Notice also that the line runs about 100 to 150 miles inland in the South but close to the coast in the North. When the falls lie near the sea, ocean ships, mills and farms all crowd into a small space, and great cities grow.

Technology overcoming geography. The falls were a barrier to boats, so engineers built canals with locks to lift boats around them. George Washington was the first president of the Patowmack Company, formed in 1785, which built short canals around the Potomac falls, and its canal at Great Falls used five locks. In 1828 work began on the Chesapeake and Ohio Canal, and the James River and Kanawha Canal climbed around the falls at Richmond. Later, steam engines and then electricity freed factories from the riverbank. Yet the fall-line cities remained. Once a city has roads, harbors, buildings and people, it keeps growing even after its first advantage fades. Geographers call this **geographic inertia**.

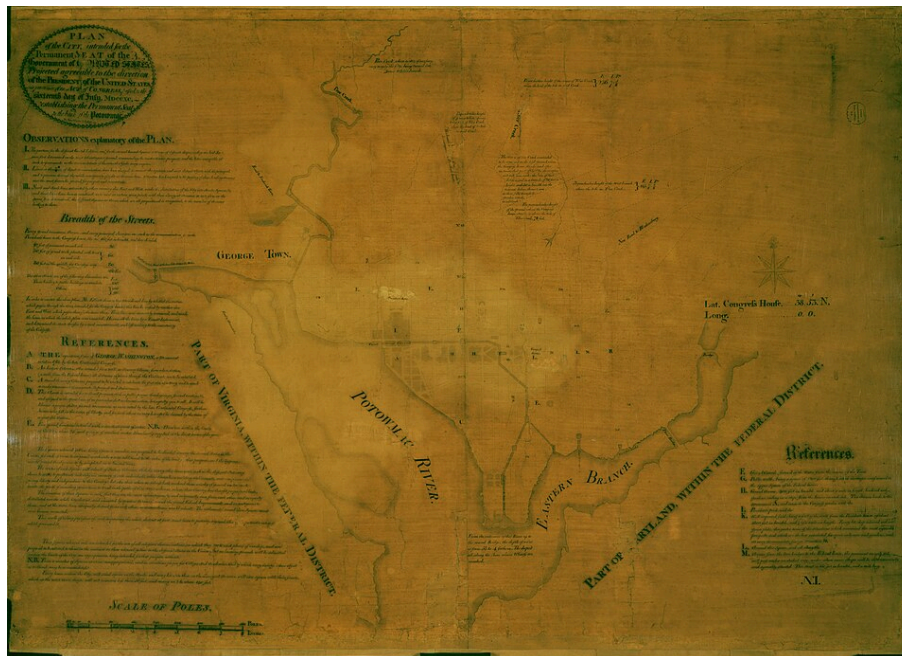


Why boats stopped and mills began: at the fall line, rivers drop from hard rock onto soft sediments.



The fall line and its chain of cities, from New Jersey to Georgia.

PICTURE STUDY



Plan of the City Intended for the Permanent Seat of the Government of the United States, Peter (Pierre) Charles L'Enfant, 1791 · Ink, watercolor and pencil on paper (manuscript plan) · Library of Congress, Geography and Map Division

Peter Charles L'Enfant was a French-born engineer who had served as an officer in the Continental Army. In 1791 President Washington asked him to design the new federal city on the Potomac. L'Enfant walked the ground, studied the hills and streams, and drew this plan:

a grid of streets crossed by grand diagonal avenues, with the house for Congress on the high ground of Jenkins Hill and the President's house to the west.

The original drawing is so fragile that the Library of Congress keeps it in the dark and shows copies. Look at how L'Enfant fitted his city between two rivers and below the old port of Georgetown.

Look closely

- Find the Potomac River and the Eastern Branch (today the Anacostia). Where do they meet? What kind of place is that?
- Find the edge of Georgetown at the upper left. Why did ships stop there?
- Find the house for Congress on its rise of ground. Why would a planner put it on a hill?
- Follow one of the diagonal avenues. Which two important places does it connect?

Talk about it

1. The new capital stood at the head of tide on the Potomac. What advantages did that give a city in 1791?
2. L'Enfant's capital is both a fall-line city and a confluence city. Explain how.
3. If you had to plan a new capital on a river near your home, where would you put the most important building, and why?

Safety first. An adult should cut the slits in the cork and push the skewer through it. Do the water tests over a sink, bathtub or outdoors.

PROJECT: A FALL-LINE WATERWHEEL

Mills grew at the fall line because falling water carries energy. You will build a small waterwheel from a cork and plastic spoons and test whether water falling from a greater height does more work. You will measure the work by how fast the wheel winds up a string and lifts a small weight.

You will need

- A cork (or a short section of thick foam pool noodle)
- 6 to 8 plastic spoons
- A bamboo skewer for the axle
- Two tall cups or a shoebox with holes punched in opposite sides to hold the axle
- About 50 cm (20 inches) of thread and a paper clip or two as the weight
- A pitcher, a measuring cup, a ruler and a stopwatch or phone timer
- A sink, tub or basin to catch the water

Steps

1. Have an adult cut 6 to 8 evenly spaced slits around the cork and push the spoons in so all the bowls face the same way.

2. Push the skewer through the center of the cork. Rest the ends of the skewer in notches on the two cups (or in the holes in the shoebox) so the wheel spins freely.
3. Tape one end of the thread to the skewer just outside the cork and tie the paper clip to the other end so it hangs down.
4. Fill the measuring cup with 500 mL (about 2 cups) of water. Hold it 10 cm (4 inches) above the spoons and pour at a steady rate. Time how long the wheel takes to wind the paper clip up to the axle.
5. Repeat with the same amount of water from 20 cm (8 inches) and 30 cm (12 inches). Do each height three times and average the times.
6. Make a table and a simple bar graph of height of fall against lifting time.
7. Write two sentences: How did the height of the fall change the work done? Why did millers build at falls and rapids instead of on slow, flat stretches of river?

Tips

- Pour onto the spoon bowls at the top of the wheel, not onto the center.
- If the wheel does not lift the clip at all, use a lighter weight or a thinner thread.
- Keep the amount of water and the pouring speed the same each time so that only the height changes. That makes it a fair test.

Check your work

- My wheel turns freely and lifts a small weight.
- I tested three heights, three times each, and recorded the results in a table.
- I can explain why falling water from a higher drop does more work and why mills gathered at the fall line.

MAP NOTEBOOK

1. Copy the fall-line cross section. Label the Piedmont, the Coastal Plain, the falls, the head of navigation, a mill and a ship.
2. On a blank outline map of the eastern United States, draw the fall line and mark at least eight fall-line cities and the river at each one.
3. Draw a small “break of bulk” scene at Richmond in 1800: a wagon of tobacco hogsheads, a warehouse and a boat at the wharf. Add arrows showing which way goods move.

From history. On July 4, 1828, two great works began on the same day. Near Georgetown, President John Quincy Adams turned the first shovel of earth for the Chesapeake and Ohio Canal, meant to carry boats past the Potomac falls and on toward the Ohio. In Baltimore, Charles Carroll of Carrollton, the last living signer of the Declaration of Independence, laid the first stone of the Baltimore and Ohio Railroad. The race was won by the railroad: it reached Cumberland, Maryland, in 1842, and the canal arrived only in 1850 and never crossed the mountains at all.

WORKED EXAMPLES

Example 1. Richmond (37.54° N, 77.44° W), Washington (38.90° N, 77.04° W) and Philadelphia (39.95° N, 75.16° W) are all fall-line cities. Estimate the straight-line distance from Richmond to Washington and from Washington to Philadelphia. Use 1° latitude $\approx$ 69 miles and 1° longitude $\approx$ 54 miles at these latitudes.

(Use the map or drawing “The three cities lie one after another along the fall line.” shown earlier in this lesson.)

1. Richmond to Washington: latitude difference $1.36^\circ \times 69 \approx 93.8$ miles; longitude difference $0.40^\circ \times 54 \approx 21.6$ miles. Distance $\approx \sqrt{(93.8^2 + 21.6^2)} = \sqrt{(8,798 + 467)} = \sqrt{9,265} \approx 96$ miles.
2. Washington to Philadelphia: latitude difference $1.05^\circ \times 69 \approx 72.5$ miles; longitude difference $1.88^\circ \times 54 \approx 101.5$ miles. Distance $\approx \sqrt{(72.5^2 + 101.5^2)} = \sqrt{(5,256 + 10,302)} = \sqrt{15,558} \approx 125$ miles.
3. Convert to kilometers ($\times 1.609$): 96 miles $\approx$ 155 km; 125 miles $\approx$ 201 km.

Answer: Richmond to Washington: about 96 miles (155 km). Washington to Philadelphia: about 125 miles (200 km).

Example 2. At Richmond the James River drops roughly 100 feet (30 m) in about 7 miles (11 km). Below Richmond the river is tidal and flows almost level to the Chesapeake. Find the gradient of the falls in feet per mile and in meters per kilometer.

(Use the map or drawing “The steep step at the fall line compared with the nearly level tidal river below” shown earlier in this lesson.)

1. Gradient = drop $\div$ distance.
2. In customary units: $100 \text{ ft} \div 7 \text{ mi} \approx 14$ feet per mile.
3. In metric units: $30 \text{ m} \div 11 \text{ km} \approx 2.7$ meters per kilometer.
4. Compare: a tidal river below the fall line drops almost nothing per mile, so boats move easily there.

Answer: About 14 feet per mile (about 2.7 m per km), steep enough for rapids and strong enough to drive many mills.

Example 3. The Great Falls of the Potomac drop about 76 feet (23 m). The Patowmack Company's canal around them used five locks. If the five locks shared the lift equally, how much did each lock lift a boat? If a later canal used locks that lift 8 feet each, how many would it need to climb the same 76 feet?

1. Lift per lock with five locks: $76 \text{ ft} \div 5 = 15.2 \text{ ft}$ (about 4.6 m).
2. Locks needed at 8 ft each: $76 \div 8 = 9.5$.
3. You cannot build half a lock, so round up: 10 locks.

Answer: About 15 feet (4.6 m) per lock with five locks; 10 locks would be needed at 8 feet each.

PRACTICE

1. **EASY** Name the two physical regions that meet at the fall line and describe the rock of each.
2. **EASY** Name three reasons towns grew at the fall line.
3. **EASY** Who laid out Richmond in 1737, and why did he give it that name?
4. **EASY** On which river does each city stand at the fall line: Richmond, Washington, Trenton, Augusta?
5. **MEDIUM** Baltimore lies at about 39.29° N , 76.61° W , and Philadelphia at about 39.95° N , 75.16° W . Estimate the distance between them using $1^\circ \text{ latitude} \approx 69 \text{ miles}$ and $1^\circ \text{ longitude} \approx 53 \text{ miles}$.
6. **MEDIUM** The Great Falls of the Potomac drop about 76 feet. Convert this to meters ($1 \text{ ft} = 0.3048 \text{ m}$).
7. **MEDIUM** A river drops 45 m over 15 km of rapids. What is its gradient in meters per kilometer? How many locks of 3 m lift would a canal need to climb past it?
8. **MEDIUM** Using the map g8-fall-line, name the fall-line cities you would pass traveling from Washington southwest to Columbus, Georgia, in order.
(Use the map or drawing "Use this map for Problem 8." shown earlier in this lesson.)
9. **HARD** Work began on the Chesapeake and Ohio Canal in 1828, and it reached Cumberland, Maryland, in 1850. The Baltimore and Ohio Railroad, begun the same year, reached Cumberland in 1842. How many years did each take? What does the difference suggest about canals and railroads?
10. **CHALLENGE** Water power has not driven Richmond's or Philadelphia's factories for over a century, yet both cities are still large. Explain this using the term geographic inertia.

COMMON MISTAKES

- Thinking the fall line is a single waterfall. It is a long zone of falls and rapids on many rivers, running hundreds of miles from New Jersey to Alabama.
- Mixing up the Piedmont and the Coastal Plain. The Piedmont is the higher, hard-rock upland; the Coastal Plain is the low, soft land near the sea.

- Assuming water power is the only reason for fall-line cities. Being the head of navigation and a break-of-bulk point mattered just as much, and often first.

Make it a game · The Boat Stops Here. One player names a river of the eastern United States: Delaware, Schuylkill, Patapsco, Potomac, Rappahannock, James, Appomattox, Congaree, Savannah, Ocmulgee, Chattahoochee. The other must name the fall-line city where the boats stopped (Trenton, Philadelphia, Baltimore, Washington, Fredericksburg, Richmond, Petersburg, Columbia, Augusta, Macon, Columbus) and point to it on the fall-line map. Score a point for each correct city and a bonus point for saying which state it is in. Switch roles after five rivers.

Scripture. “All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again.” (Ecclesiastes 1:7, KJV)

Every river at the fall line is part of the great circuit God set in motion: rain on the hills, water rushing over the rocks toward the sea, and vapor rising to fall again. Millers along the falls used the same steady flow Solomon watched, harnessing it to grind bread for whole cities.

Practice answers

1. The Piedmont, made of hard crystalline rock, and the Atlantic Coastal Plain, made of soft sand, gravel and clay.
2. It was the head of navigation for ships; it was a break-of-bulk point where cargo changed between boats and wagons; and the falls gave water power for mills. (Fords at the rocky shallows are a fourth reason.)
3. William Byrd II. The view of the James reminded him of Richmond on the Thames in England.
4. Richmond: the James. Washington: the Potomac. Trenton: the Delaware. Augusta: the Savannah.
5. Latitude $0.66 \times 69 \approx 45.5$ miles; longitude $1.45 \times 53 \approx 76.9$ miles. Distance $\approx \sqrt{(45.5^2 + 76.9^2)} \approx \sqrt{7,984} \approx 89$ miles, about 145 km.
6. $76 \times 0.3048 \approx 23.2$ m.
7. Gradient: $45 \div 15 = 3$ m per km. Locks: $45 \div 3 = 15$ locks.
8. Richmond, Columbia, Augusta, Macon, then Columbus (with smaller fall-line towns such as Fredericksburg and Petersburg in Virginia).
9. Canal: $1850 - 1828 = 22$ years. Railroad: $1842 - 1828 = 14$ years. The railroad, which did not need water or locks and could climb grades, reached the same place 8 years sooner. Railroads were overtaking canals as the better way to cross rough country.
10. Geographic inertia means a city keeps growing in a place after its original advantage fades, because it has already built up people, roads, railroads, harbors, buildings, businesses and government there. Moving all that would cost far more than staying. The fall line gave Richmond and Philadelphia their start; their size and connections kept them growing.

1.4 THE HILL AND THE HARBOR

OBJECTIVES

- Explain the trade-off between defense and trade in choosing the site of a city, and the common answer of a hill city joined to a nearby port.
- Describe how Athens and Piraeus, Rome and Ostia, and Edinburgh and Leith each balanced the hill and the harbor.
- Use map scale, ancient units, horizon distance and travel time to reason about defended sites.

Warm-up. Build a hill from sofa cushions on one side of the room and lay a blue towel “sea” on the other side. You must store a family treasure (a cookie will do) somewhere in the room. On the hill it is safe from a sibling “raider” who must climb to reach it, but every time you want to trade it you must carry it down to the sea. By the sea it is easy to trade but easy to snatch. Where do you keep it? Can you think of a way to have both?

Watch. *Did Paul really Visit Ancient Athens?* (Drive Thru History with Dave Stotts, 5:56). <https://www.youtube.com/watch?v=WeohDhepxOM>

With the story of Athens: the Acropolis, the Areopagus and Paul in Athens.

Backup video. *A Story of Rocks and Time at Holyrood Park, Edinburgh* (Historic Environment Scotland, 2:53). <https://www.youtube.com/watch?v=DrNz-twvqD8>
With the story of Edinburgh: the old volcanic rocks of Holyrood Park beside Castle Rock.

KEY TERMS

acropolis

Greek for “high city”: a fortified hilltop in or above a town, used as a refuge and holy place. The most famous is the Acropolis of Athens.

citadel

A fortress on high ground that protects a city and serves as its last stronghold.

port (outport)

A harbor town that serves a larger city standing some distance inland, such as Piraeus for Athens or Leith for Edinburgh.

crag and tail

A landform shaped by an ice sheet: a steep knob of hard rock (the crag) with a long, gentle ridge of softer rock or debris trailing behind it (the tail), sheltered from the ice.

Long Walls

The walls built by Athens in the 400s BC to join the city to its port at Piraeus, so that the city could be supplied by sea even when an army held the land around it.

trade-off

Giving up some of one good thing to gain more of another. A high, steep site gains safety but loses easy access to trade.

CORE IDEAS

The story. In 480 BC the Persian king Xerxes marched into Greece with the largest army the Greeks had ever seen. The Athenians had asked the oracle at Delphi for advice, and the answer, as Herodotus tells it, was that a “wooden wall” would not fail them. Some Athenians thought this meant the old wooden fence on their Acropolis. The statesman Themistocles argued that the wooden wall was the fleet. A few years earlier he had persuaded the Athenians to spend the silver from their mines at Laurium on new warships. Now the people of Athens left their city, the Persians climbed the Acropolis and burned its temples, and the Greek ships trapped and defeated the Persian fleet in the narrow strait of Salamis, just off the coast of Attica. The rock had not saved Athens. The sea had.

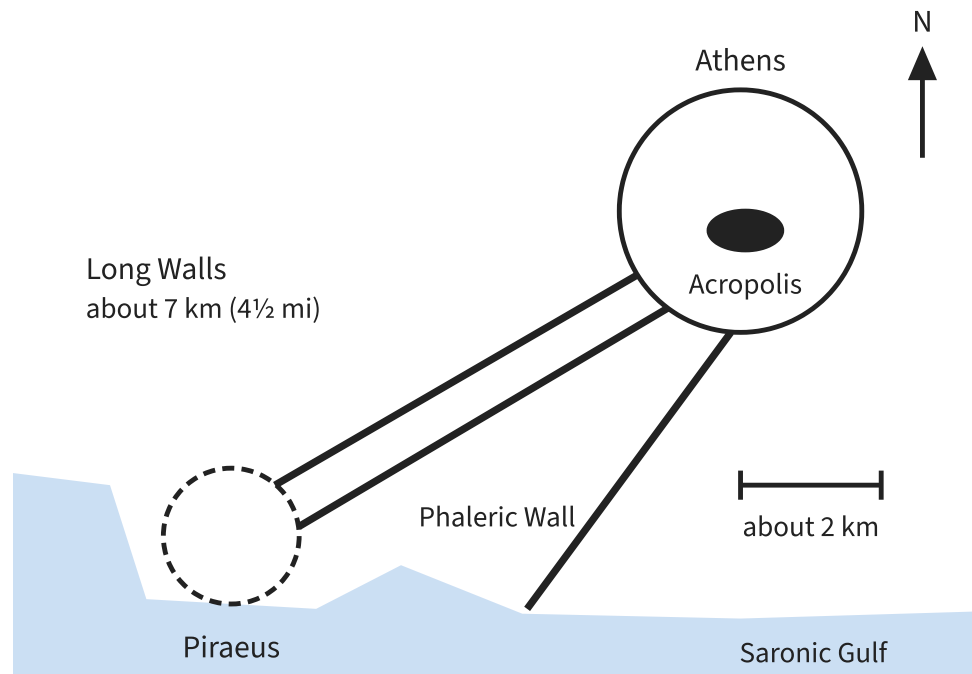
How they figured it out. The Acropolis is a steep limestone hill rising about 150 m (490 ft) above sea level, with cliffs on most sides and springs at its foot. Since the Bronze Age it had been a fortress and a holy place. But it stands about 5 km (3 miles) from the nearest shore and about 8 km (5 miles) from the harbors of Piraeus, and Athens had become a city of ships, traders and imported grain. So the Athenians fortified Piraeus, a rocky peninsula with three natural harbors, as their port. Around the middle of the 400s BC they joined city and port with the **Long Walls**. Thucydides gives the wall to Piraeus as forty stades, about 7 km (4½ miles). When Sparta invaded Attica in 431 BC, Pericles brought the country people inside the walls and fed the city by sea. Athens had made itself an island.

Rome: hills, a ford and a river port. Roman tradition dates the founding of Rome to 753 BC, when Romulus settled on the Palatine Hill. Rome’s seven hills offered strong, dry ground above the marshy valleys. Below them, an island in the Tiber made the river easier to cross, and there the oldest bridge, the wooden Pons Sublicius, and a cattle market grew up. The Via Salaria, the “salt road,” carried salt from the coast up the river valley into the hills. Rome stood about 22 km (14 miles) inland, safe from sudden raids by sea, yet linked to the sea by the Tiber and its port of Ostia at the river mouth. Centuries later, Cicero praised Romulus for this choice: he wrote that coastal cities are exposed to sudden attack, while a city on a river that flows all year to the sea can receive by water what it lacks and send out what it has to spare. As Rome grew to perhaps a million people, the emperors Claudius and Trajan built a great artificial harbor, Portus, near the Tiber’s mouth to feed it.

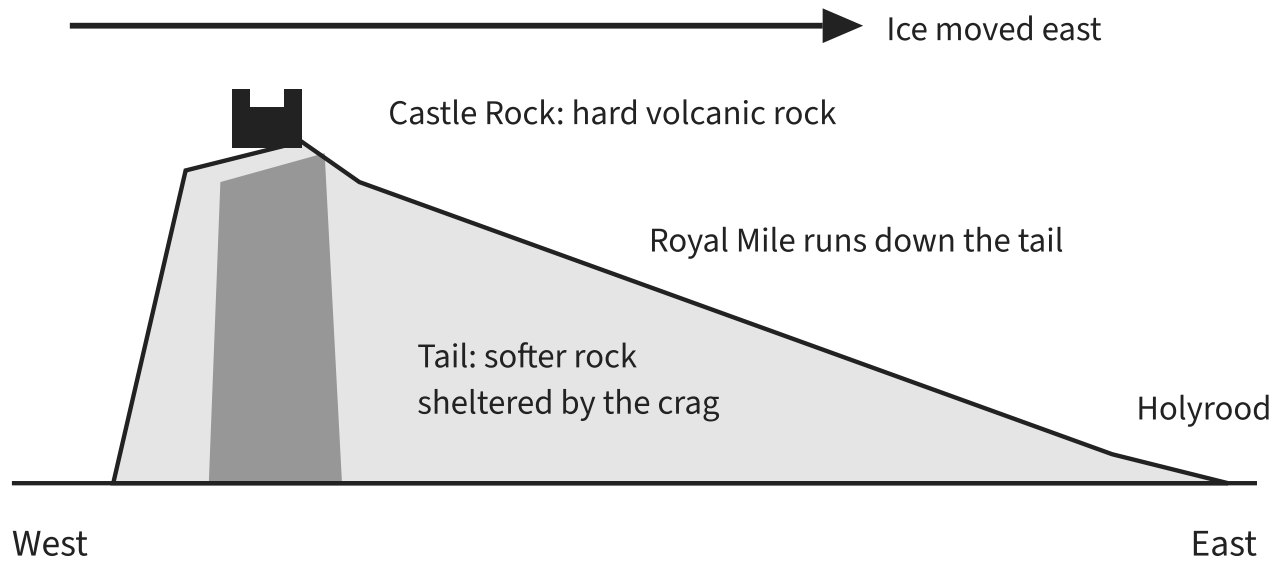
Edinburgh: the crag and the tail. Edinburgh Castle stands on Castle Rock, the hard core of an ancient volcano, with sheer cliffs on three sides. During the Ice Age, ice sheets moving eastward ground down the softer rock around it but left a long ridge sheltered in the lee of the hard crag. Geographers call this a **crag and tail**. Edinburgh’s Old Town grew along that ridge: its main street, the Royal Mile, runs about 1.8 km (a little over a mile) down the tail from the castle to Holyrood Palace. A loch at the foot of the rock, the Nor Loch, added a moat on the north. Because the town was squeezed onto a narrow ridge inside its walls, its people built upward, in tenements of ten stories or more. For trade, Edinburgh used Leith, its port on the Firth of Forth about 3 km (2 miles) to the north.

The big idea. Every city founder faces a **trade-off** between defense and trade. A steep hill is easy to hold but hard to reach. A harbor is easy to reach for friends and enemies alike. The solution in Athens, Rome and Edinburgh was the same: a defended hill city joined by road, river or walls to a nearby harbor. Jerusalem, too, stood on its hills, and the psalmist praised Mount Zion as “beautiful for situation” (Psalm 48:2). When times grew more peaceful, cities came down from their hills. After 1767, Edinburgh built its spacious New Town on the lower ridge north of the drained Nor Loch.

Technology overcoming geography. Walls, harbors and weapons changed the balance between hill and harbor. The Long Walls turned an inland city into a sea power. Portus gave Rome an artificial harbor where nature had given it only a shallow river mouth. Later, gunpowder artillery made castle rocks less decisive, and steam and rail tied hill cities to their ports more tightly than ever. In the next units you will see how harbors themselves became great engineering works.



Athens and Piraeus joined by the Long Walls. The city became, in effect, an island supplied by sea.

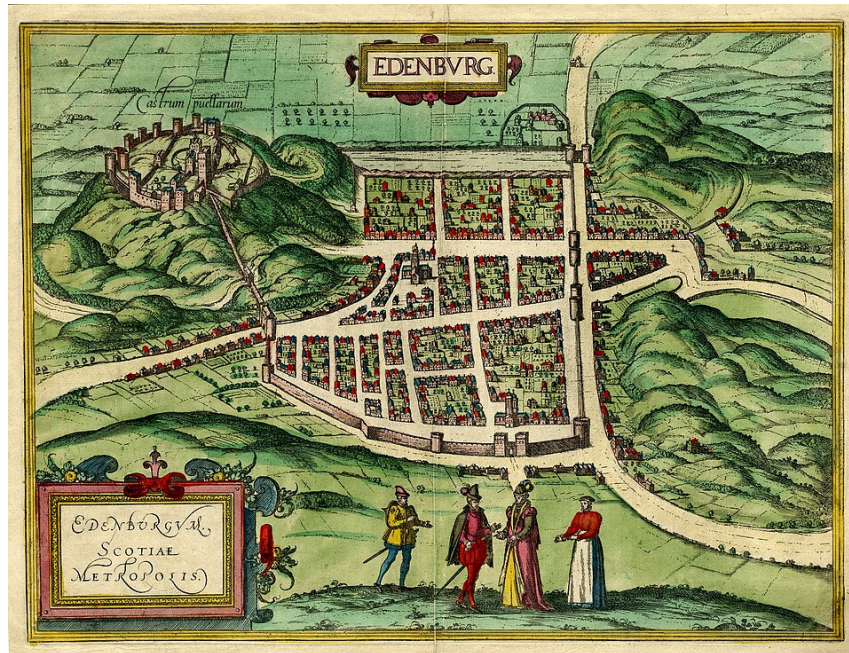


Edinburgh's crag and tail: the hard rock shielded the ridge behind it from the moving ice, and the Royal Mile runs down that ridge.



The European cities of Unit 1: fords, bridges, confluences, hills and harbors.

PICTURE STUDY



Edenburgum, Scotiae Metropolis (Edinburgh, Capital of Scotland), Georg Braun and Frans Hogenberg, about 1582 · Hand-colored engraving on paper, from the city atlas *Civitates Orbis Terrarum* · British Museum, London (this hand-colored copy); other copies are in the National Library of Scotland and many other libraries

Georg Braun was a churchman in the German city of Cologne, and Frans Hogenberg was an engraver. Together they published *Civitates Orbis Terrarum*, “Cities of the World,” a great atlas of town views that came out in six volumes between 1572 and 1617. Edinburgh appeared in the third volume, in the early 1580s. It is one of the earliest pictures of the city that we have.

Braun and Hogenberg drew Edinburgh from the south, as if from a high hill, with the buildings standing up in profile so you can recognize them. Above the castle they wrote *Castrum puellarum*, “Castle of the Maidens,” an old name for it. Look at how the whole town follows the shape of the land. The castle holds the high crag, the town runs down the tail of the ridge, and the palace of Holyrood sits at the bottom, where the ground is gentle and open.

Look closely

- Find the castle on its rock and the words *Castrum puellarum* above it. On how many sides could an enemy climb toward it?
- Follow the long main street from the castle down to Holyrood at the other end. That street is today’s Royal Mile. Find the great church of St. Giles along the way.
- Find the town wall. Is Holyrood inside it or outside it? Why might a king’s palace be built outside the walls?
- Look at the houses. Why are they so tall and so tightly packed?

- Find the four people in the foreground. Mapmakers added figures like these to show what the townspeople wore. What do their clothes tell you?

Talk about it

1. Edinburgh's port, Leith, is not in this view. Which direction would you go to reach it, and why did a hill city need a port at all?
2. What did the people of Edinburgh gain from their site, and what did it cost them in comfort and space?
3. Compare this town on a ridge with London on its riverbank in Canaletto's painting (Lesson 1.1). How did each city's ground shape its streets?

PROJECT: A SALT-DOUGH HILL CITY AND ITS HARBOR

You will model a defended hill city and its port in salt dough: a crag with a tail (like Edinburgh) or an acropolis (like Athens), a coast with a sheltered harbor, and a road or walls joining them. Then you will test your design as an attacker and as a merchant.

You will need

- Salt dough: 2 cups flour, 1 cup salt, about 3/4 cup water (makes enough for a model about 30 × 40 cm, or 12 × 16 inches)
- A sturdy piece of cardboard for the base
- A small stone or a ball of foil for the core of the crag
- Toothpicks, string, a ruler, a marble
- Paints or markers (blue, green, brown, gray)

Steps

1. Draw a coastline across one end of the cardboard. Mark a sheltered harbor: a bay protected by a headland.
2. About two thirds of the way inland, set the stone and cover it with dough to make a steep crag. Shape a long, gentle tail running away from it toward the coast, or a flat-topped acropolis with cliffs on three sides.
3. Mold the harbor town at the shore. Join the hill city to the harbor with a road along a ridge, or with two parallel lines of dough as Long Walls.
4. Choose a scale (for example, 1 cm on the model = 250 m). Measure the distance from the hilltop to the harbor and convert it to real distance.
5. Let the dough dry for two days or bake it at a low oven temperature (about 120 °C or 250 °F) for a few hours with an adult's help. Paint water, cliffs, fields, the town and the walls.
6. Attacker test: roll a marble up each side of the hill from the base. Mark with toothpick flags the sides where it fails to climb (the cliffs) and the side where it succeeds (the side you must guard).
7. Merchant test: lay string along the route a cart would take from harbor to hilltop. Measure it and compare with the straight-line distance.

8. Add a hill-and-harbor city pair to your Site-and-Situation Game board and score it.

Tips

- Keep the cliffs steep: press the dough against a ruler to make sharp edges.
- If the dough cracks while drying, fill the cracks with a little fresh dough and smooth with a wet finger.
- Label your model with a flag for the citadel, the harbor and the road or walls.

Check your work

- My model shows a defensible hill, a sheltered harbor and a protected link between them.
- I measured the distance from hill to harbor and converted it with my scale.
- I can explain which side of my hill needed the most defense and why.

MAP NOTEBOOK

1. Copy the Long Walls diagram. Mark the Acropolis, Piraeus, the Long Walls and the sea, and write one sentence on how the walls helped Athens in 431 BC.
2. Draw the crag-and-tail cross section of Edinburgh. Label west and east, the castle, the Royal Mile and Holyrood, and draw an arrow for the direction the ice moved.
3. Make a three-row chart: Athens, Rome, Edinburgh. For each, write its hill, its water route and its port.

From history. The Nor Loch, which guarded the north side of Edinburgh's castle rock, also collected the town's rubbish and sewage. In 1759 the city began to drain it so the town could spread north, and in 1766 the young architect James Craig won the competition to plan a New Town of straight, wide streets on the ridge beyond. The bed of the old loch became Princes Street Gardens, and Waverley Station now lies at its eastern end. Edinburgh came down from its crag once peace made the hill less necessary.

WORKED EXAMPLES

Example 1. Thucydides gives the Long Wall from Athens to Piraeus as 40 stades. If one stade is about 180 m, how long was the wall in kilometers and miles? How long would it take a porter walking at 5 km/h (about 3 mph) to carry a load from one end to the other?

(Use the map or drawing “The Long Walls joined the city to its harbor.” shown earlier in this lesson.)

1. Length = $40 \times 180 \text{ m} = 7,200 \text{ m} = 7.2 \text{ km}$.
2. Convert to miles: $7.2 \div 1.609 \approx 4.5 \text{ miles}$.
3. Time = distance $\div$ speed = $7.2 \text{ km} \div 5 \text{ km/h} = 1.44 \text{ h}$.
4. $0.44 \text{ h} \times 60 =$ about 26 minutes, so the walk takes about 1 hour 26 minutes.

Answer: About 7.2 km (4.5 miles); about 1 hour 26 minutes on foot.

Example 2. On a clear day, the distance to the horizon from a height h meters is about $d \approx 3.57 \times \sqrt{h}$ kilometers. How far could a lookout on the Acropolis, about 150 m above sea level, see across the sea? Could he watch ships at the entrance of Piraeus harbor, about 9 km away?

1. $\sqrt{150} \approx 12.25$.
2. $d \approx 3.57 \times 12.25 \approx 43.7 \text{ km}$.
3. In miles: $43.7 \div 1.609 \approx 27 \text{ miles}$.
4. 9 km is far less than 43.7 km, so ships at Piraeus lie well within the lookout's horizon.

Answer: About 44 km (27 miles). Yes: Piraeus, about 9 km away, is easily within view. A high site gives warning as well as protection.

Example 3. On a map with a scale of 1:500,000, the distance from the Roman Forum to Ostia measures 4.4 cm in a straight line. How far is that in kilometers and miles, and how long would a traveler walking at 5 km/h take to cover it?

1. $4.4 \text{ cm} \times 500,000 = 2,200,000 \text{ cm} = 22 \text{ km}$.
2. $22 \text{ km} \div 1.609 \approx 13.7 \text{ miles}$.
3. Time = $22 \div 5 = 4.4$ hours, or about 4 hours 24 minutes.
4. The road and the winding river are longer than the straight line, so the real journey took longer.

Answer: About 22 km (14 miles); about 4 hours 24 minutes on foot in a straight line. Rome was close enough to use the sea but far enough to be safe from raiders landing on the coast.

PRACTICE

1. **EASY** What does the Greek word acropolis mean, and what was an acropolis used for?
2. **EASY** Name the port of each city: Athens, Rome, Edinburgh.
3. **EASY** According to Herodotus, what did Themistocles say the oracle's "wooden wall" meant, and how was he proved right?
4. **EASY** Rome's traditional founding date is 753 BC, and the Battle of Salamis was in 480 BC. How many years apart are they?
5. **MEDIUM** Using $d \approx 3.57 \times \sqrt{h}$, how far is the horizon for a lookout 100 m above the sea? Give kilometers and miles.
6. **MEDIUM** On a 1:25,000 map, Edinburgh Castle and the harbor at Leith are 14 cm apart. How far apart are they on the ground?
7. **MEDIUM** Thucydides gives the Phaleric Wall as 35 stades. Using 180 m per stade, find its length in kilometers and miles.
8. **MEDIUM** Explain how a crag and tail forms and how Edinburgh's Old Town fits its shape.
9. **HARD** Using the map g8-unit1-europe, which Unit 1 city is farthest north, and in what general compass direction would you travel from Rome to Athens?
(Use the map or drawing "Use this map for Problem 9." shown earlier in this lesson.)
10. **CHALLENGE** Write a paragraph explaining the trade-off between defense and trade in a city's site, and compare how Athens and Edinburgh answered it.

COMMON MISTAKES

- Thinking a hill city cannot be a trading city. Athens, Rome and Edinburgh all traded widely; they simply kept their port a short distance away.
- Thinking the Long Walls made Athens unbeatable. They protected the city as long as Athens ruled the sea; when its fleet was destroyed in 405 BC, Athens was starved into surrender the next year.
- Writing "the acropolis" only for Athens. Many Greek cities had an acropolis; the Acropolis of Athens is simply the most famous one.

Make it a game • Defend or Trade?. Make ten cards, each describing a site: a steep rock by a river mouth, a flat beach, an island in a river, a marsh, a hill 10 km from a bay, a ford with low banks, and so on. Draw a card. Score it out of 5 for defense and out of 5 for trade, and give one reason for each score. Your opponent may challenge one score; if a parent agrees with the challenge, the opponent gains a point. After all ten cards, name the best site for a capital and the best site for a merchant town.

Scripture. "Except the LORD build the house, they labour in vain that build it: except the LORD keep the city, the watchman waketh but in vain." (Psalm 127:1, KJV)

Hills, walls and harbors are good gifts, and wise founders use them. Yet Athens' walls fell, and Rome's hills did not save it forever. The psalmist reminds us that the safety of any city finally rests with the Lord who "determined the times before appointed, and the bounds of their habitation" (Acts 17:26).

Practice answers

1. "High city." It was a fortified hilltop used as a refuge in war and as a holy place for temples.
2. Athens: Piraeus. Rome: Ostia (later also Portus). Edinburgh: Leith.
3. He said it meant the Athenian fleet of ships. The Greek fleet defeated the Persian fleet at Salamis in 480 BC, even though the Persians had taken the Acropolis.
4. $753 - 480 = 273$ years.
5. $\sqrt{100} = 10$, so $d \approx 35.7$ km, about 22 miles.
6. $14 \times 25,000 = 350,000$ cm = 3.5 km, about 2.2 miles.
7. $35 \times 180 = 6,300$ m = 6.3 km $\approx$ 3.9 miles.
8. An ice sheet moving across the land wore away soft rock but could not wear away a knob of hard volcanic rock (the crag); the softer rock in the shelter behind it survived as a long sloping ridge (the tail). Edinburgh Castle stands on the crag, and the Old Town and the Royal Mile run down the tail eastward to Holyrood.
9. Edinburgh is farthest north. From Rome to Athens you travel east-southeast (roughly east, a little south).
10. A high, steep site is easy to defend but hard to reach for traders, while a harbor is easy to reach for both merchants and enemies. Athens kept its citadel on the Acropolis and fortified the port of Piraeus, then joined them with the Long Walls so that the city could trade and be fed by sea even under siege. Edinburgh kept its castle on Castle Rock and its town on the ridge behind it, and used Leith, about 3 km away on the Firth of Forth, as its port, linked by road rather than walls. Both cities joined a defended hill to a separate harbor.

UNIT 1 REVIEW

Answer each question. Show your work for calculations, give both kilometers and miles where asked, and use complete sentences for explanations. The review is worth 60 points.

1. (6 pts) Define site and situation. Then explain how London's site and situation each helped it grow at London Bridge.
2. (6 pts) What do the names Oxford and Frankfurt mean, and on what rivers do the towns stand? What do a ford and the lowest bridging point have in common as town sites?
3. (6 pts) On a 1:200,000 map, Oxford and Reading are 19 cm apart. How far apart are they in kilometers and in miles?
4. (6 pts) Which two rivers meet at Pittsburgh, and what river do they form? Give the bearing of each incoming river from the Point as Washington described it (NE and SE) and the angle between them.
5. (6 pts) Give two reasons a confluence makes a strong site for a fort or town, and one danger. Then name one confluence city outside the United States and its rivers.
6. (6 pts) The Ohio River is about 981 miles long, while the straight-line distance from Pittsburgh to Cairo is about 550 miles. Convert the river length to kilometers and find how many times longer the river is than the straight line.
7. (6 pts) What is the fall line, and why did it form? Name the two regions that meet there.
8. (6 pts) Explain head of navigation, break of bulk and water power, and use them to explain why Richmond grew at the falls of the James.
9. (6 pts) A canal must lift boats 76 feet (23 m) around the Great Falls of the Potomac. How many locks are needed if each lifts 10 feet? What would each lock lift if five locks shared the climb equally?
10. (6 pts) Describe the trade-off between defense and trade, and explain how Athens and Rome each solved it. Then use $d \approx 3.57 \times \sqrt{h}$ to find how far a lookout 64 m above the sea can see.

UNIT PROJECT: WHERE CITIES STAND: MY MAP AND MY SETTLED LAND

Present two maps side by side. First, a hand-drawn map of the eastern United States showing the fall line with at least eight fall-line cities and their rivers, plus at least four river confluences (for example Pittsburgh, Cairo, St. Louis and Harpers Ferry), each marked with a symbol you explain in a key. Second, your finished Site-and-Situation Game board from Lessons 1.1 to 1.4, with every town labeled and its reason card attached.

Write a one-page explanation titled "Why My Capital Stands Where It Does." Use the words site, situation, ford, confluence, fall line and harbor, and compare your capital with at least two real cities from this unit.

- **Accuracy:** The fall line, its cities and rivers, and the confluences are placed correctly and labeled clearly, with a key, compass rose and scale.

- **Reasoning:** Every town on the game board has a written reason that names both a site advantage and a situation advantage.
- **Explanation:** The written page uses the unit's terms correctly and compares the imaginary capital with real cities such as London, Pittsburgh, Richmond or Athens.
- **Care:** Both maps are neat, colored and easy to read, and the work is complete.

Answer key

1. Site is the ground a town stands on; situation is its position relative to the places and routes around it. London's site: dry gravel hills on the north bank where the Thames could be bridged. Its situation: the lowest bridging point, where seagoing ships coming up on the tide met the roads leading across England.
2. Oxford: "ford of the oxen," on the Thames (where the Cherwell joins it). Frankfurt: "ford of the Franks," on the Main. Both fords and the lowest bridging point are places where travelers are forced to cross a river at one spot, so roads converge there and markets, inns and defenses follow.
3. $19 \times 200,000 = 3,800,000 \text{ cm} = 38 \text{ km}$. $38 \div 1.609 \approx 23.6 \text{ miles}$, about 24 miles.
4. The Allegheny and the Monongahela form the Ohio. Allegheny: $\text{NE} = 045^\circ$. Monongahela: $\text{SE} = 135^\circ$. The angle between them is 90° .
5. Reasons: water protects the point on two sides; the town controls traffic from two valleys and the river below (and has water and transport at hand). Danger: floods from both rivers meet there. Examples: Koblenz (Moselle and Rhine), Lyon (Saône and Rhône), Belgrade (Sava and Danube), Khartoum (White Nile and Blue Nile).
6. $981 \times 1.609 \approx 1,578 \text{ km}$. $981 \div 550 \approx 1.8$ times longer.
7. The fall line is the zone of falls and rapids where rivers flow off the hard crystalline rock of the Piedmont onto the soft sand, gravel and clay of the Atlantic Coastal Plain. The rivers wear down the soft sediments faster than the hard rock, leaving a step where the water falls.
8. Head of navigation: the farthest point ships can sail upstream. Break of bulk: where cargo changes from one kind of transport to another. Water power: energy from falling water to run mills. At Richmond, ships from the Chesapeake had to stop at the falls; tobacco and wheat from the Piedmont came by wagon and were loaded onto boats there; and the falls drove flour mills and later the Tredegar Iron Works.
9. $76 \div 10 = 7.6$, so 8 locks (round up). With five locks: $76 \div 5 = 15.2$ feet (about 4.6 m) each.
10. A high, steep site is safe but hard for traders to reach; a harbor is easy to reach for friends and enemies alike. Athens kept its citadel on the Acropolis and joined it to the port of Piraeus with the Long Walls. Rome stood on its hills about 22 km inland, safe from sea raids, but reached the sea by the Tiber and its port of Ostia. Horizon: $\sqrt{64} = 8$, so $d \approx 3.57 \times 8 \approx 28.6 \text{ km}$, about 17.7 miles.

THE RIVER CIVILIZATIONS

The first great cities of the world did not rise on mountaintops or in forests. They rose beside four rivers that cross dry lands: the Nile, the Tigris and Euphrates, the Indus and the Yellow River. Each river brought water and rich silt to a plain that would otherwise have been desert or steppe, and each made its people solve hard problems of flood, field and storage. The psalmist says of the earth, “For he hath founded it upon the seas, and established it upon the floods” (Psalm 24:2). In this unit you will see how God’s ordering of rivers and rains set the stage for the first civilizations, and how people answered with canals, dikes, levers, drains and laws.

You will sail up the Nile with Herodotus and learn why Egypt is “the gift of the river,” follow Abram out of Ur along the Euphrates, walk the planned brick streets of Mohenjo-daro, and stand with Yu the Great against the floods of China’s Sorrow. In every valley you will ask the geographer’s questions: **Where does the water come from? When does it flood? What does the river give, and what does it threaten?** Along the way you will build a working shaduf, the water lever farmers have used for four thousand years, and draw a map of all four river valleys.

BEFORE YOU BEGIN

- Can read latitude and longitude on a map (Unit 1 and earlier grades)
- Knows the ideas of site and situation from Unit 1
- Can multiply and divide decimals and use a map scale
- Knows the Bible stories of Abraham and of Joseph in Egypt

MASTERY CHECKLIST

- I can locate the Nile, the Tigris and Euphrates, the Indus and the Yellow River on a world map and name a great city of each.
- I can explain where each river’s flood water comes from and when it floods.
- I can explain how silt both builds land and causes danger, including levees and raised riverbeds.
- I can build and explain a shaduf and calculate its balancing counterweight.
- I can describe how Egyptians, Sumerians, Harappans and Chinese each used technology to live with their river.
- I can use latitude, scale and slope to calculate real distances and drops along these rivers.

OPTIONAL BOOKS AND RESOURCES

- **Herodotus, *The Histories* (free at Project Gutenberg)**
(<https://www.gutenberg.org/ebooks/search/?query=herodotus>): Free. Book 2 is

Herodotus's account of Egypt and the Nile. A parent may choose short passages to read aloud for Lesson 2.1.

- **British Museum Collection Online** (<https://www.britishmuseum.org/collection>): Free. Search "Standard of Ur" and "Ur" to see the objects Leonard Woolley found, with large photographs (Lesson 2.2).
- **UNESCO World Heritage: Archaeological Ruins at Moenjodaro** (<https://whc.unesco.org/en/list/138>): Free. Photographs and a short description of Mohenjo-daro's citadel, streets and Great Bath (Lesson 2.3).

2.1 THE NILE: THE GIFT OF THE RIVER ★

OBJECTIVES

- Explain why Egypt, a land with almost no rain, became one of the first great civilizations, using Herodotus's phrase "the gift of the river."
- Describe the yearly Nile flood: where its water came from, when it arrived, and how the Egyptians measured and used it.
- Build a working shaduf and explain how a lever and a counterweight let one farmer lift water from the river to the fields.

Warm-up. Put two spoonfuls of garden soil in a clear jar of water, screw on the lid and shake it hard. Set it on the table and watch for five minutes. What sinks first? What is still floating at the end? The fine mud that settles last is **silt**, the very stuff that built the land of Egypt.

Watch. *Geography of Ancient Egypt Explained / The Nile River & Egyptian Civilization / DAILY BELLRINGER* (The Daily Bellringer, 5:09). <https://www.youtube.com/watch?v=TV9BO5P4MyE>

After the story: the geography of ancient Egypt and the gift of the Nile flood.

Backup video. *The Nile River Explained in under 3 Minutes* (FactSpark, 2:59). <https://www.youtube.com/watch?v=iJhqKwM9JIs>

With On the map: the Nile from its sources to the sea in about three minutes.

KEY TERMS

inundation

The yearly flood of the Nile, which covered the valley floor in late summer and left fresh soil behind. The Egyptians called the flood season Akhet.

silt

Very fine soil carried by moving water and dropped when the water slows down. Nile silt made the black, fertile land of Egypt.

delta

A fan of flat land built of silt where a river splits into branches and enters the sea. Named for the Greek letter Δ.

cataract

A stretch of rapids where a river runs over hard rock. The First Cataract at Aswan was Egypt's old southern border.

exotic river

A river that rises in a rainy land and then flows through a desert, carrying water to a place that gets almost no rain of its own.

shaduf

A water lever: a long pole on a pivot with a bucket on one end and a counterweight on the other, used to lift water from a river or canal.

CORE IDEAS

The story. Around 450 BC a curious Greek traveler named Herodotus of Halicarnassus sailed up the Nile. He talked with priests, looked at temples, and kept asking one question: where did this land come from? He noticed that the soil of Egypt was black and crumbly, unlike the red, stony desert on either side. He reported that sailors a full day's voyage out from the coast could drop a weighted line and bring up river mud from eleven fathoms down. His conclusion became the most famous sentence ever written about Egypt: the country the Greeks sailed to was land the river itself had made, "the gift of the river." Herodotus was right. Almost every acre that could grow a crop in Egypt was laid down, layer by layer, by the Nile.

How it worked. Egypt itself gets almost no rain; Aswan in the south may go years without a shower. The water came from far away. The White Nile flows steadily out of the region of Lake Victoria, near the equator. The Blue Nile and the Atbara rise in the Ethiopian Highlands, where heavy summer monsoon rains pour down from June to September. The two Niles meet at Khartoum, and every summer the swollen Blue Nile sent a brown wave of water and silt north. The river began to rise in Egypt in early summer, crested around September and slowly fell in October and November. When it went down it left a fresh coat of mud on the fields. The Egyptians built their year around it: *Akhet* (the flood), *Peret* (the growing season, when the fields "came out" of the water) and *Shemu* (the harvest and the dry season). They watched for the star Sirius to rise in the dawn sky near the start of the flood, and they built **Nilometers**, stone stairways and wells marked in cubits, to measure each year's rise. The Roman writer Pliny the Elder recorded the old rule: a rise of twelve cubits meant hunger, sixteen meant plenty. Officials even set taxes by the height of the flood.

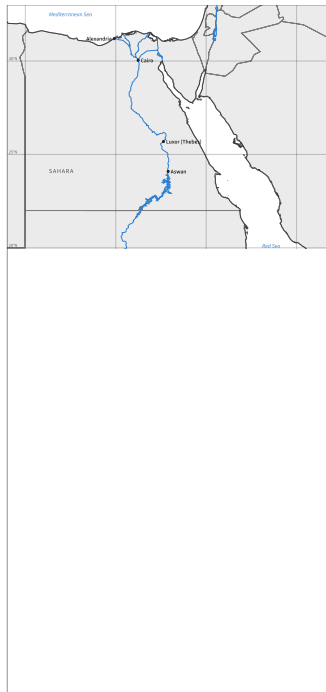
The big idea. The Nile is an **exotic river**: it rises in rainy lands and then crosses one of the driest deserts on earth. That made Egypt a long green ribbon, in most places only a few miles to a dozen or so miles wide, with the desert pressing in on both sides. The Egyptians called their country *Kemet*, "the black land," for its dark soil, and the desert *Deshret*, "the red land." The geography gave them three gifts at once. It gave them **food**, because the flood watered and fertilized the fields every year. It gave them a **highway**, because the current flows north while the usual wind blows from the north: a boat could drift downstream to the sea and raise its sail to go back upstream. In writing, a boat with its sail up came to mean "travel south." And it gave them **protection**, because deserts on the east and west, the sea on the north and the cataracts on the south made Egypt hard to invade. No wonder Egypt held together as one kingdom for so many centuries.

On the map. The Nile is about 6,650 km (4,130 mi) long, one of the two longest rivers in the world, and it flows from south to north. On a map that means it runs "up" the page, which surprises many students. Follow it from Lake Victoria north to Khartoum, past the cataracts to Aswan, then down the narrow valley past Luxor (ancient Thebes) to the point near modern Cairo where the valley opens into the Delta. The old capital, Memphis, stood right at that

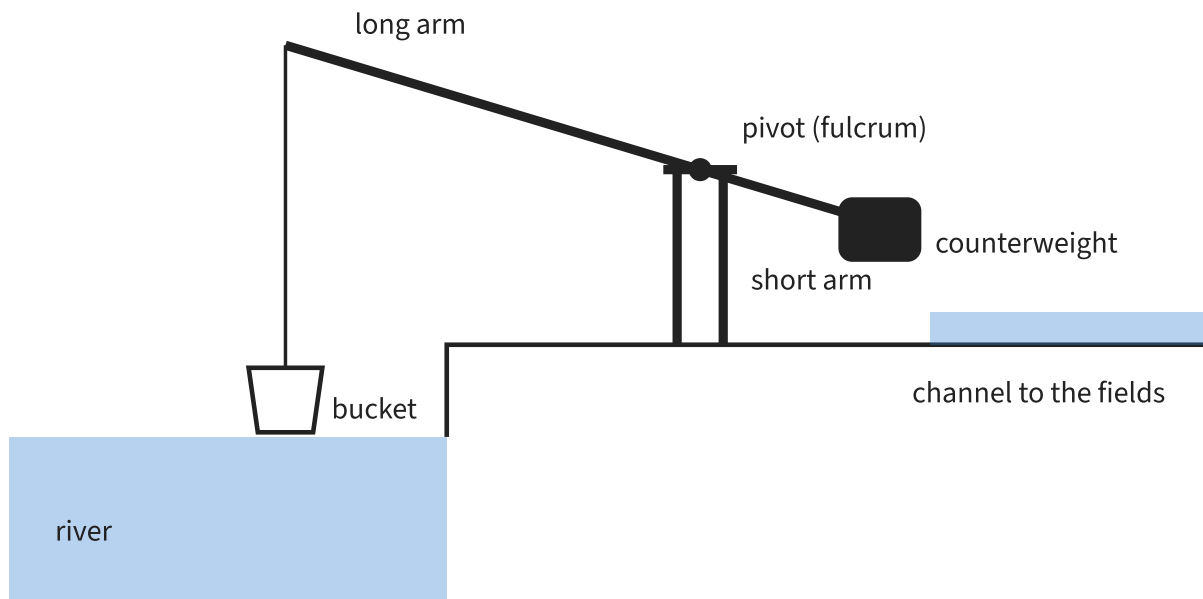
hinge between the valley (Upper Egypt) and the Delta (Lower Egypt). Remember Unit 1: Memphis is a perfect example of a city placed for its **situation**, where it could watch both halves of the country and all the river traffic between them.

Technology overcoming geography. The Egyptians did not simply wait for the flood. They built earth banks to divide the valley into basins, let the floodwater stand in each basin until the soil was soaked, then drained it and planted. To water gardens in the dry season, farmers used the **shaduf**, a lever first pictured in Mesopotamia and shown in Egyptian tomb paintings of the New Kingdom. A pole on a pivot, a bucket on the long end and a lump of mud or stone on the short end let one person lift bucket after bucket all day. Much later, in 1970, the Aswan High Dam was finished. It ended the yearly flood, stored water in Lake Nasser, made electricity and let farmers raise two or three crops a year. It also trapped the silt behind the dam, so farmers now buy fertilizer and parts of the Delta coast are wearing away. Engineers and historians still weigh both sides. Either way, the story of Egypt is the story of people learning to use a river God placed in the desert.

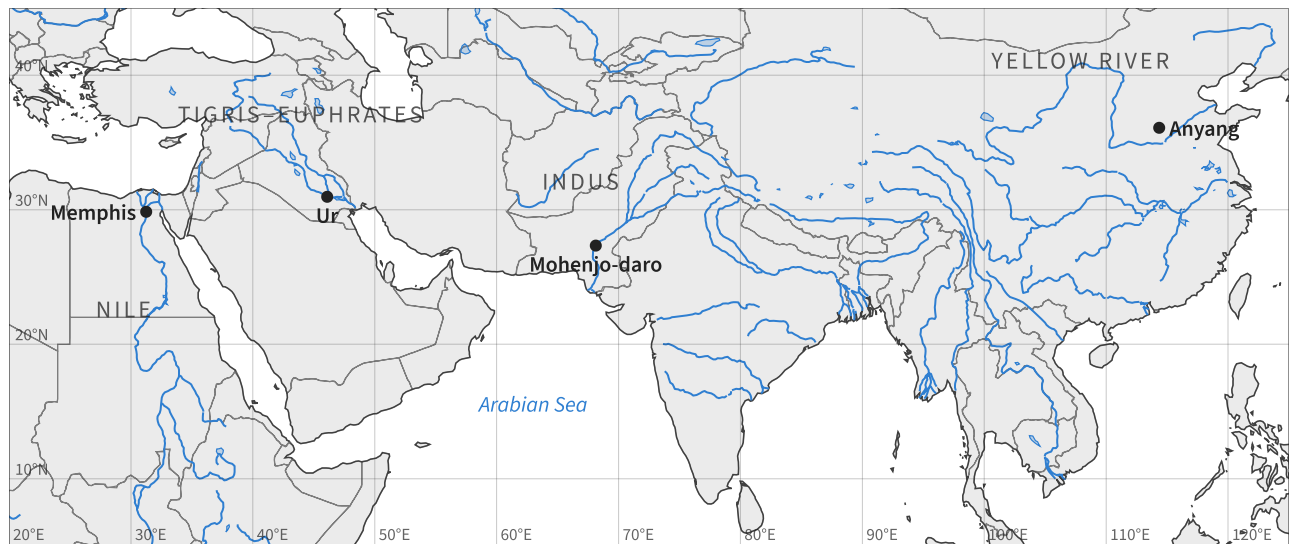
For the Christian student. The Bible knows this river well. Pharaoh dreamed that he “stood by the river” (Genesis 41:1), and Joseph used the seven good years of the Nile to store grain in the cities against seven years of famine. Joseph was doing what wise people in every river valley must do: receiving God’s gift with thanks and planning carefully for the years when the river fails.



The Nile flows north. The White Nile brings a steady flow from the Lake Victoria region; the Blue Nile brings the summer flood from the Ethiopian Highlands.



A shaduf is a lever. The counterweight on the short arm lifts the full bucket on the long arm.



The four river valleys of this unit. Notice that the four cities marked all lie between about 27° and 37° north latitude, in a belt of dry lands crossed by great rivers.

PICTURE STUDY



Farming scenes in the Tomb of Nakht (TT52), Unknown Egyptian tomb painters, 18th Dynasty, about 1400–1390 BC · Paint on plaster · Tomb of Nakht (Theban Tomb 52), Sheikh Abd el-Qurna, on the west bank of the Nile at Luxor, Egypt. Full-size painted copies made by Norman de Garis Davies are in the Metropolitan Museum of Art, New York.

Nakht was a scribe and an official who served the temple of the god Amun at Thebes. His small tomb chapel is famous for its bright, cheerful paintings. On its walls the painters showed the farming year along the Nile: men plowing the damp soil left by the flood, sowing seed, cutting the ripe grain and carrying it away. Egyptians believed these pictures would provide for the dead in the next life, but for us they are something else as well: a picture book of how the Nile valley actually worked about 3,400 years ago.

Egyptian painters followed strict rules. They drew people with the head and legs from the side and the shoulders from the front, and they arranged scenes in rows called registers, read like lines of a book. Important people are drawn larger than workers.

Look closely

- Find the oxen pulling a plow. What kind of soil would let a light wooden plow cut through it easily?
- Find a worker scattering seed and others breaking up clods. Why would they have to work quickly after the flood went down?
- Find the person who is drawn larger than the others, watching the work. Who might he be, and why is he drawn that way?
- Look at the colors of the soil, the grain and the skin of the workers. What do the colors tell you about the land and the sun?

Talk about it

1. Which season of the Egyptian year, Akhet, Peret or Shemu, does each row of the painting show?
2. If the Nile had not flooded one year, which of these scenes could not have happened?
3. What can a painting like this teach a geographer that a written record might not?

Safety first. Ask an adult to cut or saw sticks and to help with any knife. Work outdoors or on a towel, and never leave a younger child alone with a tub of water.

PROJECT: BUILD A WORKING SHADUF

For about four thousand years farmers in Egypt and Mesopotamia have lifted water with a shaduf, and some still did within living memory. You will build a tabletop shaduf that really lifts water from a “river” tub to a higher “field” tray, then balance it so it does most of the work for you.

You will need

- Two sturdy sticks or dowels about 30 cm (12 in) long for the uprights
- One short stick about 15 cm (6 in) long for the crossbar (the pivot)
- One straight stick, dowel or yardstick about 50 cm (20 in) long for the lifting pole
- String, rubber bands and strong tape
- A small paper or plastic cup with two holes punched near the rim for the bucket
- Modeling clay or a small bag of pebbles for the counterweight
- A base: a block of foam, a shoebox filled with sand, or a flowerpot of soil
- A tub of water (the river) and a baking tray set on a book (the field)
- A kitchen scale and a ruler

Steps

1. Push the two uprights into the base about 10 cm apart, or tape them firmly to the sides of a box.
2. Lash the short crossbar between the tops of the uprights with string or rubber bands. This crossbar is the **pivot**, or fulcrum.
3. Tie the long pole to the crossbar about one quarter of the way from one end, so that one arm is long and one is short. Leave the knot loose enough that the pole can swing up and down.
4. Hang the cup from the end of the long arm with about 20 cm (8 in) of string so it can dip into the tub.
5. Weigh the cup when it is full of water. Measure the length of the long arm and the short arm from the pivot.
6. Work out the counterweight you need: $\text{weight of full cup} \times \text{long arm} \div \text{short arm}$. Shape that much clay around the end of the short arm, or hang a bag of pebbles there.
7. Place the tub beside the base and the field tray on the other side, a little higher. Pull the long arm down to fill the cup, then let the counterweight lift it. Swing the pole and tip the water into the field tray.

- Count how many cupfuls you can move in two minutes. Then remove the counterweight and try again. Record both counts in your map notebook.

Tips

- If the cup will not sink, the counterweight is too heavy; if it is hard to lift, add clay. A real shaduf is balanced so that the full bucket is just a little heavier than the weight.
- Let the counterweight do the lifting. Your job is mostly to pull the empty bucket down and to swing the pole.
- Sketch your shaduf from the side and label the pivot, the long arm, the short arm, the bucket and the counterweight.

Check your work

- My shaduf lifts water from the tub and pours it into a higher tray.
- I can explain why the counterweight makes the work easier.
- I can calculate a balancing counterweight from the arm lengths and the weight of the bucket.

MAP NOTEBOOK

- Trace or draw the Nile from Lake Victoria to the Mediterranean. Mark Khartoum, Aswan, Luxor, Cairo and Alexandria, and shade the Delta and the narrow valley green and the deserts on both sides tan.
- Draw a circle divided into three parts for the Egyptian year: Akhet, Peret and Shemu. In each part draw what the river and the farmers were doing.
- Draw a side view of your shaduf with arrows showing which way each end moves, and write the balancing rule underneath.

From history. The Nilometer on Roda Island in Cairo was built in AD 861 under the Abbasid caliph al-Mutawakkil and still stands. It is a deep stone well connected to the river, with a tall marked column in the middle. For about a thousand years officials read the height of the water on that column each summer, and when the river reached the level that promised a good harvest, Cairo held a festival.

WORKED EXAMPLES

Example 1. Aswan lies at about 24.1° N and Cairo at about 30.0° N. One degree of latitude is about 111 km (69 mi). How far north of Aswan is Cairo?

(Use the map or drawing “Aswan is near 24° N; Cairo is near 30° N.” shown earlier in this lesson.)

1. Find the difference in latitude: $30.0^{\circ} - 24.1^{\circ} = 5.9^{\circ}$.
2. Multiply by the length of one degree: $5.9 \times 111 \text{ km} = \text{about } 655 \text{ km}$.
3. In miles: $5.9 \times 69 \text{ mi} = \text{about } 407 \text{ mi}$.
4. Check against the map: Cairo is also a little west of Aswan, so the true straight-line distance is somewhat longer, about 680 km (420 mi), and the winding river is longer still.

Answer: About 655 km (407 mi) farther north. The flood water reaching Cairo had traveled the whole length of the valley first.

Example 2. Pliny the Elder recorded that a Nile rise of 12 cubits meant hunger and a rise of 16 cubits meant plenty. If a cubit is about 0.52 m (about 20.5 in), how high was each flood, and how much higher was the good flood than the bad one?

1. Good flood: $16 \times 0.52 \text{ m} = 8.32 \text{ m}$, about 8.3 m. In feet: $16 \times 20.5 \text{ in} = 328 \text{ in} \div 12 = \text{about } 27 \text{ ft}$.
2. Bad flood: $12 \times 0.52 \text{ m} = 6.24 \text{ m}$, about 6.2 m, or $12 \times 20.5 \text{ in} = 246 \text{ in} \div 12 = \text{about } 20.5 \text{ ft}$.
3. Difference: $4 \text{ cubits} \times 0.52 \text{ m} = 2.08 \text{ m}$, about 2.1 m; in feet, $4 \times 20.5 \text{ in} = 82 \text{ in} \div 12 = \text{about } 6.8 \text{ ft}$, almost 7 ft.

Answer: About 8.3 m (27 ft) for plenty and 6.2 m (20.5 ft) for hunger, a difference of only about 2.1 m (almost 7 ft). A few feet of water decided whether Egypt ate well or went hungry.

Example 3. The Egyptian calendar had 3 seasons of 4 months, each month 30 days, plus 5 extra days. How many days were in the Egyptian year? The true solar year is about $365\frac{1}{4}$ days. How many years would it take for the calendar to slip a full month (30 days) behind the flood, and how long to slip all the way around?

1. Days in the calendar: $3 \times 4 \times 30 = 360$, plus 5 = 365 days.
2. The calendar is about $\frac{1}{4}$ day short each year, so it slips 1 day every 4 years.
3. To slip 30 days: $30 \times 4 = 120$ years.
4. To slip all the way around the year: $365 \times 4 = 1,460$ years.

Answer: 365 days. It slipped about one month every 120 years and all the way around in about 1,460 years, which is one reason the Egyptians kept watching the star Sirius and the river itself.

PRACTICE

1. **EASY** In which direction does the Nile flow, and into what sea does it empty?
2. **EASY** Name the three seasons of the Egyptian year and what happened in each.
3. **EASY** Where did most of the water of the yearly flood come from, and why did it come in summer?
4. **MEDIUM** Luxor (ancient Thebes) lies at about 25.7° N and Cairo at about 30.0° N. Using 111 km (69 mi) per degree of latitude, how far north of Luxor is Cairo?
5. **MEDIUM** On a full-size shaduf the bucket hangs 2.4 m from the pivot and the counterweight 0.8 m from the pivot. A full bucket weighs 10 kg. What counterweight would balance it?
6. **MEDIUM** Look at the map of the Nile. Which modern city stands near the point where the narrow valley opens into the Delta, and which ancient capital stood nearby? Why was that a good place for a capital?
(Use the map or drawing "Find where the valley meets the Delta." shown earlier in this lesson.)
7. **MEDIUM** In Egyptian writing, a boat with its sail raised came to mean "travel south." Explain why, using the river and the wind.
8. **HARD** Your model shaduf pole is 40 cm long and the pivot is 10 cm from the counterweight end. A full cup of water weighs 120 g. How much clay do you need on the short end to balance it?
9. **HARD** Herodotus said sailors a day out from Egypt found river mud at 11 fathoms. A fathom is 6 feet (about 1.83 m). How deep was that in feet and in meters?
10. **CHALLENGE** In a short paragraph, give two benefits and two costs of the Aswan High Dam (finished 1970), and say how it changed Herodotus's "gift of the river."

COMMON MISTAKES

- Thinking the Nile flows south because it runs "down" the page from the Mediterranean. Rivers flow downhill, not down the map; the Nile's source is far to the

south and its mouth is in the north.

- Thinking the flood came from rain in Egypt. Egypt gets almost no rain; the water came from the rainy highlands of Ethiopia and the lake region of East Africa.
- Thinking the flood was a disaster. The Egyptians welcomed it. Only a flood that was much too low (hunger) or much too high (destruction) brought trouble.

Make it a game · Akhet, Peret, Shemu. Make twelve cards, each with one event of the Nile year: the river rises, Sirius appears at dawn, fields are under water, the officials read the Nilometer, the water goes down, plowing, sowing, the grain grows green, reaping, threshing, the river is at its lowest, using the shaduf for gardens. Shuffle them. Players race to lay the cards in order around a circle drawn on paper and divided into the three seasons. Score one point for each card in the right season, and a bonus point for explaining one card aloud.

Scripture. “And in the seven plenteous years the earth brought forth by handfuls.” (Genesis 41:47, KJV)

The “handfuls” came from good Nile floods. Joseph gathered the surplus into the cities so Egypt and its neighbors could live through the lean years. Every river valley in this unit teaches the same lesson: God gives the gift, and people must steward it wisely.

Practice answers

1. From south to north, into the Mediterranean Sea.
2. Akhet: the flood covered the fields. Peret: the water went down and crops were planted and grew. Shemu: harvest and the hot, dry, low-water season.
3. From the Ethiopian Highlands, through the Blue Nile and the Atbara, because heavy summer monsoon rains fall there from about June to September.
4. $30.0^\circ - 25.7^\circ = 4.3^\circ$. $4.3 \times 111 \text{ km} \approx 477 \text{ km}$; $4.3 \times 69 \text{ mi} \approx 297 \text{ mi}$.
5. $10 \text{ kg} \times 2.4 \text{ m} \div 0.8 \text{ m} = 30 \text{ kg}$.
6. Cairo; ancient Memphis stood just south of it. It sat at the hinge between Upper Egypt (the valley) and Lower Egypt (the Delta), so a ruler there could control both halves and the river traffic between them.
7. The current flows north, so boats going north could drift with it. The usual wind blows from the north, so boats going south (upstream) raised their sails to be pushed against the current.
8. Long arm = $40 - 10 = 30 \text{ cm}$; short arm = 10 cm . $120 \text{ g} \times 30 \div 10 = 360 \text{ g}$ of clay.
9. $11 \times 6 = 66 \text{ ft}$; $11 \times 1.83 \text{ m} \approx 20 \text{ m}$.
10. Benefits (any two): it stopped damaging high floods and saved water through low years; it allowed two or three crops a year; it made electricity; it stored water in Lake Nasser. Costs (any two): it trapped the silt, so fields lost their yearly fertilizer and farmers must buy it; the Delta coast is wearing away without new silt; land and villages were flooded behind the dam. The river still gives Egypt water, but it no longer gives new soil each year.

2.2 THE TIGRIS AND EUPHRATES: CANALS, CITIES AND ABRAHAM'S UR

OBJECTIVES

- Locate Mesopotamia, the Tigris and the Euphrates, and the cities of Ur, Uruk and Babylon, and trace Abram's journey from Ur to Haran.
- Explain why the floods of the Tigris and Euphrates were harder to live with than the Nile's, and how canals, dikes and laws let the Sumerians farm the plain.
- Calculate the slope of a very flat river plain and use degrees and minutes, a system that comes to us from Mesopotamia.

Warm-up. Lay a ruler flat on a table and put a marble on it. Now slip one coin under one end. Does the marble roll? Try a thinner object, like a folded sheet of paper. Ancient farmers in Mesopotamia had to make water flow across land almost as flat as your ruler. How could they possibly do it?

Watch. *Ancient Mesopotamia 101 | National Geographic* (National Geographic, 4:10). <https://www.youtube.com/watch?v=xVf5kZA0HtQ>

After the story: Mesopotamia between the Tigris and Euphrates, its canals, cities and ziggurats.

Backup video. *The Euphrates and Tigris River explained in under 3 minutes* (FactSpark, 2:59). <https://www.youtube.com/watch?v=jNWZLD6mqc4>

With On the map: the two rivers and the land between them.

KEY TERMS

Mesopotamia

Greek for "between the rivers": the land along and between the Tigris and Euphrates, mostly in modern Iraq.

levee

A raised bank along a river. Floods build natural levees by dropping silt next to the channel; people make them higher to hold the river in.

irrigation canal

A dug channel that leads water from a river to fields, running gently downhill the whole way.

city-state

A city that rules itself and the farmland around it, like Ur, Uruk and Lagash in Sumer.

ziggurat

A huge stepped tower of mud brick with a temple on top, built at the heart of a Mesopotamian city.

salinization

The slow build-up of salt in soil when irrigation water evaporates and leaves its dissolved salt behind.

CORE IDEAS

The story. The Bible says that Terah took his son Abram, his grandson Lot and Abram's wife Sarai, "and they went forth with them from Ur of the Chaldees, to go into the land of Canaan; and they came unto Haran, and dwelt there" (Genesis 11:31). For centuries Ur was only a name. Then, from 1922 to 1934, the British archaeologist Leonard Woolley led a joint expedition of the British Museum and the University of Pennsylvania Museum to a desert mound in southern Iraq. Under the sand he uncovered the great stepped tower of Ur, streets of brick houses, thousands of clay tablets, and the Royal Cemetery, with its gold helmet, lyres and jewelry of lapis lazuli. Most scholars agree with Woolley that this is the Ur of Abram, though some have argued for a site farther north. Either way, the dig showed that Abram came from one of the oldest and richest cities in the world.

How it worked. Ur once stood beside the Euphrates near the marshes at the head of the Persian Gulf. Today the river has moved and the ruins stand in dry desert. That fact tells you a great deal about this land. Both the Tigris and the Euphrates rise in the mountains of eastern Turkey, and both flood in spring, when the winter snow melts. Their floods are bigger, wilder and less regular than the Nile's, and they come at a bad time: in April and May, when the winter barley is ripening. Worse, the plain is so flat that the rivers drop their silt right beside their channels and build up natural **levees**. Over the centuries the riverbed rises until the water flows *above* the surrounding fields. When a levee breaks, the river can pour out across the plain and even carve a new course. The Sumerians turned this danger into a tool. Because the river was higher than the fields, a farmer could cut a canal through the levee and let the water run gently downhill to his crops. Thousands of miles of canals, banks and basins crossed southern Mesopotamia. Every year they had to be cleared of silt, which took many hands, careful records and someone in charge.

The big idea. A hard river made a busy people. To organize canal work, store grain and keep accounts, the temples and kings of Sumer needed writers, and by about 3200 BC scribes at Uruk were pressing marks into wet clay, the beginnings of **cuneiform** writing. They counted in sixties, and we still do when we divide an hour into 60 minutes and a circle into 360 degrees, each of 60 minutes. Water also caused quarrels. Neighboring city-states such as Lagash and Umma fought for generations over border fields and the canals that watered them. About 1750 BC King Hammurabi of Babylon wrote into his laws that a man who neglected his dike, so that it broke and flooded his neighbors' fields, must repay the grain he had ruined. There was a slower danger too. River water carries a little dissolved salt, and when it evaporates from hot fields the salt stays behind. Many historians think this **salinization** is why farmers in the far south grew more and more barley, which tolerates salt, and less wheat.

On the map. The Euphrates is about 2,800 km (1,740 mi) long and the Tigris about 1,850 km (1,150 mi). They come within a few dozen miles of each other near Baghdad and Babylon,

then spread apart and finally join to form the Shatt al-Arab, which empties into the Persian Gulf. The land is astonishingly flat: Baghdad is only about 34 m (110 ft) above sea level, yet more than 500 km (300 mi) from the Gulf. Unlike Egypt, Mesopotamia had no desert walls on every side, so traders, herders and armies came and went from the mountains and the steppe. In 1916 the American historian James Henry Breasted named the whole arc of good land, from the Persian Gulf up the rivers and down to Canaan, the **Fertile Crescent**.

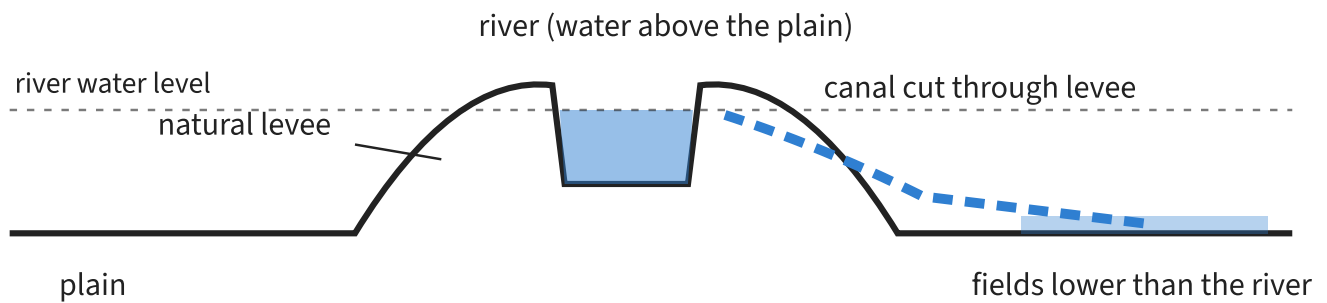
Abram's route follows it exactly. He did not cross the Syrian Desert in a straight line; he traveled up the Euphrates to Haran, where there was water and pasture, and then south into Canaan.

Technology overcoming geography. Southern Mesopotamia had rich soil and water but almost nothing else: no building stone, no good timber and no metal. The Sumerians made bricks from river mud, boats from reeds sealed with bitumen, and the rest they traded for. Copper came up the Gulf from Magan (Oman), timber came from the mountains, lapis lazuli came from what is now Afghanistan, and red carnelian beads came by sea from the Indus valley, as you will see in the next lesson. The rivers and the Gulf were the highways. Mesopotamians also used the wheel early, and a seal from the time of the Akkadian kings shows a man lifting water with a shaduf, the same lever you built in Lesson 2.1.

For the Christian student. Genesis names this land at the very beginning: "And the name of the third river is Hiddekel: that is it which goeth toward the east of Assyria. And the fourth river is Euphrates" (Genesis 2:14). Hiddekel is the Tigris. Out of this crowded, clever, idol-filled country of canals and brick towers, God called one man to leave everything and go to a land He would show him.



Mesopotamia and the traditional route of Abram from Ur to Haran, following the Euphrates around the Syrian Desert.



Because the river runs above the plain, a canal cut through the levee can water the fields by gravity alone.

PICTURE STUDY



The Standard of Ur (the "Peace" side), Unknown Sumerian craftsmen, about 2600–2400 BC · Wooden box (restored) inlaid with shell, red limestone and lapis lazuli, set in bitumen · British Museum, London

Leonard Woolley found this object crushed in a grave in the Royal Cemetery at Ur. He called it a "standard," thinking it had been carried on a pole, but no one really knows what it was for. Each long side is a picture in three rows. One side shows war: chariots, soldiers and prisoners. The other side, which we study here, shows peace and plenty.

Look at the materials as a geographer would. The shell came from the Gulf, the red limestone from the region, and the deep blue lapis lazuli from mountains more than 2,000

km (1,200 mi) away in what is now Afghanistan. A box made in a land of mud and reeds was decorated with stone from across Asia.

Look closely

- In the bottom rows, find people carrying goods on their backs and leading animals. What do you think they are bringing, and to whom?
- In the top row, find the man drawn larger than the others. Why might he be drawn that way?
- Find the musician with the lyre. Woolley found real lyres in the same cemetery.
- Look at the blue background. Where did that stone come from, and how did it travel to Ur?

Talk about it

1. What does the “Peace” side tell you about the farm produce of the Tigris and Euphrates plain?
2. Why would a city like Ur, rich in grain but poor in stone and metal, depend on trade?
3. If you were Abram growing up in a city like this, what would it have cost you to leave?

PROJECT: FLOOD, LEVEE AND CANAL: A SAND-TRAY PLAIN

You will build a model river plain, raise the river on its levees, and then water a field by gravity alone, the Sumerian way. Then you will see salinization with your own eyes.

You will need

- A large baking pan, plastic storage-box lid or shallow tub
- Sand or fine soil, slightly damp
- A pitcher or watering can and a cup of water
- A spoon or craft stick for digging
- A dark-colored plate or saucer
- 1 teaspoon of salt

Steps

1. Spread the sand about 5 cm (2 in) deep and smooth it flat. Prop one end of the pan up with a pencil so the plain tilts very slightly.
2. Pile two long ridges of sand down the middle, about 4 cm (1½ in) apart. These are your natural levees. Press a shallow channel between them.
3. Raise the bed of the channel with extra sand until it is a little higher than the flat plain on both sides. Your river now runs above the land, like the Euphrates.
4. Mark out two square fields on the plain beside the river with low walls of sand.
5. Pour water slowly into the high end of the channel. Watch where the water goes. Then pour faster, as in a spring flood. Does a levee break? Where does the escaped water go?

6. Repair the levee. Now cut a narrow canal through it and lead the canal gently downhill to one field. Pour again and watch the field fill while the other stays dry.
7. For the salt test, stir the teaspoon of salt into a cup of water and pour a thin layer onto the dark plate. Leave it in a sunny window for several days and look at what remains.
8. Record in your notebook what happened when the levee broke, how the canal worked, and what was left on the plate.

Tips

- Pour gently at first. The point is to see that a canal works because the river is higher than the field.
- Real Mesopotamian water carried far less salt than your cup, but year after year in a hot, dry land the salt still built up in the soil.

Check your work

- My model river runs higher than the plain between levees.
- I watered a field through a canal by gravity alone.
- I can explain how irrigation can slowly leave salt in the soil.

MAP NOTEBOOK

1. Draw the map of Mesopotamia: the Tigris, the Euphrates, the Persian Gulf, and the cities of Ur, Uruk, Babylon, Nineveh and Harran. Draw Abram's route in red.
2. Copy the levee cross-section and label the river, the levees, the canal, the fields and the arrows showing which way the water flows.
3. Make a two-column chart: "The Nile" and "The Tigris and Euphrates." Compare when they flood, how regular the floods are, and what protects or exposes each land.

From history. One of the oldest records of a border war is the Stele of the Vultures, a carved stone now in the Louvre in Paris. Made about 2450 BC, it celebrates King Eannatum of Lagash's victory over the neighboring city of Umma in a long quarrel over the fields and canal water along their border. The two cities fought over that same strip of land for generations.

WORKED EXAMPLES

Example 1. Baghdad lies about 34 m (110 ft) above sea level and about 540 km (335 mi) in a straight line from the head of the Persian Gulf. What is the average slope of the land, in centimeters per kilometer and in inches per mile?

(Use the map or drawing “Baghdad to the head of the Gulf is about 540 km in a straight line.” shown earlier in this lesson.)

1. Change meters to centimeters: $34 \text{ m} = 3,400 \text{ cm}$.
2. Divide by the distance: $3,400 \text{ cm} \div 540 \text{ km} \approx 6.3 \text{ cm per km}$.
3. In customary units: $110 \text{ ft} = 1,320 \text{ in}$, and $1,320 \text{ in} \div 335 \text{ mi} \approx 3.9 \text{ in per mile}$.
4. Compare: that is less than the width of your hand over the length of 10 football fields.

Answer: About 6.3 cm per km, or about 4 in per mile. The plain is so flat that canals had to be laid out with great care to keep the water moving.

Example 2. Following the Euphrates, Abram’s route ran from Ur to Babylon (about 236 km), Babylon to Mari (about 396 km) and Mari to Haran (about 307 km). How long is the route? If a family with flocks covered about 15 km (9 mi) a day, how many days of travel was it?

1. Add the legs: $236 + 396 + 307 = 939 \text{ km}$.
2. In miles: $939 \div 1.609 \approx 584 \text{ mi}$.
3. Days: $939 \text{ km} \div 15 \text{ km per day} \approx 63 \text{ days of walking, not counting rest days}$.
4. The straight line from Ur to Haran is about 925 km, almost the same, because the Euphrates itself runs northwest toward Haran. The real shortcut, straight west from Ur toward Canaan, would have crossed the Syrian Desert, with no water for the flocks.

Answer: About 939 km (584 mi), roughly 63 days of travel. Following the river cost only a little extra distance and gave water and pasture all the way.

Example 3. The ruins of Ur lie at $30^{\circ}57' \text{ N}$, $46^{\circ}06' \text{ E}$. Change these to decimal degrees.

1. A degree has 60 minutes, a Mesopotamian way of counting.
2. Latitude: $57' \div 60 = 0.95^{\circ}$, so $30^{\circ}57' = 30.95^{\circ} \text{ N}$.
3. Longitude: $6' \div 60 = 0.10^{\circ}$, so $46^{\circ}06' = 46.10^{\circ} \text{ E}$.

Answer: About 30.95° N , 46.10° E .

PRACTICE

1. **EASY** What does the word Mesopotamia mean, and in what modern country does most of it lie?
2. **EASY** In what season do the Tigris and Euphrates flood, and where does the water come from?
3. **EASY** Name two things the cities of Sumer had to get by trade because the plain did not have them.
4. **MEDIUM** Give two reasons the Tigris and Euphrates were harder to farm with than the Nile.
5. **MEDIUM** Look at the map. Which city on the map lies farthest north? Which lies nearest the Persian Gulf?
(Use the map or drawing "Compare the latitudes of the cities." shown earlier in this lesson.)
6. **MEDIUM** A canal leaves the river where the water surface is 1.2 m above a field 3 km away. If the canal drops evenly, how many centimeters does it drop per kilometer?
7. **MEDIUM** Change 33.5° (the latitude of Baghdad, rounded) to degrees and minutes.
8. **HARD** Explain, using the word levee, why a Sumerian farmer could water his field without lifting the water at all.
9. **HARD** The Euphrates is about 2,800 km long and the Tigris about 1,850 km. How much longer is the Euphrates in kilometers and in miles? What fraction of the Nile's 6,650 km is the Euphrates?
10. **CHALLENGE** In a short paragraph, explain why a hard river might have pushed the Sumerians to invent writing and law. Use canals and Hammurabi's dike law in your answer.

COMMON MISTAKES

- Thinking the Tigris and Euphrates were gentle like the Nile. Their floods were larger, wilder and badly timed for farming.
- Thinking rivers always run in low valleys below the land. On a flat silt plain a river can build its bed and levees up until it flows above the fields.
- Drawing Abram's route as a straight line across the desert. The route followed the Euphrates around the Fertile Crescent, where there was water and grass.

Make it a game • Canal Captain. Draw a 6-by-6 grid of fields on paper with a river down one side. Each turn, roll a die. On 1 to 4, dig that many squares of canal from the river toward your fields; a field touching your canal is watered and earns a grain token. On a 5, spring flood: any canal square not yet connected to a watered field silts up and must be erased. On a 6, your neighbor's dike breaks: you may move one of their grain tokens to you, unless they can quote Hammurabi's rule about dikes in their own words. After ten rounds, the player with the most grain wins.

Scripture. "Now the LORD had said unto Abram, Get thee out of thy country, and from thy kindred, and from thy father's house, unto a land that I will shew thee:" (Genesis

Abram left a great river city with canals, schools and temples to live in tents as a stranger. Hebrews 11:10 says he “looked for a city which hath foundations, whose builder and maker is God.” Geography shaped his journey, but faith decided it.

Practice answers

1. “Between the rivers.” Most of it lies in Iraq.
2. In spring, mostly from melting snow in the mountains of eastern Turkey where both rivers rise.
3. Any two: building stone, timber, copper or other metals, lapis lazuli, carnelian.
4. Their floods were larger and less regular; they came in spring, when crops were ripening, rather than before planting; they could break their levees and change course; irrigation slowly made the soil salty. (Any two.)
5. Harran (about 36.9° N) is farthest north. Basra is nearest the Gulf; of the ancient cities, Ur is nearest.
6. $1.2 \text{ m} = 120 \text{ cm}$; $120 \text{ cm} \div 3 \text{ km} = 40 \text{ cm per km}$.
7. $0.5 \times 60 = 30 \text{ minutes}$, so 33°30' N.
8. The river had built up natural levees and raised its own bed until the water surface was higher than the plain. Cutting a canal through the levee let water run downhill by gravity to the lower fields.
9. $2,800 - 1,850 = 950 \text{ km}$, about 590 mi. $2,800 \div 6,650 \approx 0.42$, a little more than two-fifths of the Nile.
10. Canals and dikes needed many workers, yearly repairs and records of grain, labor and water. Scribes began writing on clay to keep those accounts. Because one man’s broken dike could ruin his neighbors’ crops, rules were needed; Hammurabi’s laws made a careless man repay the grain lost when his dike broke. Living with an irregular, dangerous river made organization, records and law necessary.

2.3 THE INDUS: MOHENJO-DARO'S PLANNED STREETS

OBJECTIVES

- Locate the Indus River, the Punjab and the cities of Mohenjo-daro, Harappa, Lothal and Dholavira, and explain why the Indus plain could feed great cities.
- Describe the planned grid, brick drains, wells and standard bricks of Mohenjo-daro, and explain how a city on a flood plain protected itself.
- Use a map scale, a grid and the Pythagorean rule to measure distances on a plan and between cities.

Warm-up. On a sheet of graph paper, give yourself three minutes to draw a town of twelve houses, a market and a well, with streets so that every house can be reached and rainwater can drain away. Then compare it with a town that “just grew,” such as the old center of a European city on a map. Which is easier to find your way around?

Watch. *Mohenjo Daro 101* | *National Geographic* (National Geographic, 3:14).
<https://www.youtube.com/watch?v=QUng-iHhSzU>
 After the story: Mohenjo-daro, its grid of streets, drains and Great Bath.

Backup video. *Mohenjo-Daro and Harappa History* | *DAILY BELLRINGER* (The Daily Bellringer, 5:30). https://www.youtube.com/watch?v=Afd-b-_i1vY
 With the history note: Harappa and Mohenjo-daro side by side.

KEY TERMS

Harappan civilization

The Bronze Age civilization of the Indus valley, about 2600–1900 BC at its height, named after Harappa, the first of its cities to be studied.

grid plan

A town plan in which main streets run in straight lines and cross at right angles, dividing the town into blocks.

citadel

A raised, fortified part of a city. At Mohenjo-daro the citadel mound stood on the west side, above the Lower Town.

covered drain

A brick channel running along a street, roofed with bricks or stone slabs, that carried waste water away from the houses.

alluvial plain

A wide, flat land built of silt that a river has laid down in its floods.

standardization

Making things to the same agreed size or weight everywhere, like the 1:2:4 bricks and the cube weights of the Indus cities.

CORE IDEAS

The story. In 1922 an Indian archaeologist named R. D. Banerji, of the Archaeological Survey of India, was digging at a mound in Sindh, in what is now Pakistan. On top stood the ruins of a Buddhist stupa about two thousand years old. But beneath it Banerji found something much older: walls of fine baked brick and small carved stone seals with animals and a strange script, just like seals found at Harappa, some 590 km (370 mi) to the northeast. In September 1924 the director of the Survey, Sir John Marshall, announced in the *Illustrated London News* that a whole forgotten civilization had been found. The local people called the mound Mohenjo-daro, usually translated “mound of the dead.” As the diggers cleared it, they discovered one of the best-planned cities of the ancient world.

How it worked. Mohenjo-daro had two parts. On the west rose a high, walled **citadel** mound with large public buildings, including the Great Bath, a pool about 12 m by 7 m (39 by 23 ft) and about 2.4 m (8 ft) deep, waterproofed with fitted brick, gypsum mortar and a layer of bitumen. To the east lay the **Lower Town**, laid out on a grid. Its main streets ran roughly north-south and east-west, the widest about 10 m (33 ft) across, with narrow lanes between the blocks. Houses turned blank walls to the busy streets and opened onto inner courtyards. Many had a bathing room with a sloping brick floor, and some had toilets. Waste water ran through clay pipes into **covered brick drains** along the streets, with pits where solids could settle and be cleaned out. Archaeologists estimate the city had about 700 wells, lined with wedge-shaped bricks. The bricks themselves followed a standard shape whose thickness, width and length were in the ratio 1:2:4, so they fit together in strong, regular bonds.

The big idea. All of this rested on the river. The Indus is fed by snow and glaciers in the high mountains and by the summer monsoon, and it rises in a great flood from about July to September, spreading silt across a wide **alluvial plain**. Farmers grew wheat and barley in the fertile soil, and cotton too: the Indus people are among the earliest known to have spun and woven it. But a river that builds land also threatens it. Mohenjo-daro was built on huge platforms of mud brick and fill to lift it above the floods, and it was flooded and rebuilt many times, so that its streets slowly rose layer upon layer. Just as remarkable is how alike the Indus cities were. From Harappa in the Punjab to Lothal near the Gulf of Khambhat, about 900 km apart, people used the same brick proportions, the same cube-shaped stone weights (doubling 1, 2, 4, 8, 16, 32, 64) and the same kinds of seals. That points to well-organized trade and shared rules over an area larger than Egypt and Mesopotamia put together.

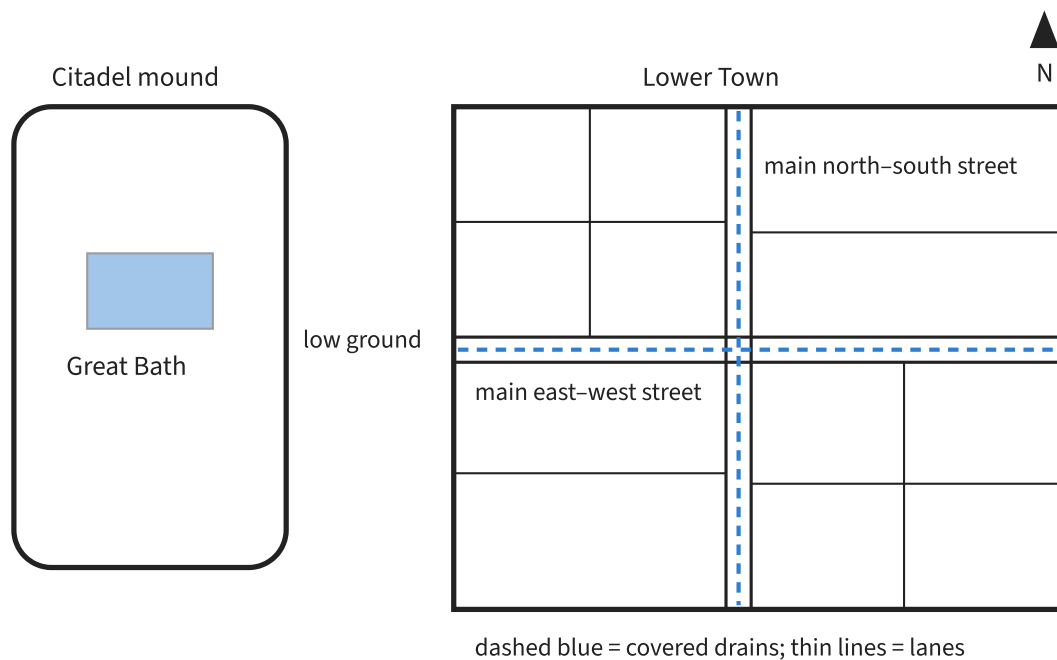
On the map. The Indus is about 3,180 km (1,980 mi) long. It rises in Tibet near Mount Kailash, flows northwest through the mountains of Ladakh, then turns south through Pakistan to the Arabian Sea near Karachi. In the north it gathers five great tributaries, the Jhelum, Chenab, Ravi, Beas and Sutlej. That land is the **Punjab**, “five waters.” Harappa stood on the Ravi; Mohenjo-daro stood beside the Indus in Sindh. To the east lies the Thar Desert, and to the west rise dry mountains. Many Harappan towns also lined a now mostly dry river system to the east, called the Ghaggar-Hakra. Sometime after about 1900 BC the great cities were slowly abandoned. Scholars still debate why; shifting rivers, the drying of

the Ghaggar-Hakra, changes in the monsoon and the decline of trade are all suggested. Honest geography says: we do not yet know for sure.

Technology overcoming geography. The Harappans used baked brick, which lasts far longer than sun-dried mud in a land of floods. Their drains and wells kept a crowded city on a hot plain clean and supplied with water. At Lothal they built a large brick basin that many archaeologists think was a dock linked to a tidal channel. Their ships reached the Persian Gulf: Indus seals and carnelian beads have been found at Ur, and Mesopotamian texts speak of ships from a land called *Meluhha*, which most scholars think was the Indus. Yet much remains a mystery. About 400 different signs of the Indus script are known, mostly in very short inscriptions, and no one has been able to read them. We know these people by their streets, drains, bricks and weights rather than by their own words.

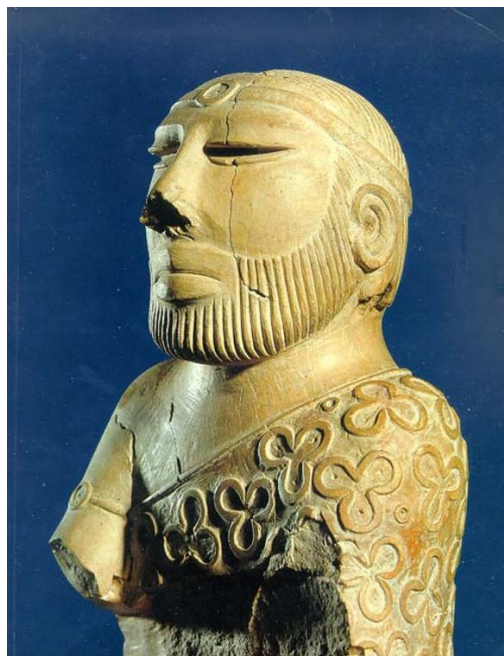


The Indus valley. The Punjab, the land of five rivers, lies in the north; the Thar Desert lies to the east.



A simplified plan of Mohenjo-daro (schematic, not to scale): the citadel to the west, the gridded Lower Town to the east.

PICTURE STUDY



The "Priest-King" of Mohenjo-daro, Unknown Harappan sculptor, about 2000 BC (Mature Harappan period) · Steatite (soapstone), about 17.5 cm (7 in) tall · National Museum of Pakistan, Karachi

This little stone figure was found at Mohenjo-daro in the 1920s. The excavators nicknamed him the "Priest-King," but no one knows whether he was a priest, a king, or neither, because no Indus writing has ever been read. He wears a band around his head with a round

ornament and a robe thrown over one shoulder, covered with a trefoil (three-lobed) pattern that once was filled with red paste.

Notice what we do *not* find at Mohenjo-daro: no great palace, no royal tomb full of gold, no giant statues of a ruler. The city's most impressive works are its streets, drains, wells and the Great Bath. This small figure is one of the very few portraits the Indus people left.

Look closely

- Look at the robe. Can you find the three-lobed pattern? Why might a people who grew cotton care about cloth and patterns?
- Look at the eyes, the beard and the headband. What kind of person does the sculptor seem to show?
- Compare its size with the Egyptian and Sumerian works in this unit. What does it suggest about how Indus rulers showed (or did not show) their power?

Talk about it

1. Why are the excavators' names for this figure only guesses?
2. If you could ask an Indus citizen one question about this figure, what would it be?

Safety first. Use an old tray outdoors or in a sink for the water test. Wash hands after working with clay or soil.

PROJECT: A MOHENJO-DARO BLOCK WITH WORKING DRAINS

You will mold your own 1:2:4 bricks, then build one block of a grid city on a raised platform, with a covered street drain that really carries water away.

You will need

- Air-dry clay, modeling clay or salt dough (2 cups flour, 1 cup salt, about $\frac{3}{4}$ cup water)
- A small mold: a matchbox tray or a strip of card folded into a box 1 cm $\times$ 2 cm $\times$ 4 cm
- A stiff cardboard base about 30 cm $\times$ 40 cm (12 $\times$ 16 in), and a few thick books or a box lid for a platform
- Aluminum foil, drinking straws and craft sticks
- Ruler, pencil and graph paper
- A cup of water and an old baking tray

Steps

1. Make a brick mold 1 cm thick, 2 cm wide and 4 cm long. Press clay into it and turn out at least 30 bricks. Let them dry.
2. On graph paper, plan one block at a scale of 1 cm = 2 m. Draw a main street 5 cm wide (10 m) along one side and a narrow lane 1 cm wide (2 m) along another. Put two or three houses with courtyards inside the block.

3. Raise the whole city: set the cardboard base on a low platform of books or a box lid, as the Harappans built on brick platforms above the floods.
4. Build the house walls from your bricks, laying them so the joints do not line up from one row to the next. Leave the street sides as blank walls with doors opening onto the lane.
5. Make the drain: fold foil into a channel and lay it along the edge of the main street. Tilt the base slightly so the drain runs downhill. Roof it with craft sticks, leaving one stick loose as a cleaning hatch.
6. Push a short straw through one house wall as a pipe from a bathing room to the street drain.
7. Set the model on the tray and pour a little water into the straw. Follow it into the drain and out of the city. Record what worked and what you would change.

Tips

- Check your bricks: two bricks laid side by side ($2 + 2 = 4$ cm) are exactly as wide as one brick is long. That is why the 1:2:4 shape bonds so neatly.
- If water pools, the drain is too flat. Raise the upper end a little, just as the Harappan builders had to slope theirs.

Check your work

- My bricks are in the ratio 1:2:4 and bond together in alternating rows.
- My block has a straight main street, a lane and houses that open inward.
- My covered drain carries water downhill out of the city.

MAP NOTEBOOK

1. Draw the Indus and its five Punjab tributaries, and mark Harappa, Mohenjo-daro, Lothal and Dholavira. Shade the Thar Desert.
2. Draw a cutaway of a Mohenjo-daro street: a house wall, a bathing-room pipe, the covered drain and a settling pit.
3. Draw the doubling series of Indus weights (1, 2, 4, 8, 16, 32, 64) as cubes of growing size, and show how to weigh 13 units with the fewest cubes.

From history. The Indus people traded by sea with Mesopotamia. Sargon of Akkad, who ruled about 2300 BC, boasted that ships from Meluhha, Magan and Dilmun tied up at the quay of his capital, Agade. Most scholars think Magan was Oman, Dilmun was Bahrain and Meluhha was the Indus region. Indus-style seals and long carnelian beads found at Ur back up the boast.

WORKED EXAMPLES

Example 1. An Indus brick is 7 cm thick. If its proportions are 1:2:4, how wide and how long is it, and what is its volume? Show why two bricks side by side match one brick's length.

1. Thickness : width : length = 1 : 2 : 4, so multiply each by 7 cm.
2. Width = $2 \times 7 = 14$ cm; length = $4 \times 7 = 28$ cm.
3. Volume = $7 \times 14 \times 28 = 2,744$ cm³.
4. Two bricks side by side are $14 + 14 = 28$ cm wide, exactly one brick's length, so a row of "headers" matches a row of "stretchers."

Answer: 14 cm wide and 28 cm long (about $2\frac{3}{4} \times 5\frac{1}{2} \times 11$ in), with a volume of 2,744 cm³. The 1:2:4 shape lets bricks bond in neat alternating rows.

Example 2. A plan of part of Mohenjo-daro is drawn at a scale of 1:2,000. On the plan the main street is 5 mm wide and one block is 12 cm long. How wide is the street and how long is the block in real life?

(Use the map or drawing "The main streets divide the Lower Town into blocks." shown earlier in this lesson.)

1. At 1:2,000, 1 unit on the plan equals 2,000 of the same units on the ground.
2. Street: $5 \text{ mm} \times 2,000 = 10,000 \text{ mm} = 10 \text{ m}$ (about 33 ft).
3. Block: $12 \text{ cm} \times 2,000 = 24,000 \text{ cm} = 240 \text{ m}$ (about 790 ft).

Answer: The street is about 10 m (33 ft) wide and the block about 240 m (790 ft) long.

Example 3. Mohenjo-daro lies at about 27.3° N, 68.1° E and Harappa at about 30.6° N, 72.9° E. Estimate the straight-line distance between them. (At about 29° N, one degree of longitude is about $111 \times 0.875 \approx 97$ km.)

(Use the map or drawing "Harappa lies northeast of Mohenjo-daro, on the Ravi." shown earlier in this lesson.)

1. North-south: $30.6^\circ - 27.3^\circ = 3.3^\circ$; $3.3 \times 111 \text{ km} \approx 366 \text{ km}$.
2. East-west: $72.9^\circ - 68.1^\circ = 4.8^\circ$; $4.8 \times 97 \text{ km} \approx 466 \text{ km}$.
3. These are the two legs of a right triangle. Distance = $\sqrt{(366^2 + 466^2)} = \sqrt{(133,956 + 217,156)} = \sqrt{351,112} \approx 593 \text{ km}$.
4. In miles: $593 \div 1.609 \approx 368 \text{ mi}$.

Answer: About 590 km (370 mi), northeast from Mohenjo-daro to Harappa.

PRACTICE

1. **EASY** What does Punjab mean, and name its five rivers.
2. **EASY** In which months does the Indus usually flood, and what two sources of water cause it?
3. **EASY** Who first dug at Mohenjo-daro in 1922, and who announced the discovery of the civilization in 1924?
4. **MEDIUM** Look at the plan of Mohenjo-daro. In which direction from the Lower Town is the citadel? Along which compass directions do the two main streets run?
(Use the map or drawing "Use the north arrow." shown earlier in this lesson.)
5. **MEDIUM** Why did the builders of Mohenjo-daro set the city on huge brick and earth platforms?
6. **MEDIUM** Using Indus weights of 1, 2, 4, 8, 16, 32 and 64 units, which weights would a merchant put on the scale to balance 13 units of beads? Which to balance 50?
7. **MEDIUM** On a plan at 1:2,000, a lane is 1.5 mm wide. How wide is it in meters and feet?
8. **HARD** Look at the map. Which Harappan site shown lies farthest south? Lothal (22.5° N) and Harappa (30.6° N) differ by how many degrees of latitude, and about how far north-south is that?
(Use the map or drawing "Compare the latitudes of Lothal and Harappa." shown earlier in this lesson.)
9. **HARD** A street drain is 200 m long and must drop 1 m from end to end. How many centimeters must it drop for every 10 m of length?
10. **CHALLENGE** No one can read the Indus script. In a short paragraph, explain three things we can still know about the Harappans from geography and archaeology, and one thing we cannot.

COMMON MISTAKES

- Thinking a grid city is a modern idea. Mohenjo-daro was laid out on a grid more than 4,000 years ago.
- Saying we know who ruled Mohenjo-daro or what the seals say. The script is still undeciphered; names like "Priest-King" are modern guesses.
- Mixing up the Indus and the Ganges. The Indus flows mostly through Pakistan to the Arabian Sea; the Ganges flows east through northern India to the Bay of Bengal.

Make it a game • Grid City Hunt. Draw a 6-by-6 grid on paper. Label the north-south streets A to F and the east-west streets 1 to 6. One player secretly marks a well, a Great Bath, a seal workshop and a granary at four crossings. The other calls out crossings like "C4." The hider answers "hit," or gives a compass hint such as "go north and east." Count how many calls it takes to find all four. Then switch. Bonus: name the real feature of Mohenjo-daro you hid and say what it tells us about the city.

Scripture. "And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their

habitation;" (Acts 17:26, KJV)

The Bible never names the Indus people, and we cannot yet read their words. But God knew them. He set the times of their cities and the bounds of their river plain, and their careful streets and drains show the wisdom and order He placed in every people.

Practice answers

1. "Five waters." The Jhelum, Chenab, Ravi, Beas and Sutlej.
2. About July to September, from melting snow and glaciers in the high mountains and from summer monsoon rain.
3. R. D. Banerji dug there in 1922; Sir John Marshall announced the civilization in 1924.
4. The citadel is to the west. The main streets run roughly north-south and east-west.
5. To lift it above the floods of the Indus on a flat alluvial plain.
6. $13 = 8 + 4 + 1$. $50 = 32 + 16 + 2$.
7. $1.5 \text{ m} \times 2,000 = 3,000 \text{ m} = 3 \text{ km}$, about 10 ft.
8. Lothal. $30.6^\circ - 22.5^\circ = 8.1^\circ$; $8.1 \times 111 \text{ km} \approx 900 \text{ km}$ (about 560 mi) north-south.
9. $1 \text{ m} = 100 \text{ cm}$ over 200 m is 0.5 cm per meter, so 5 cm for every 10 m.
10. We can know (any three): they farmed the Indus flood plain and grew wheat, barley and cotton; they planned grid cities with drains and wells; they built on platforms against floods; they used standard bricks and weights across a huge region; they traded by sea with Mesopotamia, since their seals and beads are found at Ur. We cannot know for sure (any one): their language, the names of their rulers, their laws or beliefs in their own words, or exactly why the cities were abandoned.

2.4 THE YELLOW RIVER: CHINA'S SORROW AND YU THE GREAT

OBJECTIVES

- Trace the Yellow River from the Tibetan Plateau around the Ordos bend, through the Loess Plateau and across the North China Plain to the sea.
- Explain how silt from the Loess Plateau raises the riverbed, why the river has broken its dikes and changed course, and why it was called “China’s Sorrow.”
- Tell the story of Yu the Great and compare his method of leading water away with his father’s method of walling it in.

Warm-up. Fill a clear glass with water and stir in a heaping spoonful of fine dust from a dry garden bed or a little flour. Watch it for five minutes. The water stays cloudy and yellow-brown. Now imagine a river so full of that kind of soil that it gives its name to the sea it flows into.

Watch. *Deliberate Disaster: The 1938 Yellow River Flood* (The History Guy: History Deserves to Be Remembered, 16:35). <https://www.youtube.com/watch?v=PTPgML2AQA> With the history note: the 1938 Yellow River flood, when the dikes were broken in wartime.

Note: The History Guy tells a hard wartime story with large numbers of deaths. It opens with a short sponsor message.

KEY TERMS

loess

Fine, yellowish, wind-blown dust that settles in deep, soft layers. The Loess Plateau of northern China is covered with it.

sediment load

The amount of silt and sand a river carries. The Yellow River has had one of the heaviest sediment loads of any large river on earth.

dike

A long bank of earth built along a river to keep its floods off the land. In China dikes have been built higher and higher for thousands of years.

raised (hanging) river

A river whose bed has been built up by silt until it flows higher than the plain outside its dikes.

avulsion

A sudden change of a river’s course when it breaks out of its channel and finds a new, lower path.

North China Plain

The great flat lowland of northern China, built largely of Yellow River silt, between the mountains and the sea.

CORE IDEAS

The story. The Chinese tell of a time, long ago in the reign of the wise ruler Yao, when floodwaters rose to the hills and the people fled to the high ground. A man named Gun was ordered to stop the flood. For nine years he built walls and dams to hold the water back, and for nine years the water broke through. Then his son Yu took up the work. Instead of fighting the river, Yu studied the land. He dredged channels, cleared blocked gorges and led the waters downhill to the sea. The great historian Sima Qian, writing about 100 BC, says Yu labored for thirteen years and passed the gate of his own house three times without going in. The grateful people made him king, and Chinese tradition counts him as the founder of the first dynasty, the Xia. Historians still debate how much of the story is history and how much is legend. In 2016 a team of geologists argued that a landslide dammed the upper Yellow River around 1920 BC and then burst, sending a vast flood downstream, a real event that might lie behind the tale. Whatever its source, Yu's story has taught China for three thousand years that good rulers tame floods.

How it worked. The Yellow River, the Huang He, is about 5,460 km (3,395 mi) long, the second longest river in China. It rises in the Bayan Har Mountains on the Tibetan Plateau, swings north in a great loop around the dry Ordos Plateau, and then runs south through the **Loess Plateau**. Loess is wind-blown dust, laid down in soft layers that in places are over 100 m deep. It is easy to dig and easy to wash away, and the summer monsoon storms pour it into the river by the billion tonnes. In the mid-1900s the river carried about 1.6 billion tonnes of sediment a year, more than almost any river on earth. That yellow silt gives the river its color and its name, and it even tints the Yellow Sea.

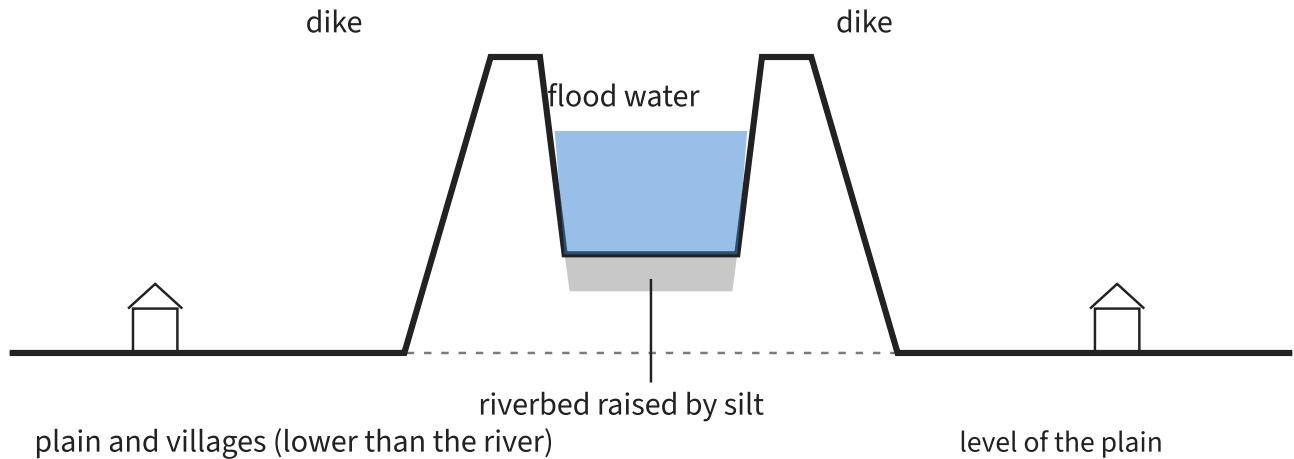
The big idea. When the river leaves the mountains near Zhengzhou and spreads onto the flat **North China Plain**, it slows down and drops its silt on its own bed. People built dikes to hold it in; the bed rose; they built the dikes higher; the bed rose again. Over centuries much of the lower river came to flow **above** the plain around it, held up between its dikes like water in a gutter on a roof. When a dike breaks, the river does not go back. It pours down onto the lower land and cuts a new course, sometimes hundreds of kilometers away. Chinese records count more than 1,500 floods and dike breaks and over two dozen major changes of course. In 1855 the river broke through at Tongwaxiang, east of Kaifeng, abandoned the channel it had used for about seven centuries south of the Shandong peninsula, and swung north to its present mouth on the Bohai Sea. The flood of 1887 in Henan killed perhaps 900,000 people or more; in 1938, during the war with Japan, the Chinese Nationalist government broke the dikes at Huayuankou to slow the Japanese army, and hundreds of thousands of civilians died. That is why the river was called **China's Sorrow**. Yet the same river laid down the soil of the plain, and the soft loess could be farmed with simple tools. Millet farming began along its middle course thousands of years ago, and the Shang kings ruled at Anyang, north of the river, around 1250 BC. Xi'an, Luoyang and Kaifeng, capitals of many later dynasties, all lie in its basin.

On the map. Follow the river on the map: west to east from the plateau to Lanzhou, north around the Ordos past Baotou, south along the border of Shaanxi and Shanxi through the loess hills, east at the great bend where the Wei River joins (the Wei flows past Xi'an), then out of the hills past Luoyang and Zhengzhou, across the plain past Kaifeng and Jinan, and into the Bohai Sea. Unlike the Nile, which floods once a year in a gentle rhythm, the Yellow River floods mostly with the summer monsoon storms of July and August, and in some winters ice jams on the northern loop dam the water and push it over the banks.

Technology overcoming geography. Chinese engineers have fought this river longer than anyone has fought any river. In the 1500s the Ming official Pan Jixun taught a rule that echoes Yu's wisdom: build the dikes close together to narrow the channel, so the water runs fast and scours its own silt out to sea, "using the water to attack the sand." Modern engineers learned hard lessons too. The Sanmenxia Dam, finished in 1960, filled with silt so quickly that it had to be rebuilt. The Xiaolangdi Dam, finished in 2001, was designed to release bursts of water that flush sediment downstream. On the Loess Plateau, terraces, check dams and replanting have greatly reduced the silt washing into the river. The lesson of Yu still holds: you cannot simply wall a great river in; you must understand where its water and its soil want to go.



The Yellow River today and its course before 1855 (approximate), when it reached the sea south of the Shandong peninsula.



A raised river: silt has lifted the bed above the plain, so a break in the dike sends the water down onto the villages.

PICTURE STUDY



Yu the Great, from the Wu Liang Shrine reliefs, Unknown Han dynasty stone carvers, Eastern Han dynasty, about AD 151 · Carved stone relief, known today mostly through ink rubbings on paper · Wu family shrines, Jiaxiang County, Shandong Province, China; rubbings are held in many museums and libraries

About AD 151 a family named Wu built small stone offering shrines in Shandong, not far from the lower Yellow River. Their walls were carved with history and legend: sage rulers, loyal ministers and faithful sons. Among the first rulers in the row stands Yu the Great. Instead of a sword or a scepter, he holds a digging tool, because in Chinese memory his greatness was his work against the flood.

The carvings are shallow and flat, so scholars have long made ink rubbings of them: damp paper is pressed onto the stone and dabbed with ink, and the carved shapes appear in black and white. These rubbings are how most people have come to know the Wu Liang Shrine.

Look closely

- Find Yu's tool. What kind of work does it tell you he did?
- Look at his hat and clothing. Does he look like a man of the palace or a man of the fields?
- Look for the small inscribed panel. Why would the carvers label each figure?

Talk about it

1. Why might a Han family living near the Yellow River want a picture of Yu in their shrine?
2. Yu is remembered for passing his own door three times without going in. What does that say about what the Chinese admired in a ruler?

PROJECT: GUN OR YU? A SILT RIVER IN A TRAY

You will measure how much soil a muddy river carries, then test the two methods of the old story on a sand-tray river: Gun's walls and Yu's channels.

You will need

- Two clear jars with lids and a ruler
- Fine garden soil or dry silt, and sand
- A long baking pan or plastic storage-box lid propped up at one end
- A pitcher of water, a spoon and craft sticks
- Small blocks or bottle caps for villages

Steps

1. Fill one jar three-quarters with water, add 3 spoonfuls of fine soil, shake and let it settle overnight. Measure the layer of silt in millimeters. This is your "sediment load."
2. In the pan, make a plain of damp sand with a river channel down the middle. Set a few "villages" on the plain beside the river.
3. Gun's method: build tall, narrow walls of sand along both banks. Pour muddy water (water stirred with soil) slowly down the channel several times. Watch where the silt settles and whether the bed rises between the walls.
4. Keep pouring, a little faster, as in a summer storm. When a wall breaks, mark where the water goes and which villages it reaches.
5. Smooth the tray and start again. Yu's method: dig a deeper, straighter channel and a second spillway channel leading away to a low corner of the tray (the sea). Narrow the main channel with craft sticks so the water runs fast, as Pan Jixun advised.
6. Pour the same amount of muddy water. Compare: where did the silt end up, and were the villages safer?

7. Write a short report in your notebook comparing the two methods, with a sketch of each.

Tips

- Use the same pitcher and count pours so the two tests are fair.
- Real rivers are not this simple. Even good dikes need constant repair, which is why Chinese governments kept huge river-works offices for centuries.

Check your work

- I measured the silt my muddy water carried.
- I saw silt raise the bed between tall walls and saw what happened when a wall broke.
- I can explain why leading water away and keeping it moving worked better than walling it in.

MAP NOTEBOOK

1. Draw the Yellow River from the Tibetan Plateau to the Bohai Sea. Mark Lanzhou, Baotou, Luoyang, Zhengzhou, Kaifeng and Jinan, shade the Loess Plateau yellow, and draw the pre-1855 course as a dotted line.
2. Copy the raised-river cross-section and add arrows to show where the water would go if the right-hand dike broke.
3. Draw Yu the Great with his digging tool, and under him write in your own words the difference between Gun's way and Yu's way.

From history. One of the oldest geography books in the world is the *Yu Gong*, the "Tribute of Yu," a chapter of the ancient Chinese *Book of Documents*. Written down many centuries after Yu's time, it describes China as nine provinces that Yu was said to have set in order after the flood. For each it names the mountains and rivers, the kind of soil, the products the people sent as tribute, and the waterways by which the tribute boats traveled to the capital. Chinese scholars studied it as a model of geography for two thousand years.

WORKED EXAMPLES

Example 1. The Yellow River falls from about 4,500 m (14,800 ft) at its source to sea level over about 5,460 km (3,395 mi). What is its average drop per kilometer and per mile? Compare it with the Mesopotamian plain (about 6.3 cm per km) from Lesson 2.2.

1. Per kilometer: $4,500 \text{ m} \div 5,460 \text{ km} \approx 0.82 \text{ m}$, or 82 cm, per km.
2. Per mile: $14,800 \text{ ft} \div 3,395 \text{ mi} \approx 4.4 \text{ ft}$ per mile.
3. Compare: $82 \div 6.3 \approx 13$.
4. Most of that drop happens in the mountains and the loess hills; on the North China Plain the river is nearly as flat as Mesopotamia, which is where it drops its silt.

Answer: About 82 cm per km (4.4 ft per mile) on average, roughly 13 times steeper than the Mesopotamian plain. A fast river picks up silt in the hills and drops it where the land flattens.

Example 2. In the mid-1900s the Yellow River carried about 1.6 billion tonnes of sediment a year. How much is that per day? If a large dump truck holds 20 tonnes, how many truckloads a day is that?

1. Per day: $1,600,000,000 \text{ t} \div 365 \approx 4,380,000 \text{ t}$, about 4.4 million tonnes a day.
2. Truckloads: $4,380,000 \div 20 \approx 219,000$ truckloads every day.
3. In customary units, a metric tonne is about 1.1 short tons, so 4.4 million tonnes is about 4.8 million tons a day.

Answer: About 4.4 million tonnes a day, or roughly 219,000 dump-truck loads a day.

Example 3. Before 1855 the river reached the sea near about 34.3° N , 120.3° E . Today its mouth is near about 37.8° N , 119.2° E . About how far did the mouth move? (Near 36° N , one degree of longitude is about $111 \times 0.81 \approx 90 \text{ km}$.)

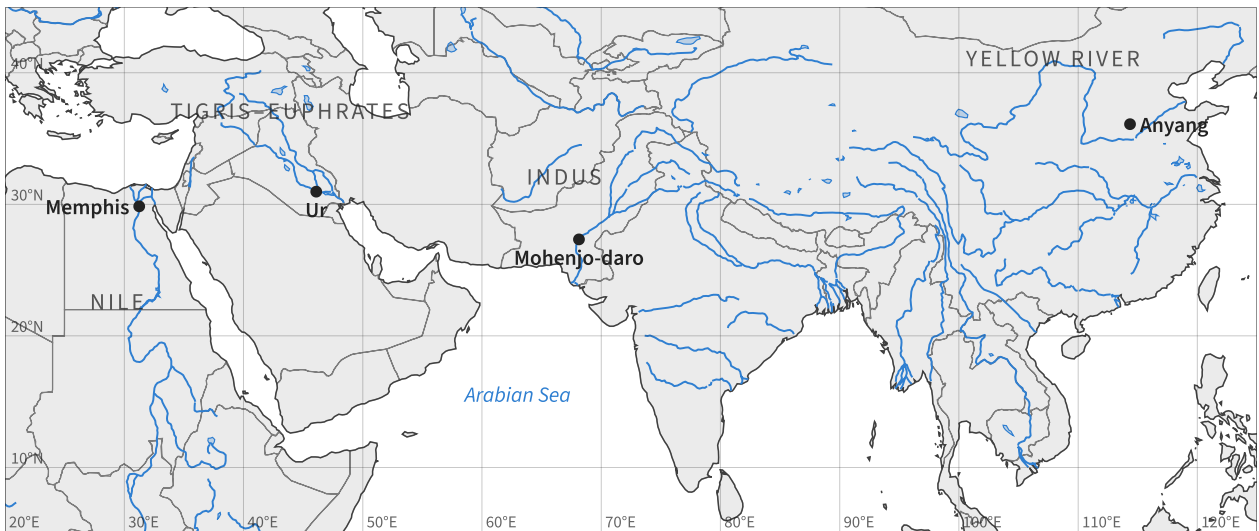
(Use the map or drawing “Compare the old mouth on the Yellow Sea with the present mouth on the Bohai Sea.” shown earlier in this lesson.)

1. North-south: $37.8^\circ - 34.3^\circ = 3.5^\circ$; $3.5 \times 111 \text{ km} \approx 389 \text{ km}$.
2. East-west: $120.3^\circ - 119.2^\circ = 1.1^\circ$; $1.1 \times 90 \text{ km} \approx 99 \text{ km}$.
3. Distance = $\sqrt{(389^2 + 99^2)} = \sqrt{(151,321 + 9,801)} = \sqrt{161,122} \approx 401 \text{ km}$.
4. In miles: $401 \div 1.609 \approx 249 \text{ mi}$.

Answer: About 400 km (250 mi), from south of the Shandong peninsula to its north side. Imagine the Mississippi suddenly reaching the sea in Texas instead of Louisiana.

PRACTICE

1. **EASY** Why is the Huang He called the Yellow River?
2. **EASY** Why was the river called “China’s Sorrow”?
3. **EASY** In the story, what did Gun do, and what did Yu do differently?
4. **MEDIUM** Explain, step by step, how a river can come to flow higher than the plain around it.
5. **MEDIUM** Suppose the riverbed between the dikes rose 3 cm (about 1.2 in) a year. How much would it rise in 300 years, in meters and feet?
6. **MEDIUM** Look at the map of the four river valleys. Which city marked there lies farthest north? How many degrees of latitude separate it from Mohenjo-daro (27.3° N), and about how many kilometers north-south is that?



Compare the latitudes of the four cities.

7. **MEDIUM** Some stretches of the Yellow River once carried about 35 kg of sediment in every cubic meter of water. How much sediment would be in a bathtub holding 0.2 cubic meters?
8. **HARD** In what months does the Yellow River usually flood, and why is that different from the Nile?
9. **HARD** Explain Pan Jixun’s rule, “using the water to attack the sand,” and why the Sanmenxia Dam taught engineers a hard lesson.
10. **CHALLENGE** In a paragraph, compare the four rivers of this unit. Which was the gentlest and most reliable, which was the most dangerous, and how did each people’s answer to its river shape their civilization?

COMMON MISTAKES

- Thinking higher dikes alone can solve a silt-laden river. Each time the dikes rise, the bed rises too, and a break becomes more dangerous.
- Confusing the Yellow River (Huang He) with the Yangtze. The Yellow River runs across northern China; the Yangtze, longer and deeper, runs through central China.

- Treating the story of Yu as either plain history or mere fairy tale. It is an ancient tradition that historians weigh carefully; it may preserve the memory of a real great flood.

Make it a game · Dike Breach. Draw a river down the middle of a sheet of paper with ten villages on each side. Each player guards one bank. On your turn, roll a die: that many grains of silt are added to the bed (keep a tally). You may spend your turn raising your dike by 2 or digging a channel to remove 3 silt. If the silt tally ever exceeds your dike height, your dike breaks and you lose villages equal to the difference, then the tally resets. After twelve rounds, the player with the most villages left wins. Talk afterward: did walling or digging work better?

Scripture. “And said, Hitherto shalt thou come, but no further: and here shall thy proud waves be stayed?” (Job 38:11, KJV)

God speaks to Job of setting bounds for the sea. Only the Creator commands the waters absolutely. Wise engineers like Yu and Pan Jixun succeeded not by pretending to master the river but by learning how God made water and soil to move, and working with that order.

Practice answers

1. Because it carries huge amounts of yellow loess silt washed from the Loess Plateau, which colors the water (and even the Yellow Sea).
2. Because its floods, dike breaks and sudden changes of course have killed enormous numbers of people and destroyed farms and towns many times.
3. Gun tried to block and wall the water in with dams and dikes, and failed after nine years. Yu dredged channels and led the water downhill to the sea, and succeeded.
4. On the flat plain the river slows and drops silt on its bed. People build dikes to hold it in. The bed rises, so they build the dikes higher. After centuries the bed and the water are above the land outside the dikes.
5. $3 \text{ cm} \times 300 = 900 \text{ cm} = 9 \text{ m}$; $1.2 \text{ in} \times 300 = 360 \text{ in} = 30 \text{ ft}$.
6. Anyang (about 36.1° N). $36.1^\circ - 27.3^\circ = 8.8^\circ$; $8.8 \times 111 \approx 977 \text{ km}$ (about 607 mi).
7. $35 \text{ kg} \times 0.2 = 7 \text{ kg}$ (about 15 lb).
8. Mostly in July and August, when summer monsoon storms fall over the basin itself, especially the Loess Plateau. The Nile’s flood came from rain far away in the Ethiopian Highlands and arrived as one steady yearly rise; the Yellow River’s floods are sudden and storm-driven.
9. Pan Jixun built dikes close together so the narrowed river would run fast and carry its silt out to sea instead of dropping it on the bed. The Sanmenxia Dam slowed the river in its reservoir, the river dropped its silt there, and the reservoir filled so quickly that the dam had to be rebuilt. A silt-laden river must be kept moving.
10. The Nile was the gentlest: one regular yearly flood from distant rain, at the right time for planting, in a land walled by deserts, so Egypt could stay united. The Tigris and Euphrates flooded wildly at the wrong season, so the Sumerians built canals and dikes, wrote records and laws, and city-states fought over water. The Indus flooded every summer across a wide plain, and its people built planned cities on platforms with drains and standard bricks. The Yellow River was the most dangerous, carrying so much silt that it rose above the plain and

broke out, so Chinese rulers were judged by flood control, as in the story of Yu. Accept any well-reasoned comparison using these facts.

UNIT 2 REVIEW

Answer each question. Show your work for calculations and use complete sentences for explanations. The review is worth 60 points.

1. (5 pts) What did Herodotus mean when he called Egypt “the gift of the river”? Give one piece of evidence he noticed.
2. (5 pts) Explain where the water of the Nile flood came from, when it reached Egypt, and what the three Egyptian seasons were.
3. (5 pts) A shaduf has a long arm of 3 m and a short arm of 1 m. The full bucket weighs 12 kg. What counterweight balances it? Explain why the counterweight helps the farmer.
4. (5 pts) Aswan is at about 24.1° N and Alexandria at about 31.2° N. About how far north-south is it between them, in kilometers and miles?
5. (5 pts) Give two ways the Tigris and Euphrates floods differed from the Nile flood, and one way the Sumerians answered the problem.
6. (5 pts) Why could a Sumerian farmer water a field through a canal without lifting the water? Use the word levee.
7. (5 pts) Trace Abram’s route from Ur to Haran. Why did he follow the Euphrates instead of going straight across?
8. (5 pts) Name three features that show Mohenjo-daro was a planned city.
9. (5 pts) On a plan drawn at 1:2,000, a street measures 4 mm wide and a row of houses 9 cm long. Find the real width and length.
10. (5 pts) What evidence shows the Indus people traded with Mesopotamia, and why can we not read their own account of it?
11. (5 pts) Explain why the Yellow River is yellow, how its bed came to be higher than the plain, and what happened in 1855.
12. (5 pts) Contrast the methods of Gun and Yu the Great, and name one later Chinese engineer or project that followed Yu’s lesson.

UNIT PROJECT: THE FOUR RIVER VALLEYS: MAP AND SHADUF REPORT

Make a large hand-drawn map that shows all four river valleys of this unit on one sheet: the Nile, the Tigris and Euphrates, the Indus and the Yellow River. For each river, draw its course from source to sea, shade its fertile valley green and the dry lands around it tan, mark at least two ancient cities, and add an arrow and a note showing where its flood water comes from and in which months it floods. Draw the lines of 20°, 30° and 40° N, and notice that all four valleys lie in the same band of the Northern Hemisphere.

Beside the map, mount a photograph or drawing of your working shaduf with its measurements and counterweight calculation, and write a one-page comparison of the four rivers: which was the gentlest, which the most dangerous, and how each people’s technology answered its river.

- **Accuracy:** All four rivers, their seas and at least eight cities are placed correctly, with correct flood sources and seasons.
- **Shaduf:** The shaduf works, its parts are labeled, and the counterweight calculation is correct.
- **Explanation:** The comparison explains how each river gave and threatened, and how canals, levers, drains and dikes answered it.
- **Care:** The map is neat, colored, titled and has a key, a compass rose and a scale.

Answer key

1. The farmland of Egypt was built of silt laid down by the Nile's floods; without the river it would be desert. Evidence: the black river soil unlike the red desert, or river mud brought up by a sounding line a day's sail out to sea.
2. Mostly from summer monsoon rain on the Ethiopian Highlands, carried by the Blue Nile and the Atbara (the White Nile adds a steady flow from the lake region). It rose in Egypt in early summer and crested around September. Seasons: Akhet (flood), Peret (growing), Shemu (harvest and dry season).
3. $12 \text{ kg} \times 3 \div 1 = 36 \text{ kg}$. The counterweight does the lifting of the full bucket; the farmer only pulls the empty bucket down and swings the pole, so one person can lift water all day.
4. $31.2^\circ - 24.1^\circ = 7.1^\circ$. $7.1 \times 111 \approx 788 \text{ km}$; $7.1 \times 69 \approx 490 \text{ mi}$.
5. They were larger and less regular, and they came in spring as crops ripened rather than before planting; they could break levees and change course. The Sumerians built canals, dikes and basins, cleared them every year, and made laws and records to organize the work.
6. The river had built natural levees and raised its bed until its water was higher than the plain, so a canal cut through the levee let water run downhill to the lower fields.
7. From Ur up the Euphrates past Babylon and Mari, then north to Haran. A straight path west from Ur toward Canaan would cross the Syrian Desert; the river route had water and pasture for people and flocks, along the Fertile Crescent.
8. Any three: a grid of straight main streets running north-south and east-west; covered brick drains along the streets; house bathrooms linked to the drains; many brick-lined wells; standard 1:2:4 bricks; a raised citadel with the Great Bath; brick platforms against floods.
9. $4 \text{ mm} \times 2,000 = 8,000 \text{ mm} = 8 \text{ m}$ (about 26 ft). $9 \text{ cm} \times 2,000 = 18,000 \text{ cm} = 180 \text{ m}$ (about 590 ft).
10. Indus-style seals and carnelian beads have been found at Ur, and Mesopotamian texts mention ships from Meluhha, probably the Indus. We cannot read their account because the Indus script has never been deciphered.
11. It carries huge amounts of loess silt from the Loess Plateau. On the flat North China Plain it drops the silt on its bed; people raised the dikes, the bed rose again, until the river flowed above the plain. In 1855 it broke its dikes near Kaifeng and moved its mouth from south of the Shandong peninsula to the Bohai Sea in the north.
12. Gun tried to block the water with walls and dams and failed; Yu dredged channels and led the water to the sea. Later examples: Pan Jixun's narrow dikes that make the river scour its own silt, or the Xiaolangdi Dam, which releases water to flush sediment downstream.

GREAT PORT CITIES, OLD AND NEW

Some cities grow where roads cross or rivers meet. The greatest trading cities of the last thousand years grew where land and sea shake hands: at a harbor. In this unit you will visit four of them in the order they rose to greatness. **Venice** was built on mud banks in a lagoon and ruled the trade between Europe and the East. **Amsterdam** was built on peat and piles and became the warehouse of Europe in the Dutch Golden Age. **London** dug enclosed docks along the tidal Thames to serve a worldwide empire. **New York** had a deep, sheltered harbor, and the Erie Canal gave it the whole Great Lakes country as its hinterland.

In every city you will ask the same questions. What was its **site**, the ground under it, and what was its **situation**, its place among other lands and routes? What gave its harbor deep water, shelter and room for docks? What problem did its geography set, and what did engineers do about it? God “hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation” (Acts 17:26). The rise and fall of these ports shows how much the times and places of nations matter, and how people made in God’s image have worked, built and traded, sometimes nobly and sometimes wrongly, with the coasts He gave them.

BEFORE YOU BEGIN

- Knows the difference between site and situation (Unit 1)
- Can read latitude and longitude to the nearest tenth of a degree
- Can convert between kilometers and miles and use a map scale written as a ratio (1:50,000)
- Can compute time from distance and speed

MASTERY CHECKLIST

- I can explain the three things a good harbor needs: deep water, shelter and docks, plus a route to a hinterland.
- I can describe how Venice’s lagoon protected it and why a city with no farms had to live by trade.
- I can explain how Amsterdam’s situation, its inventions and its joint-stock company made it the busiest port of the 1600s.
- I can explain why London’s tides led to enclosed wet docks, and work out water depths from a tide range.
- I can explain how the Erie Canal used the Mohawk Valley gap to make New York America’s great port, and compute lock lifts and travel times.
- I can compare the harbors of Venice, Amsterdam, London and New York on a map and in a model.

OPTIONAL BOOKS AND RESOURCES

- **Rijksmuseum collection online** (<https://www.rijksmuseum.nl/en>): Free. Search for Jan van der Heyden and for paintings of Amsterdam's harbor and the VOC to see the Golden Age close up. Many images can be downloaded free.
- **Library of Congress digital collections** (<https://www.loc.gov/>): Free. Search "Erie Canal" and "New York harbor" for historic maps, bird's-eye views and photographs to use in your harbor comparison.
- **Google Earth on the web** (<https://earth.google.com/web/>): Free. Fly to the Venetian lagoon, Amsterdam's canal ring, the Isle of Dogs in London and the Narrows of New York, and compare the four harbors from above. A parent should supervise.

3.1 VENICE: A REPUBLIC BUILT ON MUD BANKS AND TRADE ★

OBJECTIVES

- Describe Venice's site (a shallow lagoon behind barrier islands, entered by three inlets) and explain why it made the city safe.
- Explain how Venice's situation at the head of the Adriatic Sea made it a trading bridge between Europe and the East, and why a city with no farms had to trade.
- Trace Venice's galley routes to Constantinople and Alexandria on a map and work out distances, scales and travel times.

Warm-up. Fill a baking dish with wet sand. Stack ten coins into a little tower and set it on the sand. Press gently on top: does it sink or tip? Now push four toothpicks straight down into the sand in a small square, lay a bottle cap or square of cardboard across them, and set the coin tower on that. Press again. Which stands better? Keep your answer in mind: the people of Venice faced this very problem with whole churches and palaces.

Watch. *How Venice Was Built On a Swamp* (NOVA PBS Official, 2:54).

<https://www.youtube.com/watch?v=rJpJdCs5KFw>

After the story: how Venice was built on wooden piles driven into the lagoon mud.

Backup video. *MOSE, WHAT IS IT?* (Enjoy Respect Venezia, 3:12).

<https://www.youtube.com/watch?v=32PTDoTzxGw>

With Technology overcoming geography: the City of Venice explains the 78 MOSE gates and when they rise.

KEY TERMS

lagoon

A shallow body of salt water cut off from the open sea by a chain of sandbars or barrier islands, connected to the sea by narrow inlets.

barrier island

A long, narrow island of sand lying parallel to a coast. The Lido is the barrier island that shelters Venice.

pile

A long post driven down into soft ground to carry the weight of a building. Venice stands on millions of wooden piles.

entrepôt

A port where goods from many places are brought in, stored, bought and sold, and shipped on again.

doge

The elected chief magistrate of the Republic of Venice, chosen for life by the city's leading families through a careful voting process.

arsenal

A state shipyard and armory. The Arsenal of Venice built and repaired the Republic's galleys.

CORE IDEAS

The story. According to Venetian tradition, in the year 828 two merchants of the lagoon, Buono of Malamocco and Rustico of Torcello, were trading in Alexandria, Egypt. They carried off the body said to be Saint Mark, the writer of the Gospel, hid it in a basket under pork so the Muslim customs officers would not touch it, and sailed home. Venice took Mark as its patron, built the great Basilica of San Marco to hold the relics, and flew his winged lion on its flags for nearly a thousand years. Whatever one thinks of the legend, notice what it takes for granted: by the 800s, merchants from a cluster of mud banks at the top of the Adriatic were already sailing to Egypt and back. A refuge in a swamp had become a city of the sea.

How it worked. Venice sits in a **lagoon** of about 550 square kilometers (210 square miles) of shallow water, shut off from the Adriatic by long, thin sand islands such as the Lido. Rivers flowing down from the Alps dropped silt here and built mud banks and marshes, and the tide comes and goes through just three inlets: Lido, Malamocco and Chioggia. In the 400s and 500s, when Attila's Huns (452) and later the Lombards (568) swept into northern Italy, people from the Roman towns on the mainland fled into the lagoon. The safe channels wound between hidden shoals that only local boatmen knew. In 810 Pepin, a son of Charlemagne, attacked the lagoon and failed, and soon afterward the Venetians moved their government to the islands of Rialto, the heart of the later city. To build on mud, they drove wooden **piles** down through the soft silt into a firmer layer of clay, laid planks across the tops, and set stone from Istria on the planks. Packed in wet mud, away from the air, the wood decays very slowly, and many of those piles still hold up buildings today.

The big idea. Geographers separate a city's **site** (the ground it stands on) from its **situation** (where it lies compared with everything around it). Venice's site was safe but poor. There were no fields, no forests, no stone quarries and hardly any fresh water: Venetians caught rain in underground cisterns and drew it up through stone wellheads in every square. A city like that must trade or starve. Its situation, however, was excellent. The head of the Adriatic is the point where the Mediterranean reaches farthest north into Europe, close to the Alpine passes. German merchants crossed the Alps and kept a great warehouse, the Fondaco dei Tedeschi, beside the Rialto Bridge. From the East came spices, silk, cotton and sugar; from the North came silver, metals and wool cloth. Venice became an **entrepôt** where the goods of three continents changed hands, and from 1284 its gold **ducat** was trusted from London to Cairo.

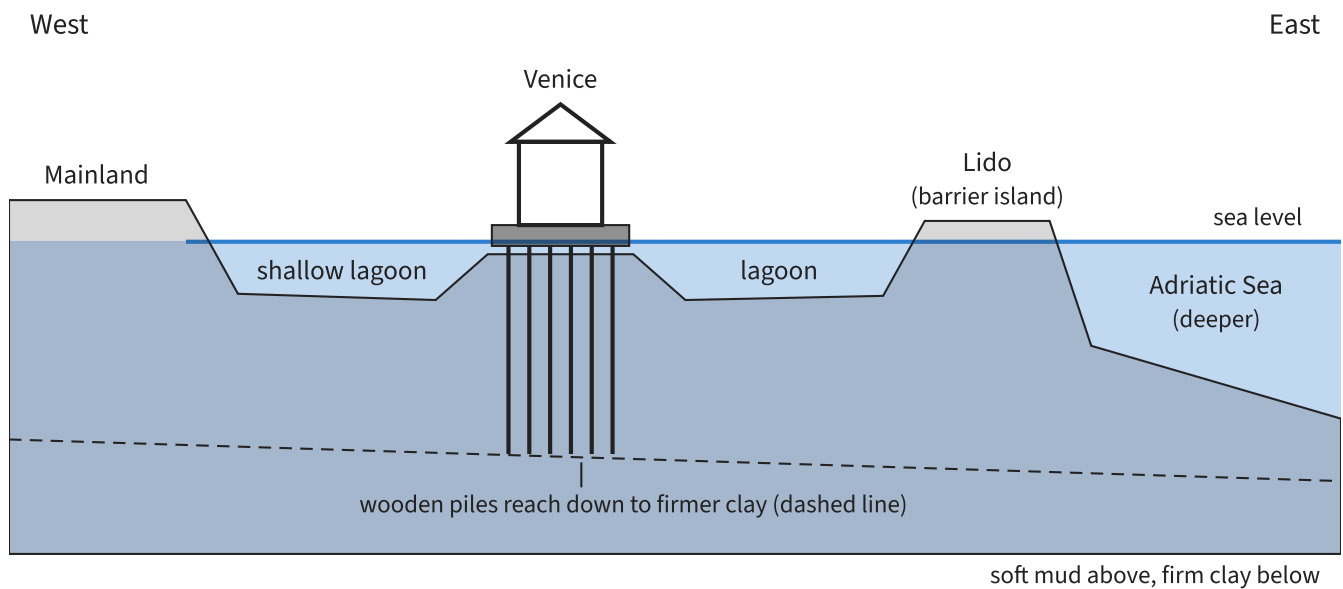
Technology overcoming geography. A city without timber or farmland made itself a sea power by organization and engineering. The **Arsenal**, the Republic's shipyard, built galleys in an orderly line of workshops and employed thousands of workers at its height; the poet Dante, writing in the early 1300s, described its workers boiling sticky pitch in winter to caulk their leaky ships. Each year the state rented out its great merchant galleys and sent

them in protected convoys on fixed routes to Constantinople, Alexandria, Beirut and even Flanders. The Republic, led by an elected **doge** and a Great Council of noble families, lasted more than a thousand years until Napoleon ended it in 1797. Its record was not spotless. In 1204 Venice's fleet, led by the old, nearly blind Doge Enrico Dandolo, carried the Fourth Crusade to the Christian city of Constantinople, which the crusaders sacked; Venice carried home the four bronze horses still kept at San Marco and took ports and the island of Crete. Venetian merchants also bought and sold slaves in the Middle Ages, as many Mediterranean traders did.

On the map. Find Venice at about 45.4°N, 12.3°E (see the map below). Follow the galley route down the Adriatic, past the island of Corfu, which Venice held from 1386 to 1797, around the south of Greece, and on to Crete, which Venice held from the early 1200s until 1669. From there one route ran to Alexandria and another north through the Aegean and the Dardanelles to Constantinople. Situation can change. After Vasco da Gama reached India by sailing around Africa in 1498 and the Ottoman Turks took more and more of the eastern Mediterranean, the spice trade slowly moved to the Atlantic ports. Yet the lagoon still guards Venice, and still threatens it: high tides flood St. Mark's Square. Since October 2020, a system of 78 steel gates called MOSE, lying on the floor of the three inlets, can be raised to hold back the highest tides, a modern answer to an ancient site.



Venice's main galley routes to Constantinople and Alexandria. Venice held Corfu and Crete as stepping stones along the way.



A cross-section (not to scale) from west to east. The Lido keeps the sea's waves out; the shallow lagoon kept enemy fleets out; piles carry the city's buildings down to firmer clay.

PICTURE STUDY



The Grand Canal from Palazzo Balbi toward the Rialto, Canaletto (Giovanni Antonio Canal), about 1720–1723 · Oil on canvas · Ca' Rezzonico (Museum of Eighteenth-Century Venice), Venice

Giovanni Antonio Canal, called Canaletto (1697–1768), was the son of a Venetian painter of theater scenery. He became the most famous painter of *vedute*, or detailed city views, and wealthy visitors, especially English gentlemen on their “Grand Tour” of Europe, carried his paintings home as the finest souvenirs money could buy. Many were sold through Joseph Smith, the British consul in Venice, and a large group later went to King George III.

This is one of Canaletto's early views, painted in the early 1720s. Like most of his work, it left Venice and spent centuries in a prince's collection in Vienna, until the city of Venice bought it back in 1983. It looks along the Grand Canal, the city's main street of water, which winds about 3.8 kilometers (2.4 miles) through the city in a backward S and passes under the Rialto Bridge, the old center of trade.

Look closely

- Find the boats. Which ones seem to carry people, and which seem to carry goods?
- Look at the bottoms of the palaces. Where are the doors, and how would a merchant's goods get inside?
- Follow the line of the canal into the distance. Does it run straight or bend?
- How much of the picture is sky? What does that do to the feeling of the painting?

Talk about it

1. What would be hard about living in a city where the main street is water? What would be easy?
2. Why do you think rich travelers wanted paintings of Venice to take home?
3. How does this painting show that Venice lived by trade?

PROJECT: A CITY ON PILES

You will build a small lagoon in a pan, with a barrier island, inlets and a mud bank, and then test whether a "palace" stands better on bare mud or on piles driven down to firmer clay. You will measure how far each building sinks.

You will need

- A deep baking pan or plastic storage tub
- Modeling clay or a layer of stiff play dough (the firm clay layer)
- Sand and a little garden soil, mixed with water into a soft mud
- Wooden toothpicks or bamboo skewers cut to about 6 cm (2½ in)
- Two squares of stiff cardboard about 5 cm (2 in) on a side, wrapped in foil or tape
- A small heavy object for the "palace" (a stack of 10–15 coins, a small stone or a die)
- Ruler, marker, water in a pitcher

Steps

1. Press a layer of modeling clay about 1 cm (½ in) thick into the bottom of the pan. This is the firm clay layer under the lagoon.
2. Spread soft mud about 3 cm (1¼ in) deep over the clay. Along one long side, pile wet sand into a long, narrow ridge that stands above the rest: this is the Lido, your barrier island. Cut three gaps in it for the inlets.
3. In the middle of the lagoon, build a low mud bank that just reaches the surface when you add water. Slowly pour water in until the mud bank barely shows.

4. Test 1: set a foil-covered cardboard square on the mud bank, put the palace on it, and press down lightly for five seconds. Measure with the ruler how far the square sank into the mud, in millimeters.
5. Test 2: on another part of the mud bank, push four to nine toothpicks straight down until they touch the clay layer. Trim or press them so their tops are level. Set the second cardboard square on top, put the palace on it and press the same way. Measure again.
6. Pour in a little more water through one inlet to make a “high tide.” Watch where the water goes first and whether the island city stays dry.
7. Record both measurements in a small table and write two sentences explaining why the Venetians drove piles down to the firm clay.

Tips

- Press with the same finger and the same force in both tests, so the test is fair.
- Real Venetian piles were set very close together, and the spaces between them were packed. More toothpicks closer together will work better than a few far apart.

Check your work

- I can name the parts of my lagoon: barrier island, inlets, mud bank and clay layer.
- I measured how far the building sank with and without piles.
- I can explain why piles help a building stand on soft ground.

MAP NOTEBOOK

1. Draw a sketch map of the Venetian lagoon: the mainland on the west, the Lido and other barrier islands on the east, the three inlets (Lido, Malamocco, Chioggia), and the city in the middle. Add a compass rose.
2. Make a two-column chart titled “Venice: Site and Situation.” List at least four facts in each column.
3. Draw the cross-section of a Venetian building: water, mud, piles, clay layer, planks, stone base and the walls above. Label each part.

From history. For centuries, on the Feast of the Ascension, the doge was rowed out in the golden state barge called the *Bucintoro* to the inlet at the Lido. There he dropped a gold ring into the Adriatic and declared that Venice was marrying the sea, a sign of its claim to rule the waters it lived by. The last *Bucintoro* was broken up after Napoleon’s army ended the Republic in 1797, but the city still holds a version of the ceremony each year.

WORKED EXAMPLES

Example 1. The Grand Canal is about 3.8 km long. How long would it be on a map drawn at a scale of 1:50,000? Also give its real length in miles.

1. Change kilometers to centimeters: $3.8 \text{ km} \times 1,000 \text{ m per km} \times 100 \text{ cm per m} = 380,000 \text{ cm}$.
2. At 1:50,000, every 1 cm on the map stands for 50,000 cm on the ground, so divide: $380,000 \div 50,000 = 7.6 \text{ cm}$.
3. Miles: 1 km is about 0.62 mi, so $3.8 \times 0.62 \approx 2.4 \text{ mi}$.

Answer: About 7.6 cm on the map. The real canal is about 3.8 km (2.4 mi) long.

Example 2. A convoy of merchant galleys sails from Venice to Alexandria by the usual route down the Adriatic and past Crete, about 2,300 km (1,400 mi). If the convoy averages 90 km (56 mi) a day, including stops, about how many days does the voyage take?

(Use the map or drawing "Trace the Alexandria route with your finger: down the Adriatic, past Corfu and C" shown earlier in this lesson.)

1. Time = distance $\div$ speed.
2. $2,300 \text{ km} \div 90 \text{ km per day} \approx 25.6 \text{ days}$.
3. Check in miles: $1,400 \text{ mi} \div 56 \text{ mi per day} = 25 \text{ days}$, which agrees once we allow for rounding.

Answer: About 26 days, or nearly four weeks.

Example 3. A Venetian builder wants to set a stone platform 10 m by 20 m on piles, with one pile under every square 0.5 m by 0.5 m. How many piles does he need? If each pile is 4 m long, how much timber is that in all?

(Use the map or drawing "The piles under the building reach down through the soft mud to the firmer clay." shown earlier in this lesson.)

1. Area of the platform: $10 \text{ m} \times 20 \text{ m} = 200 \text{ square meters}$.
2. Area served by one pile: $0.5 \text{ m} \times 0.5 \text{ m} = 0.25 \text{ square meters}$.
3. Number of piles: $200 \div 0.25 = 800 \text{ piles}$. (Or count rows: $10 \div 0.5 = 20 \text{ rows of } 20 \div 0.5 = 40 \text{ piles}$; $20 \times 40 = 800$.)
4. Timber: $800 \times 4 \text{ m} = 3,200 \text{ m} = 3.2 \text{ km}$, about 2 miles of tree trunks.

Answer: 800 piles, using about 3.2 km (2 mi) of timber, all of it brought in from forests on the mainland, because the lagoon grew none.

PRACTICE

1. **EASY** What is a lagoon, and what separates the Venetian lagoon from the Adriatic Sea?
2. **EASY** Name the three inlets that connect the Venetian lagoon to the sea.
3. **EASY** Why did people from the mainland flee into the lagoon in the 400s and 500s, and why were they safe there?
4. **MEDIUM** Venice lies at about 45.4°N and Alexandria at about 31.2°N. One degree of latitude is about 111 km (69 mi). How far apart are the two cities north to south?
5. **MEDIUM** The galley route from Venice to Constantinople was about 2,000 km (1,250 mi). At 100 km (62 mi) a day, how long would the voyage take? Why would a real voyage often take longer?
6. **MEDIUM** On a map at 1:250,000, the Venetian lagoon measures 20 cm from north to south. How long is it in real life, in km and miles?
7. **MEDIUM** Sort each fact into SITE or SITUATION: (a) built on mud banks in a shallow lagoon; (b) at the head of the Adriatic, near the Alpine passes to Germany; (c) no fresh springs, so rain was caught in cisterns; (d) halfway between the spice markets of the East and the buyers of northern Europe.
8. **HARD** Explain in three or four sentences why Venice had to become a trading city, while a town on rich farmland might not.
9. **HARD** A gold ducat held about 3.5 grams of gold. A merchant pays 2,000 ducats for a cargo of pepper. How many kilograms of gold is that?
10. **CHALLENGE** Use the words “site” and “situation” to explain why Venice’s trade slowly declined after 1500, even though the lagoon itself had not changed.

COMMON MISTAKES

- Thinking Venice was built on water with nothing underneath. It stands on islands and mud banks, strengthened by wooden piles driven down to firmer clay.
- Mixing up site and situation. Site is the ground under the city (lagoon, mud, piles); situation is its place among other lands and routes (head of the Adriatic, near the Alps, between East and West).
- Thinking the canals were Venice’s defense. The canals were its streets; the real defense was the wide, shallow lagoon with its secret channels.

Make it a game • Pilot of the Lagoon. On a sheet of paper, one player (the Venetian pilot) secretly draws a lagoon with a winding safe channel and hidden mud banks, marked on a 6 by 6 grid. The other player commands an enemy fleet and must sail from the inlet to the city one square at a time by calling out squares (“C4”). The pilot answers only “deep water” or “aground.” Each grounding costs the fleet a ship; the fleet has five. Then switch roles. Afterward, explain why King Pepin’s fleet failed to take the lagoon in 810.

Scripture. “And say unto Tyrus, O thou that art situate at the entry of the sea, which art a merchant of the people for many isles, Thus saith the Lord GOD; O Tyrus, thou hast said, I am of perfect beauty.” (Ezekiel 27:3, KJV)

Ezekiel describes Tyre, the great port of the ancient world, in words that fit Venice almost exactly: a city “situate at the entry of the sea” and a merchant to many lands. Its pride was its downfall. A good site and a rich trade are gifts from God, but they last only as long as the people who hold them stay humble and honest.

Practice answers

1. A lagoon is a shallow body of salt water cut off from the open sea. The Venetian lagoon is separated from the Adriatic by long, narrow barrier islands of sand, such as the Lido.
2. Lido, Malamocco and Chioggia.
3. They were escaping invaders such as Attila’s Huns and later the Lombards. The lagoon was safe because its shallow water and hidden mud banks stopped armies and large ships; only local boatmen knew the safe channels.
4. $45.4 - 31.2 = 14.2^\circ$. $14.2 \times 111 \approx 1,576$ km, or $14.2 \times 69 \approx 980$ mi. About 1,600 km (980 mi).
5. $2,000 \div 100 = 20$ days. Real voyages took longer because of storms, calms, contrary winds and stops in port to trade and take on water.
6. $20 \text{ cm} \times 250,000 = 5,000,000 \text{ cm} = 50 \text{ km}$, about 31 mi.
7. (a) site; (b) situation; (c) site; (d) situation.
8. Venice’s site had no farmland, forests, stone or fresh springs, so it could not feed, build or even water itself. It had to buy grain, timber, stone and much else from other places. To pay for them, Venetians sold salt and fish and, above all, acted as middlemen, buying goods in the East and selling them in Europe. A farming town could live on its own harvests and trade only its extra.
9. $2,000 \times 3.5 \text{ g} = 7,000 \text{ g} = 7 \text{ kg}$ of gold (about 15 pounds).
10. Venice’s site, the safe lagoon, stayed the same, but its situation changed. After Vasco da Gama sailed around Africa to India in 1498, spices could reach Europe by sea through Atlantic ports such as Lisbon and later Amsterdam, without passing through the Mediterranean. At the same time the Ottoman Turks took over more of the eastern Mediterranean. Venice was no longer on the best route between East and West, so its trade shrank.

3.2 AMSTERDAM AND THE DUTCH GOLDEN AGE

OBJECTIVES

- Explain how Amsterdam grew from a dam on the Amstel into the busiest port in Europe, and how its people built on peat and water with dikes, piles and a planned ring of canals.
- Describe Amsterdam's situation between the Baltic, the Atlantic and Asia, and explain how the Dutch East India Company and the Amsterdam exchange let many people share the risk of long voyages.
- Read latitude on a map, compare a harbor's depth with a ship's draft, and compute the average speed of a long voyage.

Warm-up. Float an empty plastic food tub in a sink and draw a line on its side at the waterline. Add coins or marbles a few at a time and watch the line sink. Measure, in millimeters, how much deeper it rides when fully loaded. A loaded ship needs deeper water than an empty one. Keep that in mind: Amsterdam's harbor was famous, but it was shallow.

Watch. *Why are the Dutch So Good at Waterworks?* (Practical Engineering, 22:20).

<https://www.youtube.com/watch?v=qQCB3N8Vaxk>

After the big idea: polders, dikes, windpumps and the Zuiderzee Works, from a civil engineer. Watch the first ten minutes, through the Afsluitdijk.

Note: The full video runs 22 minutes plus a sponsor message. The later part mentions rising seas and stronger storms, and the sponsor message mentions COVID vaccines and politics, so stop after the Afsluitdijk section.

Backup video. *Dutch Ships of the Golden Age* (The History Guy: History Deserves to Be Remembered, 16:43). https://www.youtube.com/watch?v=n_8rx0na7Nk

With the history note: the ships of the Dutch Golden Age and the trade that built Amsterdam. Note: The History Guy runs a little over 15 minutes.

KEY TERMS

dike

A wall of earth built to hold back the sea or a river and keep low land dry.

draft

How deep a ship sits in the water: the distance from the waterline down to the bottom of its keel.

joint-stock company

A business owned by many people who each buy shares; they share its profits and its risks.

share

One part of the ownership of a company, which can be bought and sold.

stock exchange

A marketplace where people buy and sell shares. Amsterdam's exchange, opened in 1611, is often called the first modern stock exchange.

fluyt

A Dutch cargo ship first built about 1595: long, roomy and cheap to sail with a small crew.

CORE IDEAS

The story. On 20 March 1602 the States General, the government of the young Dutch Republic, granted a charter to the **United East India Company**, known by its Dutch initials, VOC. That summer the company's books were opened in Amsterdam, and anyone could buy a part of it: great merchants, shopkeepers, craftsmen and even servants. More than a thousand people in Amsterdam signed up. A voyage to the Spice Islands of the East Indies took the better part of a year each way, and one ship in a fleet might be lost to storms, reefs, disease or enemies. No single family wanted to risk everything on one ship. By sharing the cost, many people shared the risk and the reward. Soon people were buying and selling their VOC **shares** every day, and in 1611 the city opened a handsome new exchange building, the Beurs, designed by Hendrick de Keyser. It was built on arches right over the water of the Amstel River.

How it worked. Amsterdam began in the 1200s as a fishing village where people built a dam across the little Amstel River near where it met the IJ, an arm of the inland sea called the Zuiderzee. The name says it: Amstel-dam. A document of 1275 already freed its people from paying certain tolls. The ground was soggy peat, much of it at or below sea level, so the Dutch protected it with **dikes** and pumped it dry with windmills. Every building stood on wooden piles driven through the peat into a layer of sand; the great Town Hall on the Dam, now the Royal Palace, rests on 13,659 of them. In 1613 the city began a planned expansion: three new canals, the Herengracht, Keizersgracht and Prinsengracht, curving in rings around the old center inside the Singel. Merchants built tall, narrow houses along them, each with a beam at the top to hoist goods straight from the boats into the attic warehouses.

The big idea. Amsterdam's site was poor and its harbor was shallow, yet its **situation** was superb. It lay where the rivers of the Low Countries reach the sea, halfway between the Baltic, which sent grain, timber, tar and hemp, and the south and west, which sent wine, salt and later sugar. The Dutch called the Baltic grain trade the "mother trade," because so much else grew from it. History helped too. In 1585 Spanish troops took Antwerp, then the great port of the Low Countries, and the Dutch rebels closed the river Scheldt to its ships. Thousands of merchants and craftsmen, many of them Protestants, moved north to Amsterdam, joined by Portuguese Jewish traders, and brought their money, skills and connections. The city also built trust in money: the Bank of Amsterdam, founded in 1609, kept honest coin and let merchants pay one another by bookkeeping. By the late 1600s Amsterdam had about 200,000 people and was the warehouse of Europe.

Technology overcoming geography. The Dutch beat their geography with clever machines. Cornelis Corneliszoon, a miller of Uitgeest, built a wind-powered sawmill in the 1590s that cut timber many times faster than men with hand saws, and Dutch yards turned

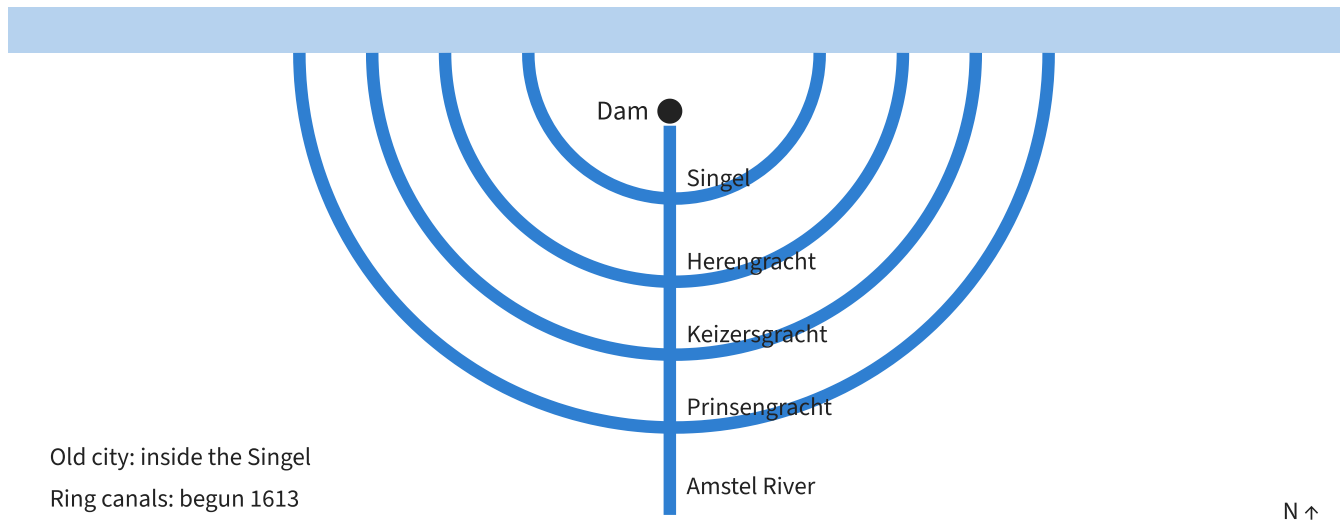
out ships quickly and cheaply. The **fluyt**, first built at Hoorn about 1595, carried big cargoes with a small crew. Big ships could not reach the city fully loaded because of a sand bar called the Pampus, so cargo was often moved into smaller boats at the island of Texel. About 1690 an Amsterdam builder invented the “ship camel,” a pair of hollow wooden floats that were filled with water, sunk alongside a ship, fastened to it and then pumped out. As the camels rose, they lifted the ship over the bar. In 1611 the VOC captain Hendrik Brouwer found a faster route to the Indies: from the Cape of Good Hope he sailed far south into the strong westerly winds of the “Roaring Forties,” then turned north toward Java.

On the map. Find Amsterdam at about 52.4°N, 4.9°E, and Batavia (today Jakarta, on Java), which the VOC founded in 1619 as its Asian headquarters, at about 6.2°S. The Golden Age had a dark side, and it should be named plainly. In 1621 the VOC governor Jan Pieterszoon Coen conquered the Banda Islands to control the nutmeg trade; most of the islanders were killed, driven out or enslaved. The VOC used slave labor in Asia and at the Cape, and the Dutch West India Company carried enslaved Africans across the Atlantic. Later engineers changed Amsterdam’s map itself: the North Sea Canal (1876) gave the city a deep, direct channel to the sea at IJmuiden, and the great Enclosure Dam (1932) closed off the Zuiderzee, which is now a freshwater lake, the IJsselmeer.



Amsterdam’s sea road: big ships left the city, crossed the shallow Zuiderzee past the Pampus bar, and waited at Texel for a fair wind into the North Sea.

The IJ (harbor), leading to the Zuiderzee



Amsterdam's canal ring (simplified, not to scale). From the center outward: Singel, Herengracht, Keizersgracht, Prinsengracht.

PICTURE STUDY



View of the Golden Bend in the Herengracht, Gerrit Adriaensz. Berckheyde, 1671–1672 · Oil on oak panel · Rijksmuseum, Amsterdam

Gerrit Berckheyde (1638–1698) lived in Haarlem and learned to paint from his older brother Job. As young men the brothers traveled up the Rhine into Germany. Back home, Gerrit spent his life painting the squares, churches and canals of Haarlem, Amsterdam and The Hague, often painting the same place again and again in clear, bright light.

This painting shows the “Golden Bend,” the stretch of the Herengracht where the richest merchants of the Golden Age built their grandest houses. When Berckheyde painted it, this

part of the canal ring was brand new. Some lots were still empty, and building materials lay on the quay. The houses stood on wooden piles, faced a canal that served as a street for boats, and were paid for largely by the trade you are studying in this lesson.

Look closely

- Follow the curve of the canal. Why do you think the canal curves instead of running straight? (Look back at the canal ring diagram.)
- Look at the fronts of the houses. What are they made of? How many windows can you count on one house?
- Find the empty lots and the building materials on the quay. What do they tell you about when this picture was painted?
- Find any boats, people or carts. What do they tell you about how goods moved in this city?
- Look at the reflections in the water. Why might the painter have chosen a still, sunny day?

Talk about it

1. Canaletto painted Venice; Berckheyde painted Amsterdam. How are the two cities alike, and how are they different?
2. Where did the wealth come from that built these houses?
3. Berckheyde painted this canal while some of its houses were still being built. Why might someone want a picture of a neighborhood that was not yet finished?

PROJECT: LIFT A SHIP OVER THE BAR: THE SHIP CAMEL

You will build a loaded “ship” that is too deep to cross a sand bar, then fit it with homemade ship camels, floats fastened alongside, and measure how much they raise it. This is the trick Amsterdam’s builders used from about 1690 to get big ships over the Pampus.

You will need

- A long plastic food tub or loaf-shaped container (the ship)
- Coins, marbles or small stones (the cargo)
- A sink, bathtub or large basin of water
- A brick or thick book sealed in a plastic bag (the sand bar)
- Two empty plastic bottles with caps (500 mL or 16 oz work well)
- Rubber bands or string, a ruler and a waterproof marker

Steps

1. Put the bagged brick on the bottom of the basin and fill the basin until the water over the brick is about 3 cm (1¼ in) deep. That is the depth over your bar.
2. Load the ship with cargo until its draft is more than 3 cm. Measure the draft with the ruler: from the waterline on the outside of the tub straight down to its bottom. Write it down.

3. Try to float the ship over the bar. It should run aground.
4. Cap the empty bottles tightly. Hold one along each side of the ship, pushed down so that most of the bottle is under water, and fasten them tightly with rubber bands or string.
5. Measure the draft again. How many millimeters did the camels lift the ship? Try floating it over the bar now.
6. Experiment: try larger bottles, or bottles fastened lower on the sides. Record which lifts the ship the most.
7. Write three sentences explaining how real ship camels worked and why Amsterdam needed them.

Tips

- The real camels were sunk full of water, fastened to the ship, and then pumped empty. Pushing your empty bottles down before fastening them does the same job: the water pushes up on them, and they push up on the ship.
- Measure from the same spot on the tub each time so your numbers can be compared.

Check your work

- I measured the ship's draft before and after fitting the camels.
- I can explain the word draft and why a shallow bar stops loaded ships.
- I can explain how the ship camels helped Amsterdam overcome its shallow harbor.

MAP NOTEBOOK

1. Copy the canal ring diagram and label the IJ, the Dam, the Amstel and the four canals in order from the center outward.
2. Draw a map of the Dutch coast with Amsterdam, the Zuiderzee, the Pampus, Texel, Hoorn, Antwerp and the North Sea. Draw the ships' route from Amsterdam to Texel.
3. Draw a simple world map showing the VOC route: Texel, the Cape of Good Hope, the "Roaring Forties," and Batavia on Java. Label the route by which spices came home.

From history. In 1609 the VOC hired an English captain, Henry Hudson, to look for a northern sea route to Asia. Ice turned his ship, the *Halve Maen* (Half Moon), back, so he crossed the Atlantic instead and sailed up the great river that now bears his name, as far as the area of today's Albany. His report led Dutch traders to the region, and in the 1620s they founded New Amsterdam on Manhattan Island. You will meet that harbor again in Lesson 3.4.

WORKED EXAMPLES

Example 1. Amsterdam lies at about 52.4°N , and Batavia at about 6.2°S . How many degrees of latitude apart are they? About how far is that north to south, in km and miles? (1° of latitude $\approx 111\text{ km} \approx 69\text{ mi.}$)

1. The cities are on opposite sides of the equator, so add: $52.4^{\circ} + 6.2^{\circ} = 58.6^{\circ}$.
2. Kilometers: $58.6 \times 111 \approx 6,505\text{ km}$.
3. Miles: $58.6 \times 69 \approx 4,043\text{ mi}$.

Answer: 58.6° of latitude, about 6,500 km (4,000 mi) north to south. The real voyage was much longer, because ships had to sail around Africa.

Example 2. Suppose a loaded VOC ship has a draft of 4.5 m, and the water over the Pampus bar is 3.0 m deep. A pair of ship camels lifts the ship 1.8 m. Can it now cross the bar, and with how much water to spare?

1. Without camels: 4.5 m draft is more than 3.0 m of water, so the ship would run aground.
2. With camels, the new draft is $4.5\text{ m} - 1.8\text{ m} = 2.7\text{ m}$.
3. Water to spare under the keel: $3.0\text{ m} - 2.7\text{ m} = 0.3\text{ m}$ (30 cm, about 1 ft).

Answer: Yes. The ship now draws 2.7 m and clears the bar by about 0.3 m (1 ft).

Example 3. A VOC ship's voyage from Texel to Batavia was about 22,000 km (13,700 mi) and took about 8 months (240 days). What was its average speed in km per day and in km per hour?

1. Average speed = distance $\div$ time = $22,000\text{ km} \div 240\text{ days} \approx 92\text{ km per day}$ (about 57 mi per day).
2. Per hour: $92\text{ km} \div 24\text{ h} \approx 3.8\text{ km/h}$.
3. Compare: a person walks about 5 km/h, so the ship's average over the whole voyage, with calms and storms and stops, was slower than walking pace, though it never stopped day or night.

Answer: About 92 km (57 mi) a day, or about 3.8 km/h (2.4 mph).

PRACTICE

1. **EASY** Where does the name Amsterdam come from?
2. **EASY** Name Amsterdam's four ring canals in order from the center outward.
(Use the map or drawing "Use the diagram to check the order of the canals." shown earlier in this lesson.)

3. **EASY** What was the VOC, and in what year was it chartered?
4. **MEDIUM** Explain how selling shares helped Dutch merchants send ships on dangerous voyages to Asia.
5. **MEDIUM** What happened at Antwerp in 1585, and how did it help Amsterdam?
6. **MEDIUM** The Royal Palace on the Dam rests on 13,659 piles. If they were driven at a rate of 15 a day, how many days would the work take? About how many years of 300 working days is that?
7. **MEDIUM** On the map of the Dutch coast, Amsterdam is at about 52.4°N and Texel at about 53.0°N. About how far apart are they north to south? Why did big ships go to Texel?
(Use the map or drawing "Find Amsterdam and Texel on the map." shown earlier in this lesson.)
8. **HARD** A ship has a draft of 5.2 m. The channel over a bar is 3.6 m deep. How much must ship camels lift the ship for it to clear the bar with 0.4 m to spare?
9. **HARD** Name two machines or inventions that helped the Dutch overcome their geography, and explain what each did.
10. **CHALLENGE** Amsterdam had a soggy site and a shallow harbor, yet it became Europe's greatest port in the 1600s. In a short paragraph, explain how situation, people and technology together outweighed a poor site. Include one honest word about the cost of the Golden Age.

COMMON MISTAKES

- Thinking Amsterdam had a deep harbor like New York. Its harbor was sheltered but shallow; its strength was its situation, its people and its inventions.
- Saying the Dutch "invented" the stock exchange out of nothing. Antwerp already had an exchange for goods and bills; Amsterdam was first to have shares of a great company traded there every day, which is why it is often called the first modern stock exchange.
- Forgetting that shares carry risk. A share could lose value as well as gain it; in 1637 Dutch buyers also learned that prices can rise in a craze (the tulip mania) and then crash.

Make it a game · Voyage to the Spice Islands. Each player starts with 10 counters (guilders) and may buy shares, at 1 guilder each, in three ships sailing to Batavia. For each ship roll a die four times, once for each leg: Texel, the Cape, the Roaring Forties and Java. A roll of 1 means the ship is lost; otherwise it reaches port. Each share in a ship that returns pays 3 guilders. Play several rounds. Who did better: players who put everything in one ship, or those who spread their shares? Explain why the VOC sold shares to many people.

Scripture. "Wealth gotten by vanity shall be diminished: but he that gathereth by labour shall increase." (Proverbs 13:11, KJV)

Amsterdam saw both halves of this proverb. Patient trade, honest money and hard work built a great city; but in the tulip craze of 1637 people paid fortunes for single flower bulbs, and when prices crashed much of that "wealth gotten by vanity" vanished almost overnight.

Practice answers

1. From a dam built across the Amstel River: Amstel-dam.
2. Singel, Herengracht, Keizersgracht, Prinsengracht.
3. The United East India Company, a Dutch joint-stock company for trade with Asia, chartered in 1602.
4. Many people each bought a share, so the huge cost of a fleet was divided among them. If a ship was lost, each owner lost only a little instead of one family losing everything; if the voyage succeeded, each shared the profit. Because shares could be sold on the exchange, owners could also get their money back without waiting years for the fleet to return.
5. Spanish troops captured Antwerp, and the Dutch rebels closed the Scheldt River to its shipping. Many merchants and craftsmen, many of them Protestants, moved north to Amsterdam, bringing money, skills and trade connections.
6. $13,659 \div 15 \approx 911$ days. $911 \div 300 \approx 3$ years.
7. $53.0 - 52.4 = 0.6^\circ$; $0.6 \times 111 \approx 67$ km (about 41 mi). Big, loaded ships could not cross the shallow Zuiderzee and the Pampus bar, so they loaded and unloaded at Texel, where they also waited for a fair wind into the North Sea.
8. The new draft must be $3.6 - 0.4 = 3.2$ m. Lift needed: $5.2 - 3.2 = 2.0$ m.
9. Any two: windmills pumped water out of low land behind the dikes; the wind-powered sawmill cut timber fast for shipbuilding; the fluyt carried big cargoes with a small crew; ship camels lifted ships over the Pampus bar; later, the North Sea Canal (1876) gave a deep direct route to the sea.
10. A good answer mentions: Amsterdam's situation between the Baltic grain and timber trade and the trade of western and southern Europe, later Asia; the merchants and craftsmen who came from Antwerp after 1585; trusted institutions such as the Bank of Amsterdam and the exchange; and technology such as dikes, windmills, the wind sawmill, the fluyt and ship camels. It should also note plainly that some of the wealth came through conquest and slavery, such as the VOC's conquest of the Banda Islands in 1621 and the Dutch part in the slave trade.

3.3 LONDON AND THE THAMES: DOCKS FOR AN EMPIRE

OBJECTIVES

- Explain how the tides of the Thames both helped and troubled the Port of London, and how enclosed wet docks with gates solved the problem.
- Describe London's situation facing Europe across the North Sea, and how it became the hub of a worldwide trade in the 1800s.
- Work with tide times, water depths and ship drafts, and compute travel times on a tidal river.

Warm-up. The Thames at London Bridge can rise and fall about 7 meters (23 feet) between low and high tide, twice a day. Go outside and find something about that high: the roof gutter of a two-story house is close. Now imagine tying a boat to a dock at high tide and coming back six hours later. Where would your boat be? What would happen to the rope? Talk it over for a few minutes before you read.

Watch. *What's inside Tower Bridge? (London, England)* (Jared Owen, 15:07).

<https://www.youtube.com/watch?v=G2e4K-wD1KY>

With the story: inside Tower Bridge, the gateway to the old Pool of London.

Note: Jared Owen's animation runs about 15 minutes.

Backup video. *How the Thames Barrier protects London from flooding.* (Environment Agency, 2:40). <https://www.youtube.com/watch?v=jp4Y1HrRBD0>

With Technology overcoming geography: how the Thames Barrier protects London from surge tides. Note: From the UK government's Environment Agency; it explains the gates and the tides, nothing more.

KEY TERMS

tide

The regular rise and fall of the sea, caused mainly by the pull of the moon and sun. Most coasts have two high and two low tides about every 24 hours and 50 minutes.

tidal range

The difference in height between high water and the next low water.

estuary

The wide lower part of a river where fresh water meets the sea and the tide flows in and out.

wet dock

An enclosed basin with gates, where water is kept at a steady level so ships stay afloat whatever the tide is doing outside.

lighter

A flat-bottomed barge used to carry cargo between ships and the shore.

bonded warehouse

A guarded warehouse where imported goods are stored under lock until the duties (import taxes) on them are paid.

CORE IDEAS

The story. On 27 August 1802 a ship dressed in flags and named the *Henry Addington*, after the prime minister, sailed through new gates into a great rectangular basin dug out of the marshes of the Isle of Dogs, a loop of land in the Thames east of the City of London. It was the opening of the **West India Docks**. For years the merchants who imported sugar, rum and coffee from the British West Indies had been losing patience. The river below London Bridge, called the Pool of London, was so crowded that ships lay moored side by side for weeks waiting to unload. Cargo went over the side into open **lighters** and lay on crowded wharves, and gangs of thieves stole huge amounts of it. A magistrate named Patrick Colquhoun even sorted them into types, from “river pirates” who cut barges loose at night to “mudlarks” who picked up what was thrown overboard. The answer was a dock surrounded by a high wall, where ships unloaded straight into guarded warehouses. Honesty requires one more fact: the sugar and rum that paid for these docks were grown on Caribbean plantations by enslaved Africans. Britain banned its slave trade in 1807 and freed the slaves in its colonies by an act of 1833.

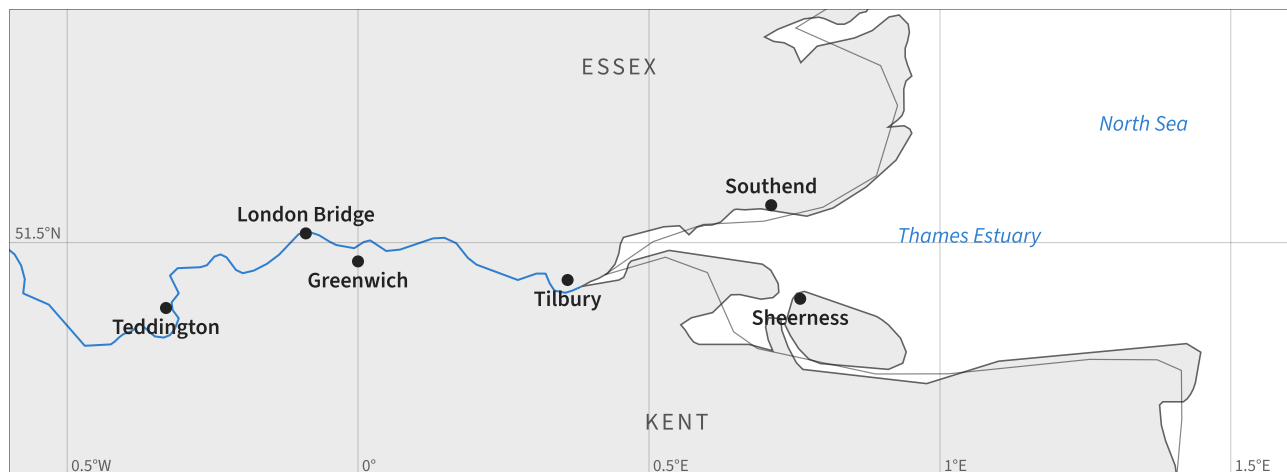
How it worked. The Thames is tidal for about 150 km (95 miles), from Teddington in the west down to the sea. At London Bridge the water rises and falls about 7 m (23 ft) at the biggest tides, twice a day. The tide was a gift: for centuries ships rode the incoming flood tide up the river to the city and the ebb tide back down, using its free push in addition to the wind. But at low water, ships moored in the river settled onto the mud, where their hulls could strain and crack. A **wet dock** fixed this. Engineers dug a basin beside the river and joined it to the river by an entrance with strong gates or a lock. Ships came in near high water, the gates were closed, and the water inside stayed at the high level while the river outside fell (see the diagram). The ships stayed afloat and unloaded along stone quays into **bonded warehouses** behind the walls.

The big idea. London’s site was chosen by the Romans soon after AD 43, at the lowest place where the Thames could be bridged, on firm gravel beside the river, as you learned in Unit 1. Its situation made it great. London faces the mouths of the Rhine and Scheldt across the narrow southern North Sea, and the tidal Thames carries seagoing ships right into the heart of a rich country. As Britain built a worldwide empire and led the world into the age of factories, London became an **entrepôt** for the globe. Each dock had its trade: sugar and rum at the West India Docks; tea, silk and spices at the East India Docks; timber and grain from the Baltic and Canada at the Surrey Commercial Docks; wool from Australia and ivory, wine and much else in the warehouses of the London and St. Katharine Docks. Around the ships grew the businesses of trade: Lloyd’s of London, which began about 1688 in Edward Lloyd’s coffee house, insured ships and cargoes all over the world.

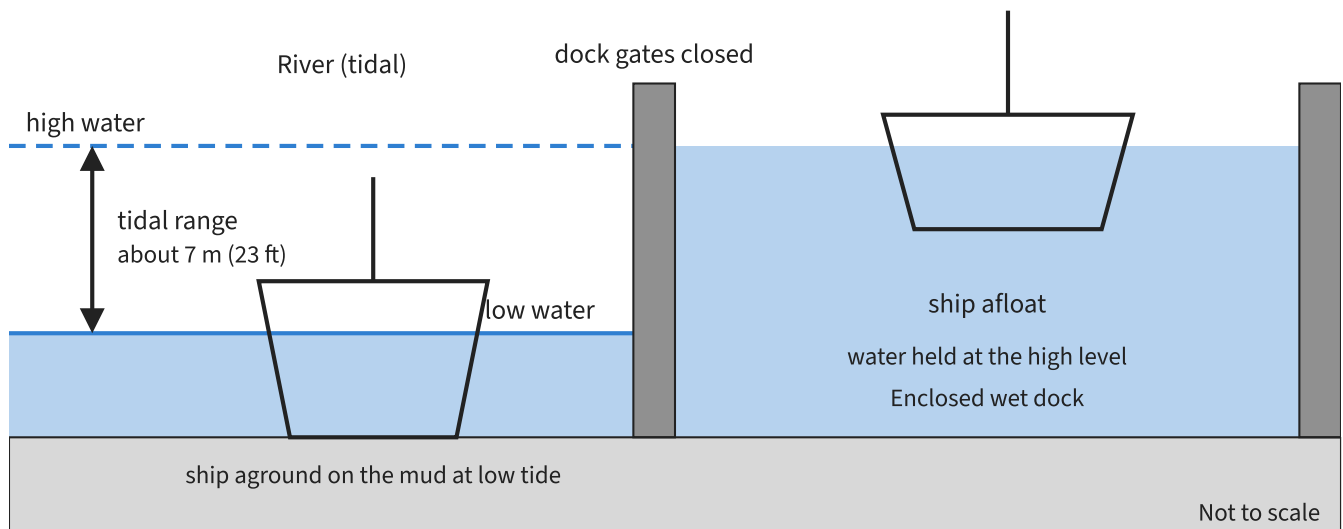
Technology overcoming geography. One dock followed another: the London Dock at Wapping (1805), the East India Docks (1806), St. Katharine Docks beside the Tower, built by

Thomas Telford (1828), and then a chain of ever bigger docks downstream as ships grew, the Royal Victoria (1855), the Royal Albert (1880), Tilbury (1886) and the King George V (1921). For much of the 1800s London was the busiest port in the world. Engineers also found ways to cross the busy river without blocking ships. Marc Brunel and his son Isambard Kingdom Brunel built the Thames Tunnel (opened 1843), the first tunnel known to have been dug under a navigable river. Tower Bridge (1894) has two great roadway leaves, called bascules, that still swing up to let tall ships into the Pool of London. Downstream, the Thames Barrier, finished in 1982, is a row of huge steel gates that can be turned up from the riverbed to block a storm surge pushing in from the North Sea.

On the map. Find London at about 51.5°N, 0.1°W, and follow the river east past Greenwich and Tilbury to the estuary between Southend and Sheerness (see the map). In the 1960s ships grew too big for the old upriver docks, and the coming of the shipping container, which you will study in Unit 4, moved the work downstream to deep water at Tilbury and, from 2013, London Gateway. Between 1967 and 1981 the old docks closed one by one. The office towers of Canary Wharf now stand on the West India Docks, beside the very basin the *Henry Addington* sailed into in 1802.



The tidal Thames. Ships rode the tide about 70 km (45 mi) up from the open estuary near Southend to the Pool of London.



Why London built wet docks. Outside, the river falls about 7 m (23 ft) at low tide; inside, the closed gates hold the water at the high level.

PICTURE STUDY



An Elevated View of the New Dock in Wapping, William Daniell, 1803 · Hand-colored aquatint and etching (a print) · Yale Center for British Art, New Haven (this impression); other impressions are at the National Maritime Museum, Greenwich, and elsewhere

William Daniell (1769–1837) was an English painter and printmaker who, as a young man, spent years traveling and drawing in India with his uncle Thomas Daniell. Back in London, he became a master of **aquatint**, a way of etching a copper plate so that a print shows soft tones like a watercolor. Between 1802 and 1808 he made a series of large bird's-eye views of the new London docks.

This view shows the London Dock at Wapping, opened in 1805, as it was planned to look when finished. Daniell climbed high in his imagination, so we look down on the whole system at once: the river, the entrance, the basin, the warehouses and the wall. It is part picture and part map.

Look closely

- Find the River Thames. Where is the entrance from the river into the dock?
- Find the wall around the dock. Why would merchants pay to build it?
- Look at the long warehouses beside the water. How would cargo get from a ship into them?
- Compare the crowded river outside with the ships inside the basin.

Talk about it

1. How is this print like a map? How is it different?
2. What problems of the old Port of London does this dock solve?
3. Why might the dock company have wanted a handsome picture of the dock before it was even finished?

PROJECT: TIDE AND DOCK MODEL

You will build a tidal river and an enclosed dock side by side, make a “tide” rise and fall, and show why a ship in the river runs aground at low water while a ship behind closed dock gates stays afloat.

You will need

- A large, clear plastic storage bin (the river)
- A smaller plastic container, such as a deep food tub, that fits inside the bin (the dock)
- Scissors or a craft knife (adult help), modeling clay and a piece of stiff plastic cut from a lid (the gate)
- Two small toy boats or bottle caps weighted with a little clay
- A pitcher and a cup for bailing, a ruler, tape and a marker

Steps

1. With an adult, cut a slot about 3 cm (1¼ in) wide down one side of the small container, from the rim almost to the bottom. This is the dock entrance.
2. Make a gate from the stiff plastic, a little wider than the slot. Press a rope of clay around the slot on the inside so the gate can be pressed against it to seal it, and lifted away to open it.
3. Set the dock inside the big bin. Weigh it down with a stone so it does not float.
4. With the gate open, pour water into the bin until it is near the top of the dock: this is high tide. Mark the level on a strip of tape on the bin and label it HW.

5. Float one boat into the dock through the entrance, and leave one in the river. Close and seal the gate.
6. Bail water out of the river (not the dock) with the cup until the river is very shallow: this is low tide. Mark and label LW. Measure the tidal range in centimeters.
7. Watch the two boats. The one in the river should be sitting on the bottom; the one in the dock should still float. Write down what happened and explain why.

Tips

- A little leaking at the gate is fine; real dock gates leaked too, and engineers pumped water back in.
- Make the boats heavy enough to need some depth, so the one in the river clearly grounds at low tide.

Check your work

- I marked high water and low water and measured my model's tidal range.
- I can show what happens to a ship in a tidal river at low water.
- I can explain why London built enclosed wet docks with gates.

MAP NOTEBOOK

1. Draw the tidal Thames from Teddington to the sea. Mark London Bridge, the Isle of Dogs, Greenwich, Tilbury, Southend and Sheerness, and write "tidal for about 150 km (95 mi)" along the river.
2. Draw and label a wet dock in cross-section at low tide: river, mud, gates, dock basin, ship afloat, quay and warehouse.
3. Make a table of London's docks with the year each opened and one cargo it handled.

From history. In 1798, with support from West India merchants, Patrick Colquhoun and John Harriott founded the Marine Police at Wapping to guard ships and cargoes on the Thames. It is often called the first organized preventive police force in Britain, older than London's Metropolitan Police (1829). Its successor, the Marine Policing Unit, still works from Wapping beside the river.

WORKED EXAMPLES

Example 1. High water at London Bridge is at 6:15 a.m. Tides on the Thames come about every 12 hours 25 minutes. When is the next high water? About when is low water in between?

1. Next high water: 6:15 a.m. + 12 h 25 min = 6:40 p.m.
2. Low water comes about halfway between: 12 h 25 min $\div$ 2 $\approx$ 6 h 12 min.
3. 6:15 a.m. + 6 h 12 min $\approx$ 12:27 p.m.

Answer: Next high water about 6:40 p.m.; low water about 12:30 p.m. (Real tide tables shift a little from these simple numbers, so sailors always checked them.)

Example 2. At a mooring in the river, the water is 1.5 m deep at low tide, and the tidal range is 7.0 m. A ship has a draft of 5.5 m. Can it float at high tide? At low tide? How deep must a dock be kept to float it with at least 1 m of water under the keel?

(Use the map or drawing “Compare the two ships at low tide.” shown earlier in this lesson.)

1. Depth at high tide: 1.5 m + 7.0 m = 8.5 m. Since 8.5 m is more than 5.5 m, the ship floats at high tide.
2. At low tide the depth is only 1.5 m, less than the 5.5 m draft, so the ship settles on the mud.
3. Dock depth needed: 5.5 m + 1.0 m = 6.5 m. If the gates close at high tide, the dock holds 8.5 m, which is plenty.

Answer: It floats at high tide (8.5 m of water) but runs aground at low tide (1.5 m). A dock needs at least 6.5 m (about 21 ft); a dock shut at high water holds 8.5 m (about 28 ft).

Example 3. A tug towing barges travels about 40 km (25 mi) up the river from Tilbury to the Pool of London. In still water it makes 8 km/h (5 mph). How long does the trip take in still water? How long if it rides the flood tide, which adds 3 km/h (about 2 mph)?

(Use the map or drawing “Find Tilbury and London on the map.” shown earlier in this lesson.)

1. Still water: 40 km $\div$ 8 km/h = 5 h.
2. With the flood tide: 8 + 3 = 11 km/h; 40 $\div$ 11 $\approx$ 3.6 h, about 3 h 40 min.
3. In miles: 25 $\div$ 5 = 5 h, and 25 $\div$ 7 $\approx$ 3.6 h. The answers agree.

Answer: 5 hours in still water; about 3 hours 40 minutes riding the tide. That is why river traffic timed its trips by the tide table.

PRACTICE

1. **EASY** What is the tidal range, and about how large is it at London Bridge at the biggest tides?
2. **EASY** What was the first of the great enclosed docks of the 1800s in London, and in what year did it open?
3. **EASY** Name two problems in the crowded Pool of London that the enclosed docks were meant to solve.
4. **MEDIUM** High water at a wharf is at 2:50 p.m. Using 12 hours 25 minutes between high waters, when are the next two high waters?
5. **MEDIUM** The Thames is tidal for about 150 km. Convert this to miles (1 km $\approx$ 0.62 mi).
6. **MEDIUM** A ship drawing 6.0 m wants to enter a dock from the river. The river is 2.0 m deep at low water, and the tidal range today is 6.5 m. What is the depth at high water? How much water is under the keel at high water?
7. **MEDIUM** Match each dock with its main trade: West India Docks, East India Docks, Surrey Commercial Docks. Trades: tea and spices; timber and grain; sugar and rum.
8. **HARD** Name two pieces of engineering that let people cross the Thames without blocking its ships, with their dates.
9. **HARD** Why did the busy docks move downstream, first to Tilbury and later to London Gateway?
10. **CHALLENGE** In a short paragraph, explain how the Thames tide was both a help and a problem for London, and how engineers turned the problem into an advantage.

COMMON MISTAKES

- Thinking a tide happens once a day. Most places, including the Thames, have two high tides and two low tides in about 24 hours and 50 minutes.
- Confusing the depth at low water with the depth at high water. Add the tidal range to the low-water depth to get the high-water depth.
- Thinking the docks were dug to make the river deeper. They were basins beside the river, closed by gates, built to hold water at a steady level and keep cargo safe.

Make it a game • Beat the Tide. Make a deck of cards, each showing a ship's draft (4 m to 8 m), and a tide table for one day: high water 7.0 m deep at 6:00 a.m. and 6:25 p.m., low water 1.0 m deep at about 12:10 p.m. Players draw a ship and a time (roll two dice for the hour, 2 to 12, morning or afternoon by a coin toss). Estimate the depth at that time, then decide: enter the dock now, or wait. A safe entry (at least 1 m under the keel) scores 2 points; a grounding loses 3. Explain each choice aloud.

Scripture. "They that go down to the sea in ships, that do business in great waters; These see the works of the LORD, and his wonders in the deep." (Psalm 107:23-24, KJV)

The sailors and dockers of London did "business in great waters" every day, timing their work by tides that God set in motion with the moon and sun. Studying the tides is one way of

seeing “the works of the LORD”: they are regular enough that a sailor can plan by them a year ahead.

Practice answers

1. The difference in height between high water and low water. At London Bridge it is about 7 m (23 ft) at the biggest (spring) tides.
2. The West India Docks, on the Isle of Dogs, opened in 1802.
3. Any two: long waits for ships to unload; ships settling on the mud at low tide; cargo damaged in open lighters and on wharves; widespread theft from ships, barges and wharves.
4. 3:15 a.m. the next morning, then 3:40 p.m.
5. $150 \times 0.62 = 93$ mi, about 95 mi.
6. High water depth: $2.0 + 6.5 = 8.5$ m. Under the keel: $8.5 - 6.0 = 2.5$ m.
7. West India Docks: sugar and rum. East India Docks: tea and spices. Surrey Commercial Docks: timber and grain.
8. The Thames Tunnel by Marc and Isambard Kingdom Brunel (1843), and Tower Bridge, whose bascules lift to let ships pass (1894).
9. Ships kept getting bigger and needed deeper water and more room to turn and unload than the old upriver docks could give. Container ships in the 1960s and after needed large, open quays with cranes and space for stacks of boxes, so the work moved downstream to deep water near the estuary, and the old docks closed between 1967 and 1981.
10. The tide was a help because it carried seagoing ships far inland on the flood tide and back out on the ebb, giving them a free push and making London a seaport though it lies about 70 km (45 mi) up the river from the open estuary. It was a problem because at low water ships settled on the mud and could be damaged, and cargo had to be handled in a crowded, falling river. Engineers built enclosed wet docks with gates that held water at the high level, so ships stayed afloat and unloaded safely into guarded warehouses; London kept the benefits of the tide without its dangers.

3.4 NEW YORK: A DEEP HARBOR AND THE ERIE CANAL

OBJECTIVES

- Describe New York's natural harbor (a deep, drowned river mouth, sheltered by islands and entered through the Narrows) and compare it with the harbors of Venice, Amsterdam and London.
- Explain how the Erie Canal (1817–1825) used the Mohawk Valley gap in the Appalachians to connect New York to the Great Lakes, and why that made it America's great port.
- Compute lock lifts, freight savings and travel times on the canal, and read the canal route on a map.

Warm-up. Stand a row of books upright on a table as a “mountain range” from one end to the other, leaving one narrow gap in the middle. Roll a marble from one side to the other: where must it go? Now imagine that the marble is a barge full of wheat, the books are the Appalachian Mountains, and the far side is Ohio. Whoever owns the gap owns the trade. In this lesson you will find that gap on a real map.

Watch. *Erie Canal History (1825) | The Waterway That Built America | DAILY BELLRINGER* (The Daily Bellringer, 5:29). https://www.youtube.com/watch?v=KDBY6sXt3_4

After the story: the Erie Canal and the Wedding of the Waters that made New York the great port.

Backup video. *Manhattan: What Henry Hudson Saw in 1609 | National Geographic* (National Geographic, 1:38). <https://www.youtube.com/watch?v=aRVSPT7A8yM>

With On the map: what Manhattan's harbor looked like when Henry Hudson arrived in 1609.

KEY TERMS

natural harbor

A stretch of deep water sheltered from wind and waves by the land itself, where ships can anchor and tie up safely.

drowned river valley

A river valley flooded by the sea, leaving a deep inlet. The lower Hudson and New York Harbor are of this kind.

hinterland

The land behind a port that sends goods to it and buys goods from it.

lock

A chamber with gates at each end in which the water level is raised or lowered to lift or lower boats from one level of a canal or river to another.

water gap

A low pass through a mountain range cut by a river. The Mohawk Valley is the only water-level route through the Appalachian highlands.

packet ship

A ship that sails on a fixed schedule between two ports, whether or not it is full.

CORE IDEAS

The story. On 26 October 1825 a canal boat named the *Seneca Chief* left Buffalo, on Lake Erie, carrying Governor DeWitt Clinton and two kegs of lake water. As it set out, a cannon fired, and then another down the line, and another, until the boom had been passed from cannon to cannon all the way across New York State and down the Hudson to New York City, carrying the news in well under two hours. The boat itself took nine days to make the trip. On 4 November, out in the Atlantic off Sandy Hook, surrounded by a fleet of steamboats and sailing ships, Clinton poured the water of Lake Erie into the sea. People called it the “Wedding of the Waters.” The **Erie Canal** was finished, and New York City’s future was settled.

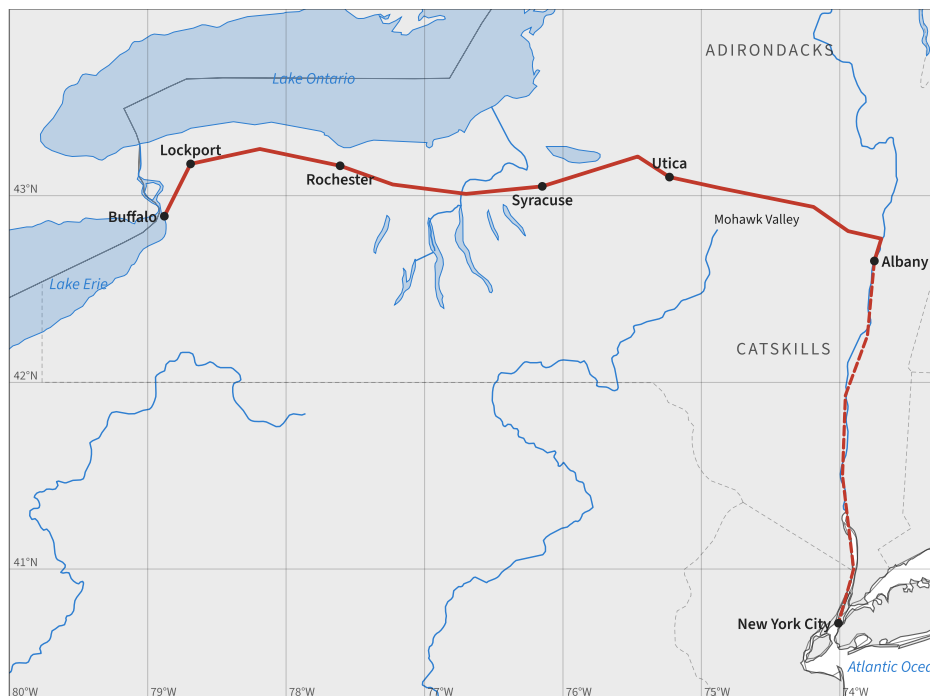
How it worked. New York already had one of the finest **natural harbors** in the world. The lower Hudson is a **drowned river valley**, deep enough for the largest ships of the age, and the sea’s tide reaches up it about 240 km (150 miles), to Troy. The Upper Bay is ringed by Manhattan, Brooklyn, Staten Island and New Jersey, which break the ocean’s waves, and ships enter it through the Narrows, a channel only about 1.6 km (1 mile) wide, from the Lower Bay and the Atlantic. Because the water is salt and the tides keep it moving, the harbor seldom froze, while the St. Lawrence at Montreal was shut by ice for months every winter. And the many miles of shoreline on Manhattan, Brooklyn and New Jersey left room for hundreds of piers. Giovanni da Verrazzano sailed into the harbor in 1524, and Henry Hudson explored the river for the Dutch in 1609.

The big idea. A great harbor is not enough; a port also needs a **hinterland**. In 1800 Philadelphia, counted with its suburbs, was about as large as New York, and Boston and Baltimore were strong rivals. Every Atlantic port was cut off from the rich new farmland of Ohio and the Great Lakes by the long wall of the Appalachian highlands. Farmers out west floated their crops down the Ohio and the Mississippi to New Orleans instead. But north of the Catskills, the Mohawk River runs east to the Hudson through a low **water gap**, the only water-level route through the mountains. Clinton’s plan was to dig a canal through that gap from Albany to Buffalo. Critics mocked it as “Clinton’s Ditch.” Built from 1817 to 1825, it was 584 km (363 miles) long, 12 m (40 ft) wide and 1.2 m (4 ft) deep, with 83 **locks** to lift boats about 173 m (568 ft) from the Hudson to Lake Erie. Mules and horses on a towpath pulled the boats. The cost of moving a ton of goods from Buffalo to New York City fell from about \$100 to about \$10, and the canal’s tolls repaid its cost of about \$7 million within roughly ten years.

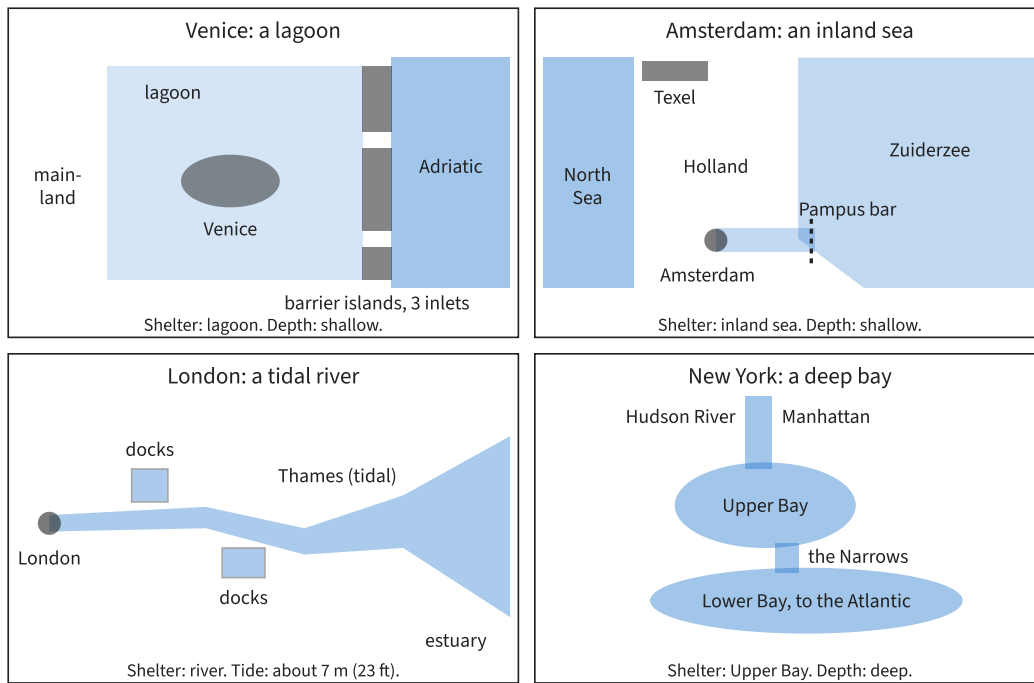
Technology overcoming geography. America had almost no trained canal engineers in 1817, so the canal trained its own. Its chief engineers, such as Benjamin Wright and James Geddes, were land surveyors who had never built a canal, and they learned by doing.

Canvass White found a local limestone that made a cement that hardens under water, perfect for the locks. At Lockport the builders cut through the rock of the Niagara Escarpment and climbed it with a double flight of five locks, one set for boats going up and one for boats coming down. Much of the digging was done by local farmers and by Irish immigrants, working with picks, shovels, horses and clever stump-pulling machines. The canal passed through lands that had belonged to the Haudenosaunee (the Iroquois), most of which had been taken from them by treaties and sales in the years after the Revolution.

On the map. Follow the canal on the map from Buffalo east through Rochester, Syracuse and Utica, down the Mohawk Valley to Albany, and then down the Hudson to New York. Wheat, flour, lumber and potash poured east; settlers, tools and manufactured goods went west, and towns along the route boomed. New York City grew from about 124,000 people in 1820 to more than 800,000 in Manhattan alone by 1860. From 1818 the Black Ball Line ran the first **packet ships** on a fixed schedule between New York and Liverpool, so New York was the place to ship from. Later came the railroads, Ellis Island (1892-1954), where about 12 million immigrants entered the country, and, as you will see in Unit 4, the container ports across the bay in New Jersey. Now compare the four harbors of this unit (see the diagram): the shallow lagoon, the shallow inland sea, the tidal river and the deep, sheltered bay.



The Erie Canal (1825) and the Hudson River: a water road from the Great Lakes to the Atlantic through the Mohawk Valley gap.



Four harbors compared (simplified, not to scale). What gives each one shelter? Which is deepest?

PICTURE STUDY



New York Harbor, Fitz Henry Lane, 1852 · Oil on canvas · National Gallery of Art, Washington, D.C.

Fitz Henry Lane (1804–1865) grew up in the fishing port of Gloucester, Massachusetts. Unable to walk without crutches from childhood, he became one of America's finest painters of ships and harbors. Lane knew ships well enough to paint their rigging rope by rope, and he loved the calm, golden light of early morning and evening on the water.

He painted this view in 1852, when the Erie Canal had been open for a generation and New York had become the busiest port in America. Merchant ships, coasters and harbor craft fill the bay that Verrazzano entered in 1524 and that Clinton's canal boats reached in 1825.

Look closely

- Count the different kinds of vessels you can find. Which are big ocean ships and which are small harbor boats?
- Look at the water. Is it rough or calm? What does that tell you about the shelter of the harbor?
- Find the city in the distance. How large does it look compared with the sky and the sea?
- Are any of the boats powered by steam? How could you tell?

Talk about it

1. What goods might these ships be carrying, and where might some of them have come from by way of the Erie Canal?
2. Compare this painting with Canaletto's Venice and Berckheyde's Amsterdam. What does each painter want you to feel about his city?
3. Why do you think Lane chose such a peaceful moment to paint a busy port?

PROJECT: A HARBOR MODEL: DEEP WATER, SHELTER AND DOCKS

You will build a model harbor that has the three things every great port needs: deep water for big ships, shelter from waves, and docks where ships can load and unload. You will add a canal or river leading inland to a hinterland, and test your harbor with waves. This model becomes the center of your unit portfolio.

You will need

- A large shallow tray or under-bed storage box (at least 40 by 60 cm, 16 by 24 in)
- Modeling clay, salt dough or wet sand packed firm (for land and islands)
- Water, a ruler and a waterproof marker
- Craft sticks or strips of cardboard covered in tape (piers and docks)
- Small toy boats or bottle caps; some weighted with clay to make "deep-draft" ships
- A flat piece of cardboard or a ruler to make waves
- Labels on toothpick flags

Steps

1. Decide which harbor type you will model: a deep bay like New York's, or another of the four harbors in this unit. Sketch a plan first, with a scale (for example, 1 cm = 1 km).
2. Shape the land in the tray: a coastline with an opening to the "open sea" at one end, and islands or headlands that wrap around a bay, leaving a narrow entrance like the Narrows.

3. Carve a deep channel from the entrance into the bay, and leave some shallow shoals elsewhere. Add a river or canal leading inland from the back of the bay to a “hinterland” town.
4. Pour water in slowly. Measure the depth at five points (channel, bay, shoal, entrance, open sea) and record them on your plan.
5. Build docks or piers along the sheltered shore with craft sticks. Test whether a deep-draft boat can reach them along the channel without touching bottom.
6. Make waves at the open-sea end by pushing the cardboard back and forth. Watch the water inside the bay. Is it calmer? Adjust your headlands until it is.
7. Label the parts with toothpick flags: deep channel, shelter, entrance, docks, shoals, river or canal, hinterland. Photograph your model and write a paragraph telling what makes it a good harbor.

Tips

- A narrow entrance gives shelter, but too narrow an entrance makes it hard for ships to get in. Real harbors balance the two.
- Clay holds its shape under water better than sand. If you use sand, pack it wet and pour the water in very slowly along the side.

Check your work

- My model shows deep water, shelter and docks, and I measured and recorded depths.
- I tested my harbor with waves and improved the shelter.
- I can explain which real harbor my model is most like and why.

MAP NOTEBOOK

1. Trace the Erie Canal route on an outline map of New York State. Label Buffalo, Lockport, Rochester, Syracuse, Utica, the Mohawk River, Albany, the Hudson River and New York City.
2. Draw New York Harbor: the Hudson, Manhattan, the Upper Bay, the Narrows, the Lower Bay and Sandy Hook. Mark where Clinton poured the Lake Erie water.
3. Make a comparison table of the four harbors of this unit, with columns for shelter, depth, tides, link to the hinterland and the main problem engineers had to solve.

From history. In January 1818 the ship *James Monroe* of the new Black Ball Line sailed from New York for Liverpool on the advertised day, even though the weather was poor and the ship was not full. Before this, merchant ships waited until they had a full cargo and a fair wind, so no one knew when a letter or a load would leave. Regular departures on a fixed schedule made merchants trust New York, and other lines soon copied the idea.

WORKED EXAMPLES

Example 1. The original Erie Canal rose about 568 ft (173 m) from the Hudson to Lake Erie and had 83 locks. If the rise were shared equally, how much would each lock lift a boat?

1. Divide the total rise by the number of locks: $568 \text{ ft} \div 83 \approx 6.8 \text{ ft}$.
2. In meters: $173 \text{ m} \div 83 \approx 2.1 \text{ m}$.
3. Check: $83 \times 6.8 \text{ ft} \approx 564 \text{ ft}$, close to 568 ft, so the answer is reasonable.

Answer: About 6.8 ft (2.1 m) per lock. Real locks varied; the canal also went down in some places and back up, but the average gives a good picture.

Example 2. Before the canal, carrying a ton of goods from Buffalo to New York City cost about \$100; after it opened, about \$10. How much would a miller save on 30 tons of flour? By what percent did the cost fall?

1. Old cost: $30 \times \$100 = \$3,000$.
2. New cost: $30 \times \$10 = \$300$.
3. Savings: $\$3,000 - \$300 = \$2,700$.
4. Percent drop: \$90 saved on each \$100, so $90 \div 100 = 90\%$.

Answer: He saves \$2,700, a 90% drop in the cost of shipping.

Example 3. A freight boat pulled by mules averages 2 mph (3.2 km/h) along the 363-mile (584 km) canal and travels 15 hours a day. About how many days does it take from Buffalo to Albany? Then a steamboat carries the cargo 150 miles (240 km) down the Hudson at 10 mph (16 km/h). How long is that leg?

(Use the map or drawing “Trace both legs of the trip: Buffalo to Albany by canal, Albany to New York by r” shown earlier in this lesson.)

1. Canal hours: $363 \text{ mi} \div 2 \text{ mph} = 181.5 \text{ hours}$. (In km: $584 \div 3.2 \approx 182.5 \text{ hours}$, the same allowing for rounding.)
2. Canal days: $181.5 \div 15 \approx 12.1$, so about 12 days.
3. Hudson leg: $150 \text{ mi} \div 10 \text{ mph} = 15 \text{ hours}$ ($240 \text{ km} \div 16 \text{ km/h} = 15 \text{ h}$).

Answer: About 12 days on the canal and 15 hours down the Hudson, roughly 13 days in all, with no mountains to climb.

PRACTICE

1. **EASY** What did DeWitt Clinton do on 4 November 1825, and what did it celebrate?

2. **EASY** Name the three things every good harbor needs.
3. **EASY** Which two bodies of water did the Erie Canal connect, and through which river valley did it cross the Appalachian highlands?
4. **MEDIUM** Convert the Erie Canal's size to metric: 363 miles long, 40 ft wide, 4 ft deep. (1 mi $\approx$ 1.61 km; 1 ft $\approx$ 0.305 m.)
5. **MEDIUM** Using the map, which direction does a boat travel from Buffalo to Albany? From Albany to New York City?
(Use the map or drawing "Use the map's grid lines to judge direction." shown earlier in this lesson.)
6. **MEDIUM** At Lockport, the canal climbs the Niagara Escarpment with a flight of five locks. If the five locks together lift a boat about 60 ft (18 m), what is the average lift per lock?
7. **MEDIUM** New York City (Manhattan) had about 124,000 people in 1820 and about 814,000 in 1860. By how many people did it grow? About how many times larger was it?
8. **HARD** Use the four-harbors diagram. For each of Venice, Amsterdam, London and New York, name what gives the harbor shelter, and say whether it is deep or shallow.
(Use the map or drawing "Compare shelter and depth in the four harbors." shown earlier in this lesson.)
9. **HARD** In 1800 Philadelphia, counted with its suburbs, was about as large as New York. Give two geographic reasons, and one human reason, why New York pulled far ahead after 1825.
10. **CHALLENGE** Write a paragraph comparing how each of this unit's four cities overcame a problem in its geography with technology.

COMMON MISTAKES

- Thinking a good harbor alone made New York great. Without the Erie Canal's link to the Great Lakes hinterland, it might have stayed one rival port among several.
- Thinking the Erie Canal ran across the whole Appalachian chain from north to south. It crossed the highlands at one place, through the low Mohawk Valley gap.
- Confusing the Erie Canal with the Hudson River. The canal ran from Buffalo to Albany (and Troy); from there boats used the Hudson, a natural river, to reach New York City.

Make it a game • Race to the Sea. Two players each ship 10 tons of wheat from Ohio to the Atlantic. One takes the old route by flatboat down the Ohio and Mississippi to New Orleans and then by ship; the other takes the Erie Canal route through Buffalo and Albany to New York. Before the game, mark both routes on a map and divide each into stages of about 300 km (about 200 mi). Roll a die each turn to move one or two stages; on the river route a 1 means a snag or a fever stop and a lost turn; on the canal route each lock stage costs a toll of 1 point but no lost turns. Count turns and costs. Then discuss which route farmers would choose after 1825 and why.

Scripture. "Then are they glad because they be quiet; so he bringeth them unto their desired haven." (Psalm 107:30, KJV)

A “haven” is a harbor, a place of shelter after a storm. The psalm pictures sailors who have cried to God in a tempest and are brought safely in. God shaped the coasts and bays of the earth; the deep, quiet water inside the Narrows has been a desired haven for millions of sailors and immigrants.

Practice answers

1. He poured a keg of water from Lake Erie into the Atlantic off Sandy Hook, the “Wedding of the Waters,” celebrating the opening of the Erie Canal.
2. Deep water for ships, shelter from wind and waves, and docks or piers where ships can load and unload. (A good port also needs a route to a hinterland.)
3. Lake Erie (at Buffalo) and the Hudson River (at Albany), and through it the Atlantic. It crossed through the Mohawk Valley.
4. $363 \times 1.61 \approx 584$ km long; $40 \times 0.305 \approx 12.2$ m wide; $4 \times 0.305 \approx 1.2$ m deep.
5. Buffalo to Albany: east. Albany to New York City: south, down the Hudson.
6. $60 \div 5 = 12$ ft per lock ($18 \div 5 = 3.6$ m).
7. $814,000 - 124,000 = 690,000$ more people. $814,000 \div 124,000 \approx 6.6$, so about $6\frac{1}{2}$ times larger.
8. Venice: barrier islands and the lagoon; shallow. Amsterdam: the inland Zuiderzee and the IJ; shallow, with the Pampus bar. London: a long tidal river far from the open sea, plus enclosed docks; deep enough at high tide, but with a big tidal range. New York: the islands and shores around the Upper Bay, entered by the narrow Narrows; deep.
9. Geographic: New York’s deep, sheltered, seldom-frozen harbor near the open sea; and the Hudson–Mohawk route, the only water-level gap through the Appalachians, which the Erie Canal used to reach the Great Lakes. Philadelphia lies about 160 km (100 mi) up the Delaware and had no such route west. Human: the State of New York’s decision to build the canal (Clinton’s leadership), or the scheduled packet lines such as the Black Ball Line from 1818.
10. A strong answer names one problem and one solution for each: Venice built on mud with wooden piles and today guards its inlets with the MOSE gates; Amsterdam drained its land with dikes and windmills and lifted ships over the Pampus bar with ship camels, later cutting the North Sea Canal; London beat the great tidal range of the Thames with enclosed wet docks and crossed the river with a tunnel and a lifting bridge; New York broke through the Appalachian barrier with the Erie Canal and its 83 locks.

UNIT 3 REVIEW

Answer each question. Show your work for calculations, give both metric and U.S. units where asked, and use complete sentences for explanations. The review is worth 60 points.

1. (6 pts) Describe the site of Venice in two or three sentences, using the words lagoon, barrier island and inlet. Why did the site keep the city safe?
2. (6 pts) A galley convoy sails 2,300 km (1,400 mi) from Venice to Alexandria at 90 km (56 mi) a day. About how many days does it take? On a 1:50,000 map, how long is the 3.8 km Grand Canal?
3. (6 pts) Venice built its buildings on wooden piles. Explain how this worked and why the piles did not quickly rot.
4. (6 pts) Amsterdam lies at about 52.4°N and Batavia (Jakarta) at about 6.2°S. How many degrees of latitude apart are they, and about how far is that in km and miles?
5. (6 pts) What was the VOC, and how did selling shares on the Amsterdam exchange help merchants send ships to Asia?
6. (6 pts) A loaded ship draws 4.8 m. The water over the Pampus bar is 3.2 m deep. How much must ship camels lift the ship to clear the bar with 0.5 m to spare?
7. (6 pts) High water at London Bridge is at 9:20 a.m., and tides come every 12 hours 25 minutes. When is the next high water? If the water at a mooring is 2.0 m deep at low tide and the tidal range is 7.0 m, can a ship drawing 6.5 m float there at high tide? At low tide?
8. (6 pts) Why did London build enclosed wet docks such as the West India Docks (1802)? Give two reasons.
9. (6 pts) The Erie Canal was 363 mi (584 km) long and rose about 568 ft (173 m) through 83 locks. What was the average lift per lock? Before the canal it cost about \$100 to move a ton from Buffalo to New York, and afterward about \$10. How much was saved on 20 tons?
10. (6 pts) Compare the four harbors of this unit. For each of Venice, Amsterdam, London and New York, name what gave it shelter and the main problem of its geography, then explain in two sentences why New York became America's greatest port.

UNIT PROJECT: FOUR HARBORS: A MODEL AND A MAP

Finish and display your harbor model from Lesson 3.4, showing deep water, shelter, docks and a route inland. Beside it, make a large comparison sheet with four simple maps you have drawn of the harbors of Venice, Amsterdam, London and New York, each with a compass rose, a scale bar and labels for the city, the harbor entrance, the source of shelter and the docks or quays. Add a table comparing shelter, depth, tides, hinterland and the engineering each city used against its geography (piles and MOSE gates, dikes and ship camels, wet docks and the Thames Barrier, the Erie Canal). Finish with a paragraph answering: Which harbor had the best gifts of nature, and which city did the most with the least?

- **Accuracy:** The four maps place cities, harbors, entrances and waterways correctly, with correct compass directions and labels.
- **Model:** The harbor model clearly shows deep water, shelter, docks and a link to the hinterland, with measured depths recorded and a successful wave test.
- **Reasoning:** The comparison table and paragraph use site, situation, harbor and hinterland correctly and name a real problem and a real technological answer for each city.
- **Care:** The display is neat, colorful and easy to read, with a title, scale bars and a short caption for each map.

Answer key

1. Venice stands on islands and mud banks in a shallow lagoon, cut off from the Adriatic by long, narrow barrier islands such as the Lido and connected to the sea by three inlets (Lido, Malamocco, Chioggia). The shallow water and hidden shoals stopped armies and large warships, and only local pilots knew the safe channels.
2. $2,300 \div 90 \approx 26$ days ($1,400 \div 56 = 25$). $380,000 \text{ cm} \div 50,000 = 7.6 \text{ cm}$.
3. Builders drove wooden piles down through the soft mud into a firmer layer of clay, laid planks across their tops and set a stone base on the planks. The piles stay buried in wet mud, cut off from the air, so the wood decays very slowly.
4. $52.4 + 6.2 = 58.6^\circ$. $58.6 \times 111 \approx 6,500 \text{ km}$; $58.6 \times 69 \approx 4,000 \text{ mi}$.
5. The VOC was the Dutch United East India Company, chartered in 1602. Many people bought shares, so the cost and risk of each fleet were divided among them, and the profits were shared. Because shares could be sold on the exchange (opened in its own building in 1611), owners did not have to wait years to get their money back.
6. New draft must be $3.2 - 0.5 = 2.7 \text{ m}$. Lift needed: $4.8 - 2.7 = 2.1 \text{ m}$.
7. Next high water: 9:20 a.m. + 12 h 25 min = 9:45 p.m. At high tide the depth is $2.0 + 7.0 = 9.0 \text{ m}$, so the ship floats (2.5 m to spare). At low tide the depth is 2.0 m, so it sits on the mud.
8. Any two: gates held the water at the high level so ships stayed afloat whatever the tide; ships no longer waited for weeks in the crowded Pool of London; cargo was unloaded straight into guarded warehouses behind high walls, stopping theft; goods were kept safe until import duties were paid.
9. $568 \div 83 \approx 6.8 \text{ ft}$ ($173 \div 83 \approx 2.1 \text{ m}$) per lock. Savings: $20 \times (\$100 - \$10) = \$1,800$.
10. Venice: sheltered by barrier islands and the lagoon; problem: soft mud, shallow water, no farmland or fresh water. Amsterdam: sheltered by the inland Zuiderzee and the IJ; problem: shallow water and the Pampus bar, low land below sea level. London: sheltered far up a tidal river; problem: a tidal range of about 7 m. New York: sheltered by the islands around the Upper Bay and the narrow Narrows; problem: the Appalachian barrier between the coast and the interior. New York had a deep, sheltered, seldom-frozen harbor near the open sea, and the Erie Canal used the Mohawk Valley gap to link it to the Great Lakes, giving it a huge hinterland no rival could match.

MODERN PORTS AND THE CONTAINER

In Unit 3 you walked the wharves of Venice, Amsterdam, London and New York, where cargo moved on men's backs and in ships' slings. In this unit you will see what became of the great port in the age of steel, steam and the box. You will follow the Rhine down to **Rotterdam**, the gateway to Europe, which the Dutch built out of mud and sand and rebuilt after war. You will sail east to **Singapore** and **Hong Kong**, two small islands at the crossroads of Asia that became two of the busiest trading places on earth. Then you will meet **Malcom McLean**, a North Carolina truck driver whose ship *Ideal X* sailed from Port Newark in 1956 with 58 boxes on its deck and changed the trade of the whole world.

Last, you will spend a day at a container terminal, among the cranes, stacks and trucks, and become a ship planner yourself with a loading puzzle of blocks and weights. All through the unit you will ask the questions of this course: why did the port grow here, what land and sea does it serve, and how did people use **technology to overcome geography**? You will also learn to measure ports in tonnes and TEU, to work with nautical miles and knots, and to read the map of the world's twenty busiest container ports.

Scripture tells us that God "hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation" (Acts 17:26). The sea roads that join those nations, and the harbors set along them, are part of that providential ordering. A container that leaves a factory in Asia and arrives at a store near you passes through the hands of hundreds of people you will never meet. Trade, done honestly, is one way the nations serve one another.

BEFORE YOU BEGIN

- Can explain site and situation and describe a good natural harbor (Units 1 and 3)
- Can read latitude and longitude and use a map scale
- Can compute time, speed and distance and work with percents and ratios
- Can convert between kilometers and miles

MASTERY CHECKLIST

- I can explain why Rotterdam is Europe's gateway port, using the words site, situation and hinterland, and trace the Rhine from the Alps to the North Sea.
- I can tell how Singapore and Hong Kong became British ports and great Asian hubs, and explain the difference between a gateway port and a transshipment hub.
- I can tell the story of Malcom McLean and the *Ideal X* and explain how the standard container and intermodal shipping cut the cost of trade.
- I can describe a day at a container terminal and write a stowage plan that keeps a ship balanced and avoids restows.
- I can compute with tonnes, TEU, nautical miles and knots, crane rates and balancing weights.

- I can locate the world's twenty busiest container ports and explain why most of them are in East and Southeast Asia.

OPTIONAL BOOKS AND RESOURCES

- **Port of Rotterdam (official website)** (<https://www.portofrotterdam.com/en>): Free. Maps, aerial photographs, facts and figures about Europe's largest port, useful for Lessons 4.1 and 4.4. A parent may want to choose the pages, since some are written for businesses.
- **World Shipping Council: Top 50 World Container Ports** (<https://www.worldshipping.org/top-50-ports>): Free. A yearly table of the world's busiest container ports by TEU. Use it to check and update the twenty-ports map, since the lower ranks change from year to year.
- **MarineTraffic live ship map** (<https://www.marinetraffic.com/>): Free basic map with advertising; a parent should preview it. Zoom in on Rotterdam, Singapore or Hong Kong to watch real container ships, tankers and barges moving in and out of port, and click a ship to see its name, size and destination.

4.1 ROTTERDAM: EUROPE'S GATEWAY ON THE RHINE ★

OBJECTIVES

- Tell how Pieter Caland's New Waterway (dug 1863–1872) opened Rotterdam to the sea, and how the city rebuilt after 1940 to become the busiest port in the world.
- Explain site, situation and hinterland, and why a gateway port at the mouth of a great river can serve a whole continent.
- Read a map of the Rhine from the Alps to the North Sea and compute distances, barge travel times and cargo loads.

Warm-up. Pour a cup of dry rice from a wide bowl into a narrow jar, first straight from the bowl and then through a kitchen funnel (or a cone of rolled paper). Which way is faster and spills less? Now picture the funnel lying on its side: the wide end faces the ocean and the narrow spout points into Europe. What would pour in at the wide end, and what would carry it out through the spout?

Watch. *How Do 80,000 "Lipsticks" Help The Largest Port In Europe Run On Automation?* / Richard Hammond's Big (Discovery UK, 5:28). <https://www.youtube.com/watch?v=NULoelb7PzA>

After the story: inside Rotterdam's automated container terminal.

Backup video. *The Rhine River explained in under 3 Minutes* (FactSpark, 2:59). <https://www.youtube.com/watch?v=IpFTi7-T-TI>

With On the map: the Rhine from the Alps to the North Sea in about three minutes.

KEY TERMS

gateway port

A port that serves as the main entrance for goods going into and out of a large inland region.

hinterland

The land behind a port that it serves: the farms, factories, cities and customers that send and receive its cargo.

delta

The flat land at a river's mouth, built of mud and sand the river drops, where the river often splits into several branches.

inland waterway

A river or canal deep enough for barges and boats to carry cargo far from the sea.

dredging

Digging mud and sand from the bottom of a harbor or channel to make it deeper for ships.

tonne

A metric ton: 1,000 kilograms, or about 2,205 pounds (about 1.1 U.S. tons). Ports measure bulk cargo in tonnes.

CORE IDEAS

The story. In the 1860s, Rotterdam had a problem it could not see from its own quays. The city stood on the Nieuwe Maas, one of the branches of the great Rhine and Maas (Meuse) rivers, about 30 km (19 miles) from the North Sea. But the old river mouths downstream were silting up with sand and mud, and the new, larger steamships could not get in. Ships had to wind through shallow channels and canals among the islands of the delta, and many simply went to other ports. An engineer of the Dutch waterways department, **Pieter Caland**, proposed a bold answer: cut a brand-new, straight river mouth right through the coastal dunes near the village of Hook of Holland. Work began in 1863, and in 1872 the **Nieuwe Waterweg** (New Waterway) opened. Rotterdam had its own front door to the sea.

How it worked. Caland did not want to dredge the channel by hand forever, so he built long dams of stone and brushwood along both sides of the new cut. Squeezed between them, the river's current and the outgoing tide would run faster and scour the bottom deep. At first the sea pushed in more sand than the river carried out, and dredgers had to help, but the channel was steadily deepened and widened. Ships came. Docks spread along both banks of the river, and by the early 1900s Rotterdam was one of Europe's great ports. Then came disaster. On 14 May 1940, German bombers destroyed the old center of the city, and in 1944 the occupying German army blew up much of the port. The Dutch rebuilt with astonishing energy, and in 1962 Rotterdam passed New York as the busiest port in the world. It held that title for about forty years.

The big idea. Remember **site** (the ground a city stands on) and **situation** (where it lies compared with everything around it) from Unit 1. Rotterdam's site is flat, wet and low; much of the land around it lies below sea level behind dikes. Its situation is superb. It sits where Europe's busiest river meets one of the world's busiest seas. Behind it lies a huge **hinterland**: the Netherlands, Germany's Ruhr valley of mines and steel mills, and the cities along the Rhine as far as Switzerland. Tens of millions of people and many thousands of factories lie within a few days' barge trip. That is why Rotterdam calls itself the **gateway to Europe**. A **gateway port** works like a funnel: ocean ships pour cargo in at the wide end, and barges, trains, trucks and pipelines carry it out through the narrow spouts into the continent.

On the map. The **Rhine** runs about 1,230 km (765 miles) from the Swiss Alps to the North Sea. It flows through Lake Constance, tumbles over the Rhine Falls near Schaffhausen, and turns north at Basel, where Switzerland, France and Germany meet. Large barges can sail up as far as Basel. From there the river runs north past Strasbourg, Mainz, Cologne and Duisburg, where the Ruhr River joins it and where Europe's largest inland port stands. Near the Dutch border the Rhine splits into branches that wind west through the delta it shares with the Maas, and Rotterdam lies on one of them. A large Rhine barge carries about 3,000 tonnes, as much as about 120 trucks, and a push boat shoving several barges lashed

together can move more than 10,000 tonnes at once. Water is the cheapest road on earth, because a floating load needs very little push.

Technology overcoming geography. Rotterdam has kept growing toward the sea. When ships became too big for the city's old docks, the port built new harbors farther downstream: the Botlek in the 1950s, the Europoort from 1958, and the **Maasvlakte**, new land made of sand pumped up from the seabed, from the 1960s on. Maasvlakte 2, opened in 2013, added about 2,000 hectares (about 8 square miles) more. Dredged channels let the largest ships afloat sail straight in from the open sea. Today the port stretches about 40 km (25 miles) from the city to the coast and handles about 440 million tonnes of cargo a year, far more than any other port in Europe. The Dutch had no rocky fjords like Norway and no great natural bay like New York. They made a world port out of mud, sand and a river, with dredgers, dikes and patience.



The Rhine, Europe's river highway, and Rotterdam at its mouth. The New Waterway (1872) gave Rotterdam a straight channel to the North Sea.

PICTURE STUDY



Aerial photograph of the Port of Rotterdam and the Maasvlakte, Photograph by Nitot (Wikimedia Commons), CC BY-SA 3.0, 2007 · Color aerial photograph · Wikimedia Commons

Painters of the Dutch Golden Age, like those you met in Unit 3, painted harbors from the shore or from a ship's deck. In the twentieth century the airplane gave geographers a new way to see a port: from straight above, the way a map sees it. An aerial photograph is a map made of light. Every quay, basin and crane is in its true place.

This photograph shows part of the Port of Rotterdam out toward the sea, where much of the ground is new land pumped up from the seabed. Look slowly, as you would at a painting, and then read it as you would a map.

Look closely

- Find the edge between land and water. Is it curved like a natural coast or straight like something built?
- Find the tall cranes. Where do they stand, and what are they lined up beside?
- Find the patches of small colored rectangles. Those are containers. How are they arranged?
- Look for railway tracks, roads, round storage tanks or barges. How does cargo leave this place for the rest of Europe?

Talk about it

1. What clues in the photograph tell you that much of this land was made by people?
2. Why would a port build its newest harbors near the open sea instead of near the old city?
3. How is an aerial photograph like a map, and how is it different?

PROJECT: THE FOIL BARGE CHALLENGE

Why can one barge on the Rhine do the work of a hundred trucks? You will build a barge from aluminum foil, load it with coins until it nearly sinks, and compare it with a toy “truck.” Then you will change the shape of your barge to see what makes a better cargo boat.

You will need

- Aluminum foil (two sheets about 30 cm or 12 inches square)
- A baking pan or sink filled with 5 cm (2 inches) of water
- 100 or more pennies or other identical coins
- A ruler and a kitchen scale (if you have one)
- A small toy car or matchbox and a pencil and notebook

Steps

1. Fold one sheet of foil into a flat-bottomed barge 10 cm by 15 cm (about 4 by 6 inches) with sides 2 cm (about 3/4 inch) high. Pinch the corners so it does not leak.
2. Float the barge. Add pennies one at a time, spreading them evenly over the bottom, until water is about to pour over the side. Record the number of pennies.
3. Weigh the pennies, or multiply: a U.S. penny made since 1983 weighs 2.5 grams. Write your barge’s cargo in grams.
4. Now load your toy car or matchbox with as many pennies as it can carry without spilling while you push it 1 meter across the table. Record that number. This is your “truck.”
5. Divide: how many “truck loads” did your barge carry? Write it as a sentence: “My barge did the work of ___ trucks.”
6. Build a second barge from the other sheet with a different shape: deeper and narrower, or wider and shallower. Predict which will carry more, then test it.
7. Gently push each loaded barge across the pan with one finger, then push the loaded car across the table. Which takes less force to keep moving? Write two sentences about why rivers make cheap roads.

Tips

- Spread the coins evenly. If they pile up on one side, the barge will tip and sink early. Real barge crews load evenly for the same reason.
- A wider barge with low sides usually carries more coins, because it pushes aside more water before the sides go under. Real Rhine barges are long, wide and fairly shallow so they fit the river’s depth.

Check your work

- I can explain why a floating load is easier to move than a rolling one.
- I can compute how many truck loads my barge carried.
- I can explain how the shape of a barge changes how much it can carry.

MAP NOTEBOOK

1. Draw the Rhine from the Alps to the North Sea. Mark Basel, Strasbourg, Mainz, Cologne, Duisburg and Rotterdam, and draw the New Waterway as a straight line from Rotterdam to Hook of Holland.
2. Draw a funnel lying on its side. Label the wide end “ocean ships” and draw three spouts labeled “barges,” “trains” and “trucks and pipelines.” Write “gateway port” on the funnel.
3. Make a two-column chart titled “Rotterdam: Site and Situation.” List at least two facts about its site and three about its situation.

From history. Rotterdam has an older link to American history. Delfshaven, once the little harbor of the city of Delft and now part of Rotterdam, is where the Pilgrims boarded the ship *Speedwell* in July 1620 to leave the Netherlands, where they had lived for about twelve years. They sailed to Southampton in England to join the *Mayflower*. William Bradford later wrote that as they left the city that had been their home, they knew they were pilgrims, and lifted their eyes to heaven, their dearest country. The old church at Delfshaven where they are said to have prayed before sailing still stands.

WORKED EXAMPLES

Example 1. A large Rhine barge carries 3,000 tonnes of coal. A truck carries 25 tonnes. How many truck loads does one barge replace? If the trucks drove nose to tail, each taking up 20 meters of road, how long would the line be?

1. Trucks needed: $3,000 \div 25 = 120$ trucks.
2. Length of the line: $120 \times 20 \text{ m} = 2,400 \text{ m} = 2.4 \text{ km}$.
3. Convert to miles: $2.4 \div 1.609 = \text{about } 1.5 \text{ miles}$.

Answer: One barge replaces 120 trucks, a line about 2.4 km (1.5 miles) long.

Example 2. On a map with a scale of 1 cm = 20 km, the straight-line distance from Rotterdam to Duisburg measures 8.3 cm. The river route between them is about 220 km. How long is the straight-line distance, and how many times longer is the river route?

(Use the map or drawing “Measure from Rotterdam to Duisburg.” shown earlier in this lesson.)

1. Straight line: $8.3 \text{ cm} \times 20 \text{ km per cm} = 166 \text{ km}$.
2. In miles: $166 \div 1.609 = \text{about } 103 \text{ miles}$.
3. Compare: $220 \div 166 = \text{about } 1.3$. The river route is about 1.3 times as long, because the river bends and splits through the delta.

Answer: About 166 km (103 miles) in a straight line; the river route is about 1.3 times as long.

Example 3. A barge moves through the water at 12 km/h. The Rhine’s current flows downstream at 3 km/h. How long does the 220 km trip from Rotterdam up to Duisburg take, and how long does the trip back down take?

1. Going upstream, the current pushes against the barge: $12 - 3 = 9 \text{ km/h}$ over the ground.
2. Upstream time: $220 \div 9 = 24.4 \text{ hours}$, about 24 hours 27 minutes.
3. Going downstream, the current helps: $12 + 3 = 15 \text{ km/h}$. Downstream time: $220 \div 15 = 14.7 \text{ hours}$, about 14 hours 40 minutes.
4. In miles: 220 km is about 137 miles; 9 km/h is about 5.6 mph and 15 km/h about 9.3 mph.

Answer: About 24.4 hours upstream and about 14.7 hours downstream.

PRACTICE

1. **EASY** Which two rivers share the delta where Rotterdam stands?
2. **EASY** What is a hinterland? Which country makes up the largest part of Rotterdam’s hinterland outside the Netherlands?
3. **EASY** Who designed the New Waterway, and in what year did it open?
4. **MEDIUM** The Rhine is about 1,230 km long. How long is that in miles? (1 mile = 1.609 km)
5. **MEDIUM** A barge carries 2,800 tonnes of grain. A truck carries 25 tonnes. How many trucks would it take to carry the same load?
6. **MEDIUM** The Port of Rotterdam handles about 440 million tonnes of cargo a year. About how many tonnes is that per day?
7. **MEDIUM** Use the map of the Rhine. Which city is farther upstream, Cologne or Duisburg? In what general direction is Basel from Rotterdam?

(Use the map or drawing “Upstream is toward the river’s source in the Alps.” shown earlier in this lesson.)

8. **HARD** A ship leaves Rotterdam at 8:00 AM on a January morning. Rotterdam keeps Central European Time (UTC+1) in winter, and New York keeps Eastern Standard Time (UTC−5). What time is it in New York when the ship leaves?
9. **HARD** Rotterdam lies at about 51.9°N and Singapore at about 1.3°N. One degree of latitude is about 111 km (69 miles). How far apart are they north to south?
10. **CHALLENGE** Amsterdam was the greatest port of the Dutch Golden Age (Unit 3), but Rotterdam is far busier today. Using the words site, situation and hinterland, explain in a short paragraph why.

COMMON MISTAKES

- Thinking the busiest port must belong to the biggest or most famous city. Ports grow where the situation is best: deep water, a short route to the sea and a large hinterland.
- Mixing up tonnes and TEU. Tonnes measure the weight of all cargo, including oil, coal and grain; TEU count containers only (Lesson 4.3).
- Picturing Rotterdam on the open coast. The old city is about 30 km inland on the river; its port has grown out along the river to the sea.

Make it a game · Upstream, Downstream. Write Basel, Strasbourg, Mainz, Cologne, Duisburg and Rotterdam on six cards and shuffle them. Your parent draws two cards and reads them aloud. You have five seconds to say which city is upstream and what country each is in. One point for each right answer. For a bonus point, name the cargo a barge might carry between them (coal, steel, grain, containers or oil). Then lay all six cards in order from the Alps to the sea as fast as you can, and time yourself.

Scripture. “And they that shall be of thee shall build the old waste places: thou shalt raise up the foundations of many generations; and thou shalt be called, The repairer of the breach, The restorer of paths to dwell in.” (Isaiah 58:12, KJV)

Isaiah spoke of God’s people rebuilding ruined Jerusalem. Rotterdam’s people, after their city was burned in 1940, also rebuilt the old waste places. Rebuilding with patience and hard work is a way of caring for the place and the neighbors God has given us.

Practice answers

1. The Rhine and the Maas (Meuse).
2. The land behind a port that sends and receives its cargo. Germany, especially the Rhine valley and the Ruhr.
3. Pieter Caland; it opened in 1872 (work began in 1863).
4. $1,230 \div 1.609 =$ about 764, or about 765 miles.
5. $2,800 \div 25 = 112$ trucks.
6. $440,000,000 \div 365 =$ about 1,205,000 tonnes, or about 1.2 million tonnes a day.
7. Cologne is farther upstream (Duisburg is downstream of it). Basel is southeast of Rotterdam, more south than east (about south-southeast).
8. New York is 6 hours behind Rotterdam, so it is 2:00 AM in New York.
9. $51.9 - 1.3 = 50.6^\circ$. $50.6 \times 111 =$ about 5,620 km; $50.6 \times 69 =$ about 3,490 miles.

10. Sample answer: Rotterdam's situation is better for modern trade. It lies right on a branch of the Rhine and Maas, so barges from Germany and Switzerland reach it directly by river, and the New Waterway gives it a short, straight, deep channel to the North Sea. Its hinterland is the whole Rhine valley and the Ruhr. Amsterdam's site on the IJ is farther from the Rhine, so it needs canals to reach both the sea and the river, and its channels could not take the largest ships so easily. Ships and barges go where the route is shortest and deepest.

4.2 SINGAPORE AND HONG KONG: PORTS AT THE CROSSROADS OF ASIA

OBJECTIVES

- Tell how Stamford Raffles founded British Singapore as a free port in 1819 and how Britain took Hong Kong after the First Opium War (1839–1842), naming that war’s wrong plainly.
- Explain the difference between a gateway port and a hub (transshipment) port, and why a hub-and-spoke network needs fewer routes.
- Locate Singapore, Hong Kong, the Strait of Malacca and the Pearl River Delta on a map, and compute sea distances and voyage times in nautical miles and knots.

Warm-up. Draw six dots in a circle on a sheet of paper and label them with six towns. Connect every dot to every other dot with a straight line and count the lines. Now draw a seventh dot in the middle and, on a fresh sheet, connect each of the six towns only to the middle dot. Count again. Which picture looks more like a map of airline routes, and why might ships work the same way?

Watch. *1819 - Raffles Journey to Find a New Trading Base* (Singapore Bicentennial, 2:00). <https://www.youtube.com/watch?v=ID67utDx7rw>
With the story: Stamford Raffles searches for a new trading base and lands at Singapore in 1819.

Note: Made by the Singapore government for the 2019 bicentennial.

Backup video. *Why did Britain Handover Hong Kong to China? (Short Animated Documentary)* (History Matters, 4:01). <https://www.youtube.com/watch?v=l7UxedFC9zs>
With the history note: why Britain handed Hong Kong back to China in 1997. Note: A short, even-handed history of the handover.

KEY TERMS

free port

A port where ships of any nation may trade without paying customs duties on the goods they bring in and take out.

entrepôt

A trading port where goods are brought in, stored, sorted and shipped out again to other places (French for “warehouse”).

transshipment

Moving cargo from one ship to another at a port on the way, without the cargo entering the country where the port stands.

hub-and-spoke network

A pattern of routes in which many places connect through one central hub instead of each being linked directly to all the others.

monsoon

A seasonal wind that reverses direction during the year; in the Indian Ocean and South China Sea it blows from the southwest in summer and from the northeast in winter.

nautical mile and knot

A nautical mile is 1,852 m (about 1.15 ordinary miles), equal to one minute of latitude. A speed of one nautical mile per hour is one knot.

CORE IDEAS

The story. On 29 January 1819, **Sir Thomas Stamford Raffles**, an officer of the British East India Company, came ashore at the mouth of a small river at the southern tip of the Malay Peninsula. The island before him held a small settlement of Malay fishermen and a few Chinese planters under a local chief, the Temenggong, a noble of the Sultanate of Johor. Raffles wanted a harbor on the sea road between India and China that the Dutch, who held most of the nearby islands, did not already control. On 6 February 1819 he signed a treaty with the Temenggong and with Hussein, whom he recognized as Sultan of Johor, and the British flag flew over **Singapore**. Raffles made it a **free port**, open to the ships of every nation without customs duties. He wrote that Britain's aim there was trade, not territory. Merchants of many peoples soon crowded in.

The second island. Twenty-two years later and about 2,600 km (1,600 miles) to the northeast, Britain took another island, and for a worse reason. In the 1830s British merchants were smuggling opium from India into China, where the drug was illegal and was ruining many lives. When Chinese officials seized and destroyed the merchants' opium at Canton in 1839, Britain went to war to protect the trade. It was a shameful cause, and some in Parliament said so at the time. On 26 January 1841 British sailors raised their flag on **Hong Kong** Island, and the Treaty of Nanking (1842) gave the island to Britain. The foreign secretary, Lord Palmerston, was not impressed; he called it "a barren island with hardly a house upon it." But Hong Kong had one great treasure: **Victoria Harbour**, a deep, sheltered anchorage between the island and the Kowloon peninsula, at the mouth of the Pearl River, the trade road to Canton (Guangzhou) and southern China. Britain added Kowloon in 1860 and leased the New Territories for 99 years in 1898. On 1 July 1997, all of Hong Kong returned to China.

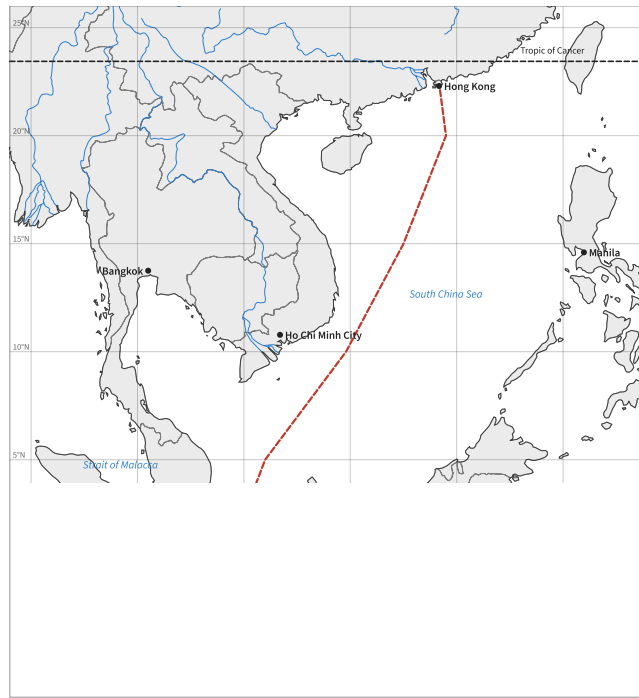
How they grew. Both cities grew as **entrepôts**, where goods were landed, stored, sorted and shipped on: pepper and tin from the Malay world, cotton cloth from India, tea and silk from China. After the Suez Canal opened in 1869, both became coaling stations for steamships on the route from Europe to the Far East. After 1949, when China came under a Communist government and its trade with the West was largely cut off during the Korean War, Hong Kong turned to making goods in its own factories. Singapore became an independent republic on 9 August 1965, an island with almost no farmland and no minerals, and its first prime minister, Lee Kuan Yew, staked its future on its harbor. Both ports opened

their first container terminals in the early 1970s, and for much of the 1990s they took turns as the busiest container port in the world.

The big idea. Singapore and Hong Kong show two kinds of great port. A **gateway port**, like Rotterdam, serves a large hinterland. A **hub port** serves the sea itself. Giant ships unload containers there, and smaller “feeder” ships carry them on to dozens of nearby ports, and the other way around. About 85 percent of the containers handled in Singapore never enter the country; they are only changing ships, as a traveler changes planes at a big airport. This is a **hub-and-spoke network**, and it lets the biggest ships make a few long, cheap voyages instead of many short ones. Hong Kong was both hub and gateway, the door to southern China. Since China opened to world trade after 1978, the factory cities of the Pearl River Delta have built ports of their own. Shenzhen, a small market town across the border from Hong Kong in 1979, now handles about twice as many containers as Hong Kong.

On the map. **Singapore** lies at about 1.3°N, 103.8°E, only about 140 km (90 miles) north of the equator, at the southern end of the **Strait of Malacca**, the long, narrow sea between the Malay Peninsula and Sumatra that ships from the Indian Ocean use to reach the South China Sea (you will study it in Unit 5). For centuries the **monsoon** set its calendar: ships from India rode the southwest wind in summer, ships from China the northeast wind in winter, and they met halfway. **Hong Kong** lies at about 22.3°N, 114.2°E, just south of the Tropic of Cancer, on the east side of the Pearl River mouth. Both sit on the main sea road between Europe and East Asia.

Technology overcoming geography. Both cities ran short of flat land and made more. Singapore has pushed its shores out into the sea with sand and rock and has grown from about 580 to about 730 square kilometers (from about 225 to 280 square miles). Hong Kong built its airport on an island leveled for the purpose, and Singapore is gathering its container terminals into one great automated port at Tuas, on reclaimed land in the west. Two small islands with no natural resources became two of the busiest trading places on earth because they sit at a crossroads of the sea and their people put that gift to work.

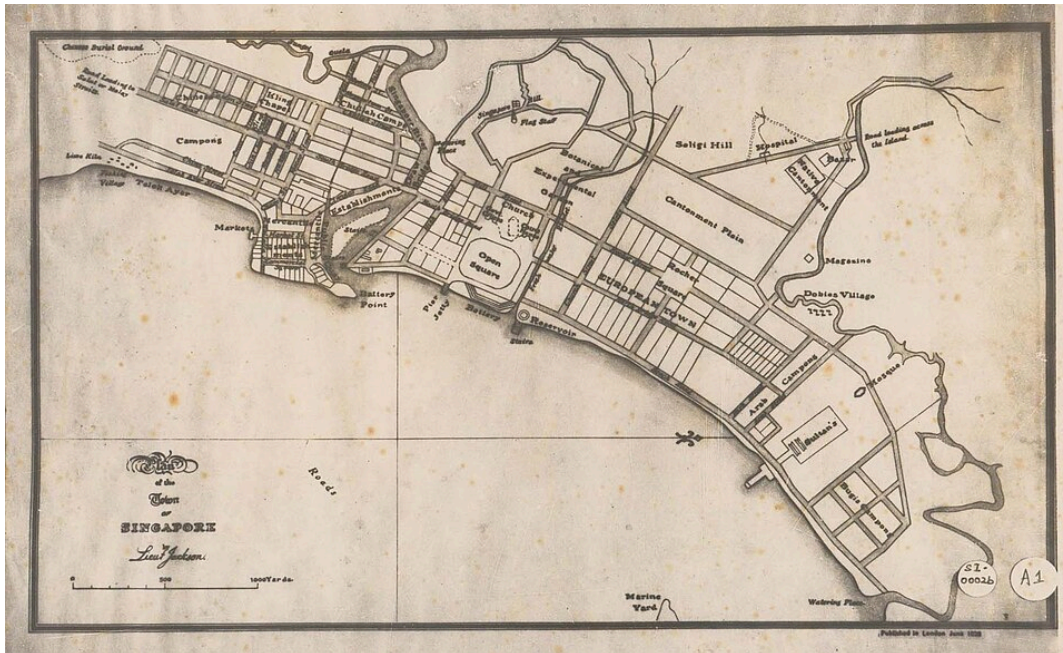


Singapore and Hong Kong on the sea road between the Indian Ocean and the Pacific.



The Pearl River Delta: Hong Kong and its giant neighbor Shenzhen guard the east side of the river's mouth.

PICTURE STUDY



*Plan of the Town of Singapore (the "Jackson Plan"), Lieutenant Philip Jackson, drawn late 1822 or early 1823; published 1828 · Printed map · Published in John Crawfurd, *Journal of an Embassy from the Governor-General of India to the Courts of Siam and Cochin China* (London, 1828)*

Raffles did not want his new port to grow in a muddle. In 1822 he gave orders for a town plan, and a young surveyor and engineer, Lieutenant Philip Jackson, drew it up. It laid out straight streets, a central government area, wharves along the Singapore River, and separate districts for the European, Chinese, Malay, Bugis, Arab and Indian merchants, each with its own leaders, as was common in colonial port towns of the time.

The plan was printed in 1828 in a book by John Crawfurd, who had served as Resident, the chief British official in Singapore, from 1823 to 1826. Much of the old center of Singapore still follows the lines on this map.

Look closely

- Find the Singapore River. Where does it meet the sea, and where would boats unload?
- Find the hill. Why might a government build its house and fort on high ground above a harbor?
- Look at the street pattern. Is it a grid or a tangle? What does that tell you about how the town was made?
- Find the labels for the different districts. Which group lives closest to the river mouth?

Talk about it

1. Why would the founder of a trading port care so much about wharves, streets and a plan?
2. What does the plan tell you about the many peoples who came to trade in Singapore?

3. Compare this plan with a modern map of Singapore. What has stayed the same, and what has changed?

PROJECT: HUB OR WEB? A STRING NETWORK

You will build two shipping networks with string and pins on a map of Asia and count what each one costs. One network links every port directly to every other port. The other runs everything through a hub. By the end you will know why Singapore and Hong Kong became hubs.

You will need

- A printed outline map of East and Southeast Asia (letter size or larger)
- A corkboard, a piece of thick cardboard or a foam board
- Eight pushpins and a ball of string or yarn (two colors if possible)
- Scissors, a ruler and a notebook

Steps

1. Pin the map to the board. Put pushpins at eight ports: Singapore, Port Klang, Bangkok, Ho Chi Minh City, Manila, Hong Kong, Shanghai and Busan.
2. Network 1 (the web): with one color of string, connect every port directly to every other port. Count the strings. Check your count with the rule: for n ports, the number of direct routes is $n \times (n - 1) \div 2$.
3. Measure the total length of string you used, in centimeters, and write it down.
4. Remove the strings. Network 2 (the hub): with the other color, connect every port only to Singapore. Count the strings and measure their total length.
5. Suppose each route needs one ship. How many ships does each network need? Which network lets you use fewer, bigger ships?
6. Now move the hub to Hong Kong and repeat Network 2. Is the total string shorter or longer? Which hub is better for these eight ports?
7. Write a paragraph: what does a hub save, and what does it cost? (Think about the time a box waits at the hub to change ships.)

Tips

- Keep the strings straight from pin to pin. Real ships cannot sail over land, but straight lines are good enough to compare the two networks.
- A hub works best when it sits near the middle of its ports and on the main sea road. That is the whole secret of Singapore's situation.

Check your work

- I can count the routes in a web network and in a hub network.
- I can explain why a hub lets shipping lines use fewer, bigger ships.
- I can explain one disadvantage of sending cargo through a hub.

MAP NOTEBOOK

1. Draw a map of the Strait of Malacca and the South China Sea. Mark Singapore, Hong Kong and the equator, and draw arrows for the summer and winter monsoon winds.
2. Draw the Pearl River Delta. Mark Guangzhou, Shenzhen, Hong Kong and Macau, and shade Victoria Harbour blue.
3. Make a timeline from 1819 to 1997 with at least six dates from this lesson.

From history. Missionaries also followed the sea road. In 1843 the Scottish missionary **James Legge** of the London Missionary Society moved the Anglo-Chinese College from Malacca, on the strait, to newly British Hong Kong. He preached, taught and spent decades translating the Chinese classics into English with the help of Chinese scholars such as Wang Tao. In 1876 Legge became the first professor of Chinese at the University of Oxford.

WORKED EXAMPLES

Example 1. Singapore lies at about 1.3°N and Hong Kong at about 22.3°N . One degree of latitude is about 111 km (69 miles). How far north of the equator is Singapore, and how far apart are the two cities north to south?

(Use the map or drawing “Read the latitude of each city from the grid.” shown earlier in this lesson.)

1. Singapore to the equator: $1.3 \times 111 \text{ km} = \text{about } 144 \text{ km}$, or $1.3 \times 69 = \text{about } 90 \text{ miles}$.
2. Difference in latitude: $22.3 - 1.3 = 21.0^{\circ}$.
3. North-south distance: $21.0 \times 111 = \text{about } 2,330 \text{ km}$, or $21.0 \times 69 = \text{about } 1,450 \text{ miles}$.
4. Hong Kong is also about 10° of longitude east of Singapore, so the straight-line distance is longer still, about 2,600 km (1,600 miles).

Answer: Singapore is about 140 km (90 miles) north of the equator; Hong Kong is about 2,330 km (1,450 miles) farther north.

Example 2. The sea route from Singapore to Hong Kong is about 1,450 nautical miles. A container ship cruises at 18 knots. How long is the voyage? How far is it in kilometers and in ordinary miles?

1. A knot is one nautical mile per hour, so $\text{time} = \text{distance} \div \text{speed} = 1,450 \div 18 = 80.6$ hours.
2. $80.6 \text{ hours} \div 24 = 3.36$ days, about 3 days and 9 hours.
3. Kilometers: $1,450 \times 1.852 =$ about 2,685 km.
4. Ordinary miles: $1,450 \times 1.15 =$ about 1,670 miles.

Answer: About 80.6 hours (3 days 9 hours); about 2,685 km or 1,670 miles.

Example 3. A giant ship unloads 6,000 TEU of containers at Singapore. About 85 percent are transshipment boxes that will be loaded onto feeder ships; the rest are for Singapore itself. Ports count every box lifted off a ship and every box lifted onto one. How many TEU does the port count for these boxes?

1. Transshipment boxes: $85\% \text{ of } 6,000 = 0.85 \times 6,000 = 5,100$ TEU.
2. Boxes for Singapore: $6,000 - 5,100 = 900$ TEU.
3. All 6,000 TEU are counted once when they are unloaded.
4. The 5,100 transshipment TEU are counted again when they are loaded onto feeder ships: $6,000 + 5,100 = 11,100$ TEU.

Answer: 11,100 TEU. A hub port's figures are large partly because each transshipped box is counted twice.

PRACTICE

1. **EASY** Who founded British Singapore, in what year, and what kind of port did he make it?
2. **EASY** What is an entrepôt? Name two goods that passed through Singapore or Hong Kong in the 1800s.
3. **EASY** Which treaty gave Hong Kong Island to Britain, after which war? When did Hong Kong return to China?
4. **MEDIUM** Singapore and Hong Kong both keep time at UTC+8. Rotterdam keeps UTC+1 in winter. When it is 3:00 PM in Singapore on a January day, what time is it in Rotterdam and in Hong Kong?
5. **MEDIUM** A shipping line serves 8 ports. How many routes does it need to link every port directly to every other port? How many if all 8 connect through a hub that is one of the 8?
6. **MEDIUM** How long does the 1,450-nautical-mile voyage from Singapore to Hong Kong take at 20 knots? Give hours and days.

7. **MEDIUM** A hub port unloads 4,000 TEU from a large ship; 90 percent are transshipped onto feeder ships. Counting every lift off and every lift on, how many TEU does the port record?
8. **HARD** Use the map. In what direction does a ship sail from Singapore to reach Hong Kong? Which sea does it cross?
(Use the map or drawing "Follow the route line from Singapore." shown earlier in this lesson.)
9. **HARD** Singapore has grown by land reclamation from about 580 km² to about 730 km². By how many square kilometers and by what percent has it grown? (1 km² = 0.386 square miles)
10. **CHALLENGE** In a short paragraph, explain why Singapore became one of the world's greatest ports even though it has almost no farmland or natural resources, and why Shenzhen now handles more containers than Hong Kong.

COMMON MISTAKES

- Thinking a port needs a big hinterland to be great. A hub port like Singapore lives mostly on boxes changing ships.
- Counting a transshipped box only once. Port statistics count it twice: once off one ship and once onto another.
- Using ordinary miles with knots. A knot is one nautical mile (1,852 m, about 1.15 miles) per hour.

Make it a game • Hub Hop. Lay out eight paper plates around the room as ports, with one in the middle as the hub. Your parent calls out a cargo and a trip, such as "rubber from Port Klang to Busan." You must hop from the starting plate to the hub and then to the destination, naming each port as you land. If you can name the sea or strait the ship would cross, score a bonus point. Then switch: you call the trips and your parent hops.

Scripture. "And say unto Tyrus, O thou that art situate at the entry of the sea, which art a merchant of the people for many isles, Thus saith the Lord GOD; O Tyrus, thou hast said, I am of perfect beauty." (Ezekiel 27:3, KJV)

Tyre was the Singapore of the ancient world, a rich island port at the entry of the sea that traded with many lands. Ezekiel 27 lists its goods and partners like a ship's manifest. But Tyre grew proud, and God judged it. A great harbor is a gift; the right response is gratitude and honest dealing, not boasting.

Practice answers

1. Sir Stamford Raffles of the British East India Company, in 1819; he made it a free port open to all nations without customs duties.
2. A port where goods are landed, stored, sorted and shipped on to other places. Any two of: pepper, tin, cotton cloth, tea, silk (opium also passed through, as the lesson explains).
3. The Treaty of Nanking (1842), after the First Opium War. Hong Kong returned to China on 1 July 1997.
4. Rotterdam is 7 hours behind, so 8:00 AM. Hong Kong is in the same zone, so 3:00 PM.

5. Direct: $8 \times 7 \div 2 = 28$ routes. Through a hub: 7 routes (each of the other 7 ports to the hub).
6. $1,450 \div 20 = 72.5$ hours, or about 3 days (3.0 days and half an hour).
7. Transshipped: $0.90 \times 4,000 = 3,600$ TEU. Recorded: 4,000 (unloaded) + 3,600 (reloaded) = 7,600 TEU.
8. North-northeast (more north than east). It crosses the South China Sea.
9. $730 - 580 = 150 \text{ km}^2$ (about 58 square miles). $150 \div 580 = 0.26$, about a 26 percent increase.
10. Sample answer: Singapore's situation is its resource. It sits at the southern end of the Strait of Malacca, on the main sea road between the Indian Ocean and the Pacific, so ships pass its door whether or not they trade there. It has deep, sheltered water, it was a free port from the start, and its government invested in container terminals and efficient service, so shipping lines use it as a hub to transship boxes. Shenzhen grew because China opened to world trade after 1978 and the factories of the Pearl River Delta are right behind it; once it built deep-water terminals, cargo no longer needed to cross the border to Hong Kong.

4.3 MALCOM MCLEAN'S BOX ★ ⚙️

OBJECTIVES

- Tell the story of Malcom McLean and the *Ideal X*, which sailed from Port Newark to Houston with 58 containers on 26 April 1956.
- Explain how break-bulk shipping worked, why the standard container and the intermodal system cut the cost of shipping so sharply, and what TEU means.
- Compute shipping costs, TEU counts, container volumes and scale-model sizes, and trace the *Ideal X*'s route on a map.

Warm-up. Dump 30 small, mixed things on the table: spoons, socks, blocks, pencils, an orange. Time how long it takes to carry them one at a time across the room and pack them neatly into a box. Now put them all back in the box, pick up the box and carry it back. Time that too. How many times faster was the box? What did you have to do before the box trip could happen?

Watch. *Shipping Containers: The Box that Changed the World* (The History Guy: History Deserves to Be Remembered, 18:33). <https://www.youtube.com/watch?v=WyNkcsQGaV4>
After the story: Malcom McLean and the container that changed world trade.

Note: The History Guy runs about 18 minutes. Near the end there is one sentence on recent supply-chain trouble during COVID-19.

Backup video. *Malcom McLean: The Modern Intermodal Shipping Container / Heroes of Progress / Ep. 17* (Human Progress, 2:30). <https://www.youtube.com/watch?v=Ua2ZCnl3JDc>

As review: McLean's story in two and a half minutes. Note: From HumanProgress.org, a project of the Cato Institute; this video tells McLean's story only.

KEY TERMS

break-bulk cargo

Cargo loaded piece by piece (sacks, crates, barrels, bales) instead of in containers or as loose bulk like grain or oil.

longshoreman

A dock worker who loads and unloads ships (also called a stevedore or docker).

shipping container

A standard steel box, usually 20 or 40 feet long, that is packed once and moves by ship, train and truck without being opened.

intermodal

Using more than one mode of travel (ship, rail, truck) for one trip, with the cargo staying in the same container the whole way.

twistlock

A locking pin that fits into a container's corner fitting and turns a quarter turn to lock the box to a crane, a truck, a railcar or another box.

TEU

Twenty-foot equivalent unit: the measure of container traffic. One 20-foot box is 1 TEU; a 40-foot box is 2 TEU.

CORE IDEAS

The story. On 26 April 1956, a worn tanker left over from the Second World War, the *Ideal X*, lay at Port Newark, New Jersey. A crane swung 58 aluminum truck bodies, without their wheels, onto a steel deck built over the ship's tanks, one box every few minutes. The ship sailed south along the Atlantic coast, around Florida and across the Gulf of Mexico to Houston, Texas, where trucks waited to hook up the boxes and drive them away. The man behind it was **Malcom McLean** (1913–2001), a trucking businessman from Maxton, North Carolina, who had bought his first used truck in 1934 and built McLean Trucking into one of the largest trucking companies in the country. He was not a sailor. He simply hated wasted time and money.

The old way. McLean later told how the idea began. In 1937 he drove a truckload of cotton bales to a pier in Hoboken, New Jersey, and waited most of a day while gangs of **longshoremen** carried other cargo into a ship one sling-load at a time. This was **break-bulk** shipping, and it had hardly changed since the days of sail. One ship might carry many thousands of separate pieces: sacks of coffee, barrels, crates of machinery, bundles of pipe. Each was lifted aboard, then carried and wedged into place by hand. Loading and unloading could take a week or more, and ships often spent nearly as much time tied up in port as they did at sea. Goods were broken, soaked or stolen on the docks. McLean wondered: why not lift the whole truck body onto the ship and never touch the cargo at all?

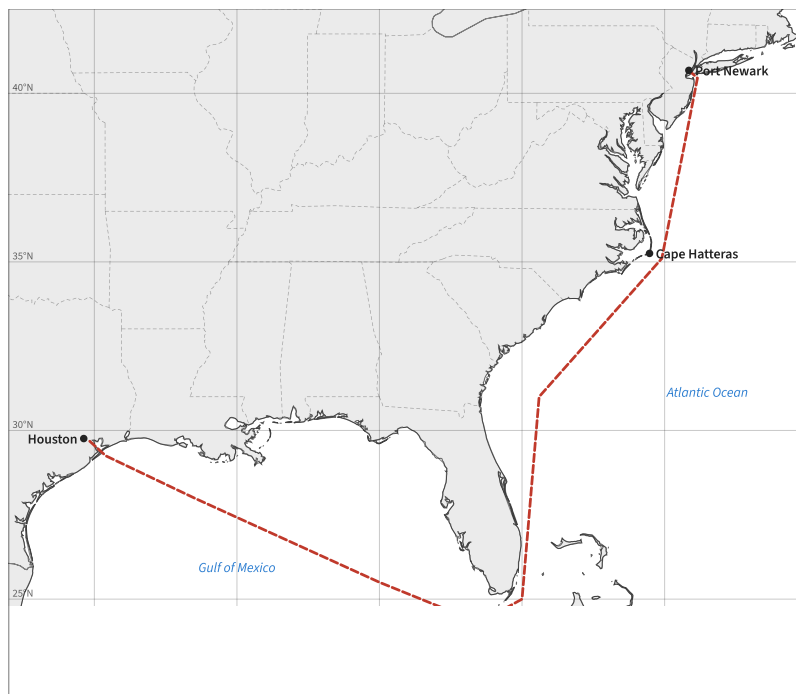
How it worked. In 1955 McLean bought a shipping company, Pan-Atlantic Steamship. Federal rules would not let him control a shipping line and a trucking line at once, so he gave up his trucking company to do it. He hired an engineer, **Keith Tantlinger**, to design a box strong enough to be stacked and lifted. Tantlinger's boxes had steel **corner fittings** at all eight corners and used a **twistlock**, a pin that drops into a fitting and turns to lock the box to a crane, to a truck chassis or to another box. The savings were enormous. Figures gathered by the historian Marc Levinson show that in 1956 loading loose cargo onto a medium-sized ship cost about \$5.83 a ton, while loading the *Ideal X* cost about 16 cents a ton. In 1957 McLean's company sailed the *Gateway City*, fitted with steel cells that held nothing but containers, and in 1960 the company took a new name, **Sea-Land**.

The big idea. McLean's genius was not the box alone; railroads and armies had used cargo boxes before. He saw that the box had to be part of a whole system, with ships, cranes, trucks, trains and terminals all built around one container that stays shut from the factory to the store. This is **intermodal** shipping. The system only works if everyone's boxes fit everyone's cranes, so the size had to be **standardized**. In the 1960s McLean let other companies use his patents on corner fittings without charge, and by the end of the decade the International Organization for Standardization had set the sizes still used today: 8 feet

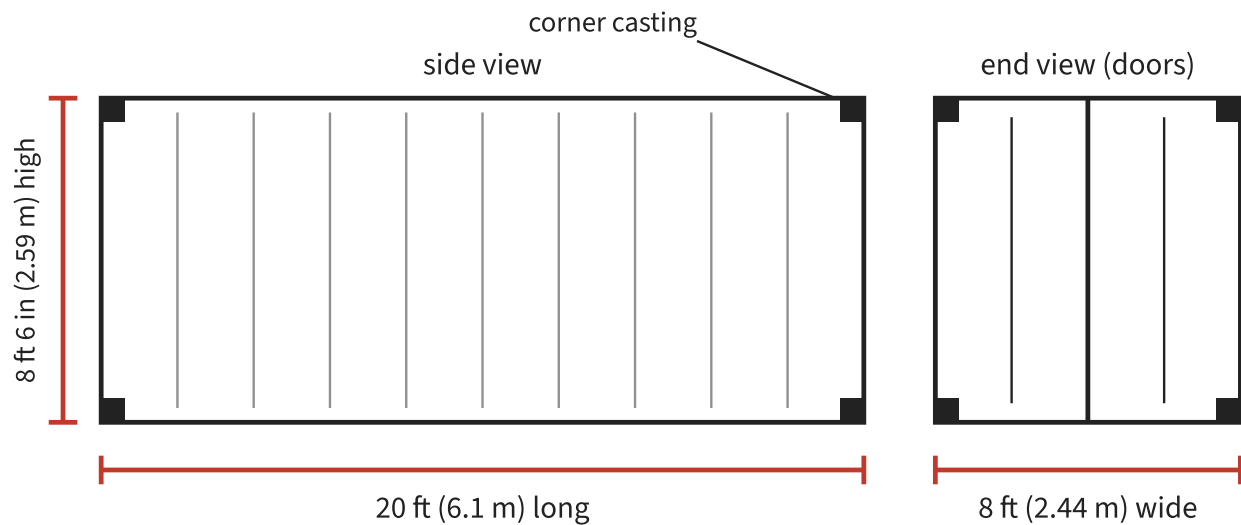
(2.44 m) wide, 20 or 40 feet (6.1 or 12.2 m) long, and on most boxes now 8 feet 6 inches (2.59 m) high. Ports count their traffic in **TEU**: a 20-foot box is 1 TEU and a 40-foot box is 2 TEU.

Technology overcoming geography. The container made distance cheap. Once the sea voyage cost only a small part of the price of most goods, factories could be built far from their customers, and a single product could be designed in one country, made from parts from several others and sold all over the world. Ships grew from the *Ideal X*'s 58 boxes to giants nearly 400 m (about 1,300 feet) long that carry about 24,000 TEU. The change was hard on many workers: one container crane did the work of a large gang of longshoremen, and dock jobs in the old ports fell sharply. Ports moved, too. The piers of Manhattan and Brooklyn emptied as cargo went to wide new terminals at Port Newark and Port Elizabeth in New Jersey, and London's old docks, which you studied in Unit 3, closed by the early 1980s while Felixstowe on the coast became Britain's busiest container port.

On the map. Trace the *Ideal X*'s voyage: out through New York Harbor, south past Cape Hatteras, through the Straits of Florida south of the Florida Keys, west across the Gulf of Mexico to Galveston Bay and up the ship channel to Houston, about 1,900 nautical miles or 3,500 km (2,200 miles). Coastal trips like this one were McLean's first market, because they competed with trucks on crowded highways. Within twenty years his boxes were crossing the Atlantic and the Pacific.



The first voyage of the Ideal X, 26 April 1956: Port Newark to Houston.

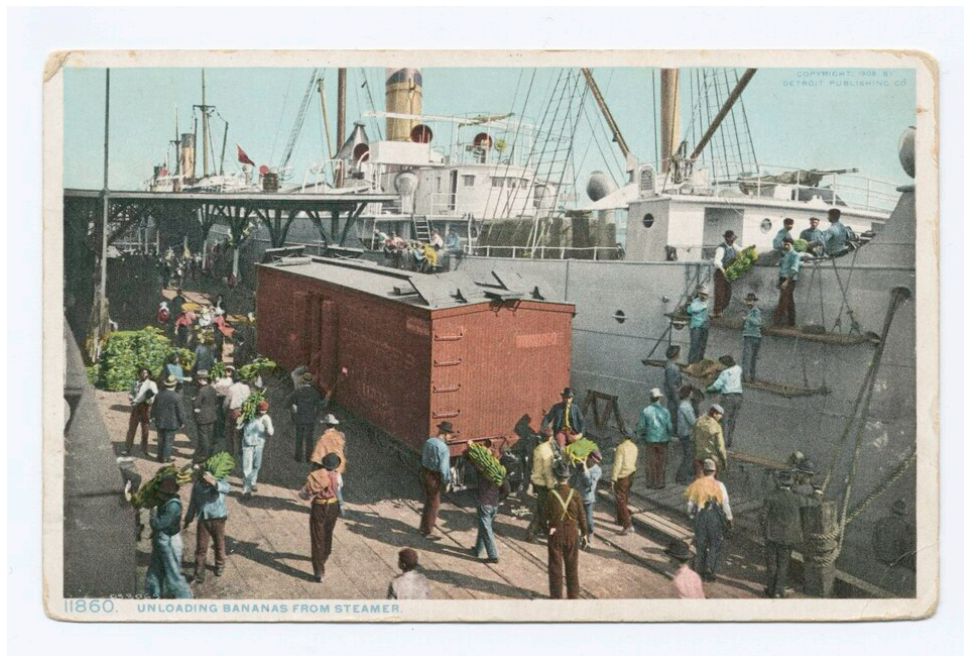


One 20-foot box = 1 TEU. A 40-foot box (12.2 m long) = 2 TEU.

Corner castings at all 8 corners take crane spreaders and twistlocks.

The standard 20-foot container: 1 TEU. Corner castings at all eight corners take cranes and twistlocks.

PICTURE STUDY



Unloading Bananas from Steamer, New Orleans, La., Detroit Publishing Company, photographed about 1900-1907; postcard issued about 1907-1908 · Color postcard printed from a photograph · New York Public Library, Photography Collection. The Library of Congress holds the company's glass-plate negatives of the same subject.

Before the container, every piece of cargo passed over a worker's shoulder or through a sling. This picture from the docks of New Orleans shows how bananas from Central America

were unloaded early in the twentieth century: one bunch at a time, carried on the shoulders of dock workers.

The Detroit Publishing Company made thousands of photographs of American cities, harbors and landscapes and sold many of them as colored postcards. Look at this picture as a record of the break-bulk world Malcom McLean set out to change.

Look closely

- Count the workers you can see. How many people does it take to move this one ship's cargo?
- Find the ship and the wharf. Trace the path a bunch of bananas follows from the hold to wherever it goes next.
- Look at what each man carries. How much could one worker move in an hour?
- Look for any machines in the picture. What work is done by machine, and what by hand?

Talk about it

1. How would this scene change if the bananas came packed in refrigerated containers?
2. What would be gained by the change, and what would these workers lose?
3. Why might fruit be damaged or spoiled in a break-bulk port more often than in a container port?

Safety first. Use scissors, not a craft knife, unless an adult cuts for you. Cardboard edges can be sharp.

PROJECT: BREAK-BULK VERSUS THE BOX

You will race the old way against the new way with a model ship and a string crane, then build a true-to-scale model of a 20-foot container. You will see for yourself why the box changed the world.

You will need

- A shoebox (the ship's hold) and four small boxes that fit inside it side by side, such as tea or gelatin boxes (the containers)
- About 40 small mixed items: dried beans in a bag, buttons, erasers, paper clips, small blocks, bottle caps
- A "crane": a ruler or pencil, 50 cm (20 inches) of string and a paper clip bent into a hook
- A timer, a notebook, a ruler and pencil
- Thin cardboard (a cereal box), scissors, tape and a marker for the scale model

Steps

1. Break-bulk round: put the 40 loose items on a “dock” at the edge of the table. Using only the string crane (hook each item, or lower a little paper sling made from a folded index card), lift them one at a time into the shoebox. Time it. This is the time the ship waits in port.
2. Container round: at a separate “factory” table, pack the 40 items into the four small boxes. This packing time does not count against the ship, because in real life it happens far from the port.
3. Tie the string to each small box (or slide the hook under a loop of tape on its lid) and lift the four boxes into the shoebox. Time it.
4. Compare: how many times faster was the container round? Write the ratio, for example “break-bulk 6 minutes, containers 1 minute: 6 times faster.”
5. Scale model: a 20-foot container is about 6.1 m long, 2.44 m wide and 2.59 m high. At a scale of 1:50, compute each measurement in centimeters (divide meters by 50, then multiply by 100).
6. Draw the six faces on cardboard at those sizes, cut them out and tape them into a box. Draw the doors on one end and the corrugated ridges on the sides. Mark a small square at each of the eight corners for the corner fittings.
7. Paint or mark a container number on your box in the real pattern: a three-letter owner code, the letter U, six digits and a check digit, such as ABCU 123456 0.

Tips

- Make the break-bulk round fair: the crane must place each item neatly so the hold could be closed. Real longshoremen had to stow cargo so it would not shift at sea.
- Your 1:50 model should be about 12.2 cm long, 4.9 cm wide and 5.2 cm high. Two of them end to end make a 40-foot container, 2 TEU.

Check your work

- I can explain why loading containers is faster than loading loose cargo.
- I can compute a ratio from my timed trials.
- I can build a scale model with correct measurements and explain what TEU means.

MAP NOTEBOOK

1. Trace the *Ideal X*'s route from Port Newark to Houston. Label the Atlantic Ocean, Cape Hatteras, the Straits of Florida and the Gulf of Mexico.
2. Draw a container with its measurements in feet and meters, and draw a close-up of a corner fitting with a twistlock.
3. Make a T-chart titled “Break-Bulk and the Box,” comparing time in port, cost, damage and theft, and the number of workers.

From history. Malcom McLean died in May 2001 at the age of 87. On the morning of his funeral, ships in ports around the world sounded their horns in his honor. He had started

with one used truck during the Great Depression, and his box had reshaped the trade of every nation on earth.

WORKED EXAMPLES

Example 1. In 1956, loading loose cargo cost about \$5.83 per ton, and loading the *Ideal X* cost about \$0.158 per ton. What would it cost to load 1,000 tons each way? How many times cheaper was the container ship?

1. Break-bulk: $1,000 \times \$5.83 = \$5,830$.
2. Container: $1,000 \times \$0.158 = \$158$.
3. Ratio: $\$5,830 \div \$158 = \text{about } 36.9$, so about 37 times cheaper.

Answer: \$5,830 for loose cargo versus \$158 by container: about 37 times cheaper.

Example 2. A container ship carries 3,000 forty-foot containers and 2,500 twenty-foot containers. How many boxes is that, and how many TEU?

1. Boxes: $3,000 + 2,500 = 5,500$ containers.
2. Each 40-foot box is 2 TEU: $3,000 \times 2 = 6,000$ TEU.
3. Each 20-foot box is 1 TEU: $2,500 \times 1 = 2,500$ TEU.
4. Total: $6,000 + 2,500 = 8,500$ TEU.

Answer: 5,500 boxes, 8,500 TEU.

Example 3. Make a 1:50 scale model of a 20-foot container that is 6.1 m long, 2.44 m wide and 2.59 m high. What are the model's measurements in centimeters?

(Use the map or drawing "Use the real measurements from the diagram." shown earlier in this lesson.)

1. At 1:50, every length is divided by 50.
2. Length: $6.1 \text{ m} \div 50 = 0.122 \text{ m} = 12.2 \text{ cm}$.
3. Width: $2.44 \text{ m} \div 50 = 0.0488 \text{ m} = \text{about } 4.9 \text{ cm}$.
4. Height: $2.59 \text{ m} \div 50 = 0.0518 \text{ m} = \text{about } 5.2 \text{ cm}$.

Answer: About 12.2 cm long, 4.9 cm wide and 5.2 cm high (about 4.8 by 1.9 by 2.0 inches).

PRACTICE

1. **EASY** On what date did the *Ideal X* sail, from which port to which port, and how many containers did it carry?
2. **EASY** What does TEU stand for? How many TEU is one 40-foot container?

3. **EASY** What is break-bulk cargo? Give two examples.
4. **MEDIUM** A ship carries 1,200 forty-foot containers and 800 twenty-foot containers. How many TEU is that?
5. **MEDIUM** Using the 1956 figures (\$5.83 per ton for loose cargo and \$0.158 per ton for the *Ideal X*), what would it cost to load 500 tons each way? What is the saving?
6. **MEDIUM** The inside of a 20-foot container is about 5.9 m long, 2.35 m wide and 2.39 m high. What is its volume in cubic meters? ($1 \text{ m}^3 = 35.3 \text{ cubic feet}$)
7. **MEDIUM** A 40-foot container is about 12.2 m long. How long is a 1:100 scale model of it, in centimeters?
8. **HARD** The sea route from Port Newark to Houston is about 1,900 nautical miles. At 15 knots, about how long would the voyage take? Give the distance in kilometers and ordinary miles too. ($1 \text{ nautical mile} = 1.852 \text{ km} = 1.15 \text{ miles}$)
(Use the map or drawing “The route runs around Florida, not across it.” shown earlier in this lesson.)
9. **HARD** In two or three sentences, explain why containers had to be standardized for McLean’s idea to work around the world.
10. **CHALLENGE** The largest container ships carry about 24,000 TEU. If 24,000 twenty-foot containers, each 6.1 m long, were laid end to end, how long would the line be in kilometers and in miles?

COMMON MISTAKES

- Saying McLean invented the first cargo box. Boxes had been used before; McLean’s achievement was a whole system of ships, cranes, trucks and terminals built around a box that is never opened on the way.
- Counting containers and TEU as the same thing. A 40-foot box is one box but 2 TEU.
- Thinking the change happened overnight. It took about twenty years for containers to take over most ocean trade, and ports had to rebuild to handle them.

Make it a game · Box or No Box?. Your parent names a cargo, and you call out how it travels: “Box!” for a container, “Bulk!” for loose cargo poured into a hold (grain, coal, iron ore), “Tanker!” for liquids (crude oil, gasoline), or “Roll on!” for things driven aboard (new cars, trucks). Try sneakers, wheat, bananas, crude oil, tractors, televisions, coal and frozen chicken. Bonus point: say which boxes must be refrigerated containers (reefers). Play to ten points, then switch roles.

Scripture. “Seest thou a man diligent in his business? he shall stand before kings; he shall not stand before mean men.” (Proverbs 22:29, KJV)

McLean was a hard-working truck driver who noticed waste and patiently found a better way. Diligence, careful attention to one’s daily work, is honored in Scripture. Good work done well can serve millions of people one will never meet.

Practice answers

1. 26 April 1956, from Port Newark, New Jersey, to Houston, Texas, with 58 containers.

2. Twenty-foot equivalent unit. A 40-foot container is 2 TEU.
3. Cargo loaded piece by piece rather than in containers or as loose bulk. Examples: sacks of coffee, crates of machinery, barrels, bales of cotton, bunches of bananas.
4. $1,200 \times 2 + 800 \times 1 = 2,400 + 800 = 3,200$ TEU.
5. Loose: $500 \times \$5.83 = \$2,915$. Container: $500 \times \$0.158 = \$79$. Saving: \$2,836.
6. $5.9 \times 2.35 \times 2.39 =$ about 33.1 m^3 , or about $33.1 \times 35.3 = 1,170$ cubic feet.
7. $12.2 \text{ m} \div 100 = 0.122 \text{ m} = 12.2 \text{ cm}$.
8. $1,900 \div 15 =$ about 127 hours, or about 5.3 days. Distance: $1,900 \times 1.852 =$ about 3,500 km; $1,900 \times 1.15 =$ about 2,200 miles.
9. Sample answer: A container is only useful if every crane, ship cell, truck chassis and railcar can handle it. If each company used a different size, boxes could not move from one line or port to another, and the savings would be lost at every transfer. Standard sizes and corner fittings let any box travel on any ship, train or truck in the world.
10. $24,000 \times 6.1 \text{ m} = 146,400 \text{ m} =$ about 146 km; $146 \div 1.609 =$ about 91 miles.

4.4 A DAY AT A CONTAINER PORT 🚚

OBJECTIVES

- Describe the work of a modern container terminal from the ship's arrival to the truck gate, naming the ship-to-shore crane, spreader, straddle carrier, container yard and stowage plan.
- Apply the rules of stowage (heavy boxes low, first port on top, weight balanced) to load a model ship, and compute crane times and balancing weights.
- Locate the world's twenty busiest container ports on a map and explain why most of them lie in East and Southeast Asia.

Warm-up. Stack six books in a single pile on a table. Put a sticky note on three of them marked "Stop 1" and on the other three "Stop 2," mixing them up. Now "deliver" the Stop 1 books by taking them off the pile, but any Stop 2 book that is in the way must be lifted off and put back. Count those extra lifts. Then restack the pile so that Stop 1 needs no extra lifts at all. What rule did you discover?

Watch. *The Crazy-Complex Process of Organizing a Container Ship* (Half as Interesting, 8:37). https://www.youtube.com/watch?v=KgE_iK_NGmE
Before the project: how a container ship is loaded so it stays balanced and the right boxes come off first.

Note: Half as Interesting is fast and jokey. It has a sponsor message for a news app; stop the video when the explanation ends.

Backup video. *How does a Shipping Container work?* 🚢 *Maddie's Do You Know* 🧐 (Maddie's Do You Know?, 5:48). https://www.youtube.com/watch?v=Us2mBd_HhtQ
As a quick review: Maddie follows a container from the ship to a train. Note: Maddie's Do You Know is made for younger children; it is a quick, clear review.

KEY TERMS

quay

The solid wharf wall where a ship ties up to load and unload (pronounced "key"). The place along it where one ship lies is a berth.

ship-to-shore crane

A tall gantry crane on rails along the quay whose boom reaches out over a ship to lift containers on and off (also called an STS crane).

spreader

The steel frame hanging from a container crane that drops onto a box and locks its four twistlocks into the corner fittings.

straddle carrier

A tall vehicle that drives over a container, lifts it from above and carries it between the quay and the stacks.

stowage plan

The plan that gives every container on a ship its slot by bay (along the ship), row (across) and tier (up).

reefer

A refrigerated container with its own cooling unit, plugged into electric power on ship and in the yard.

CORE IDEAS

The story. In 1959, at Alameda, California, across the bay from San Francisco, the Matson Navigation Company set up something new on its pier: a tall steel crane built only to lift containers between ship and shore. It was made by the Paceco company and became known as a **Portainer**. Matson had begun carrying containers to Hawaii the year before and wanted a faster way to load them than the ship's own booms. The new crane rolled along rails beside the ship and reached out over its deck with a long boom. That basic design, a high steel frame on rails with a boom over the ship, is still the shape of container cranes in every great port today.

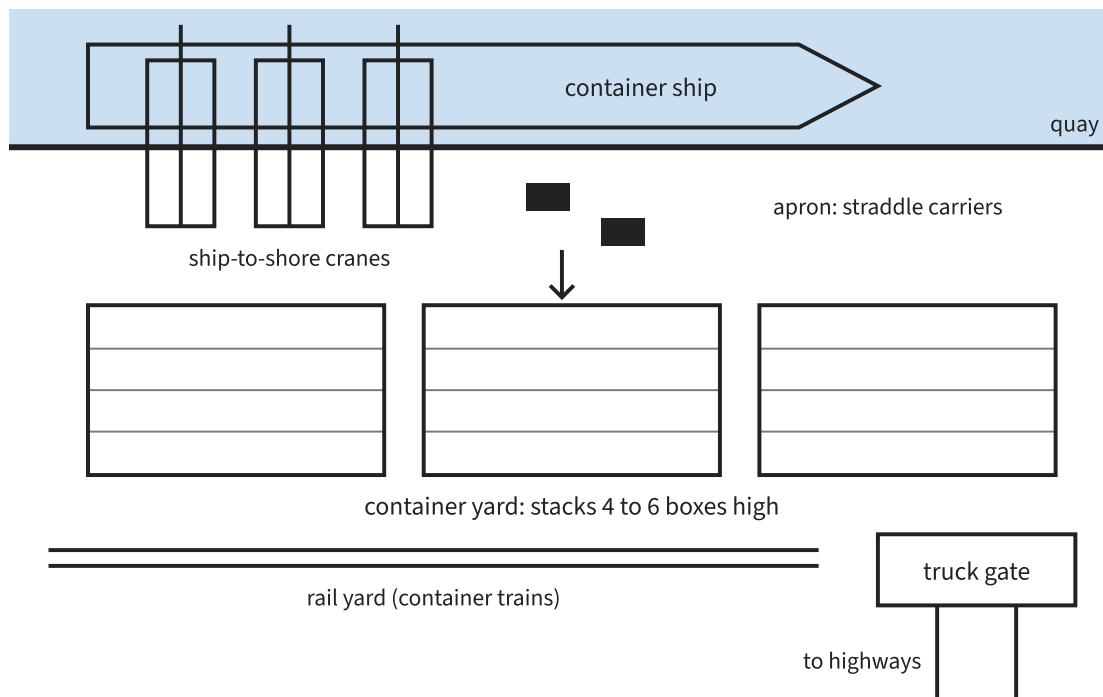
How it works: the ship arrives. Follow one ship through a day at a modern terminal such as Rotterdam's Maasvlakte or Singapore's Pasir Panjang. Far out at sea a harbor **pilot** climbs aboard to guide the ship in, and tugboats ease it against the **quay**. Lashers climb over the deck to unlock the steel rods and twistlocks that held the stacks steady at sea. Then the **ship-to-shore cranes**, often five or six on one big ship, roll into place. An operator rides in a cab that runs out along the boom, and beneath it hangs the **spreader**, which drops onto a container, turns its four twistlocks and lifts. A crane makes about 25 to 35 moves an hour, roughly one box every two minutes, unloading and loading at the same time.

The yard. On the quay the boxes are taken by **straddle carriers**, tall machines that drive over a container and lift it, or by driverless vehicles. They carry each box to the **container yard**, long blocks of stacks four to six boxes high, where yard cranes set them in place. Every box carries a unique number such as ABCU 123456 0: a three-letter owner code, the letter U for a freight container, six digits and a check digit. The terminal's computer knows where every box sits, which ship brought it and where it goes next. Refrigerated **reefers** full of fruit, meat or medicine are plugged into electric racks to stay cold.

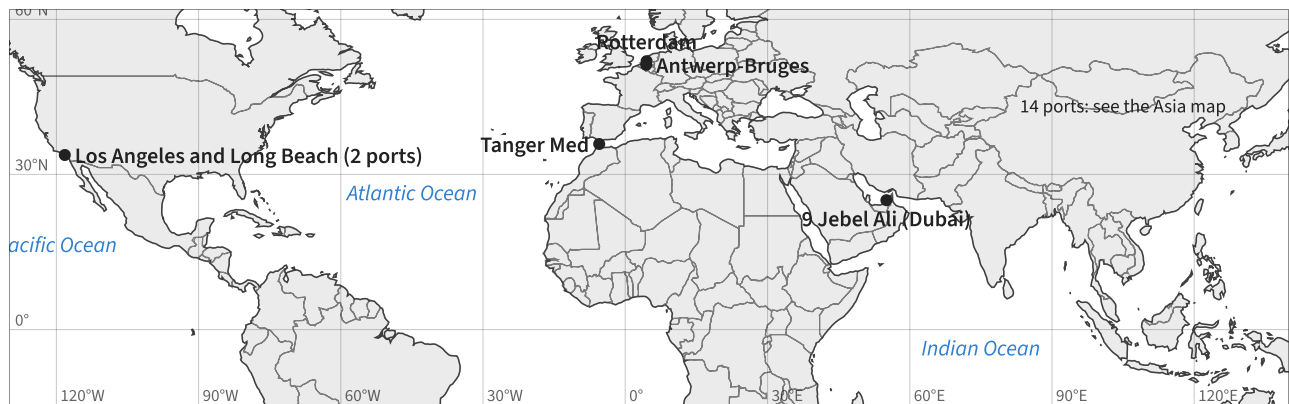
The big idea: the stowage puzzle. Before the ship sails again, planners make a **stowage plan** that gives every box a slot by bay, row and tier. Several rules pull against each other. Heavy boxes go low, to keep the ship's center of gravity down so it does not roll dangerously in a storm. Weight must be balanced left and right, or the ship will lean (list), and front and back, or it will tip bow-down or stern-down (trim); the crew also pumps seawater ballast in and out of tanks to help. Boxes for the next port must be on top, or cranes will have to lift others off and put them back, an expensive extra move called a **restow**. Reefers need power sockets, and dangerous cargo must be kept apart. A planner must satisfy all the rules at once, and that is the puzzle you will solve in this lesson's project.

The land side. All day and all night, trucks arrive at the terminal **gate**. Cameras read container numbers and license plates, and each driver is sent to the right block of the yard. Long container trains load on the rail sidings, and at Rotterdam barges load boxes for the Rhine. A ship earns money only when it is moving, so the terminal works around the clock, and after a day or two at the berth the ship is back at sea.

Technology overcoming geography. In 1993 the ECT Delta terminal in Rotterdam became the first container terminal in the world where boxes were carried between the cranes and the yard by driverless vehicles under computer control. Today many terminals in Rotterdam, Singapore, Shanghai and elsewhere are partly or fully automated, and some crane operators work from screens in an office. A terminal can move several thousand boxes off and onto a ship in a day or two, work that would have taken break-bulk longshoremen months. Look at a map of the world's twenty busiest container ports and you will see where the factories and the great sea roads are: fourteen of them lie in East and Southeast Asia.



The parts of a container terminal, from the sea side (top) to the land side (bottom).

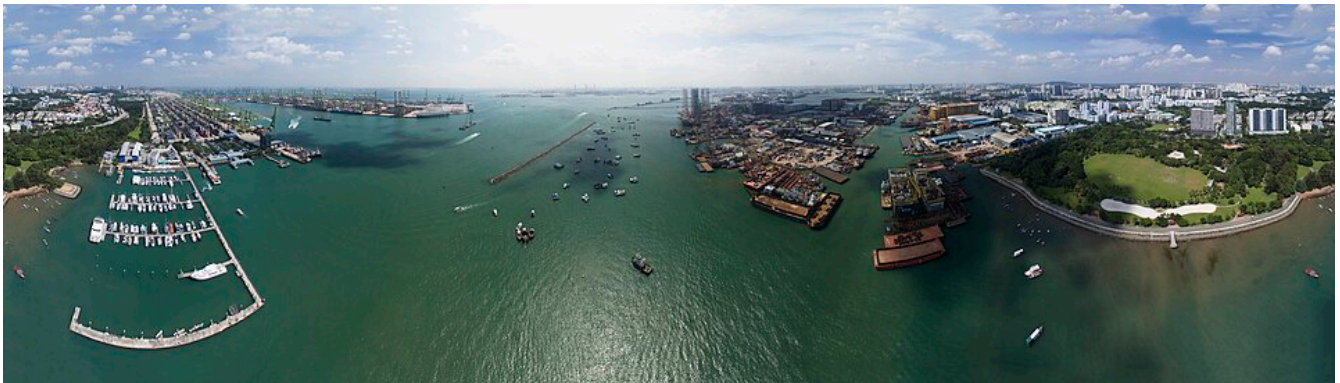


Twenty of the world's busiest container ports (about 2023), part 1: the ports outside East and Southeast Asia. Numbers give the rank of the top ten.



Twenty of the world's busiest container ports, part 2: the fourteen in East and Southeast Asia.

PICTURE STUDY



Aerial panorama of the Pasir Panjang container terminal, Port of Singapore, Photograph by Bob Tan (Wikimedia Commons), CC BY-SA 4.0, 2016 · Color aerial photograph · Wikimedia Commons

In Lesson 4.1 you studied an aerial photograph of Rotterdam. Now look at one of Singapore's container terminals from the air and read it with what you have learned about how a terminal works. From above, a terminal looks like a page of a ledger: neat rows, numbered blocks and straight lines, because every box must be found again in minutes.

Use the terminal diagram in this lesson as a key. Try to find each part of the diagram in the photograph.

Look closely

- Find the quay and the ships tied up along it. How many ships can you count?
- Find the ship-to-shore cranes. Are their booms up (resting) or down over a ship (working)?

- Find the container yard. Can you see lanes between the blocks where machines drive?
- Look for the land side: roads, a gate, or buildings. Where would a truck enter?

Talk about it

1. Which parts of the terminal diagram can you find in the photograph, and which can you not see?
2. Why are the stacks arranged in straight rows and blocks instead of wherever there is room?
3. Compare this photograph with the Rotterdam photograph from Lesson 4.1. What is the same, and what is different?

Safety first. Keep coins and small blocks away from small children, who can choke on them. Wipe up spilled water so no one slips.

PROJECT: THE CONTAINER-SHIP LOADING PUZZLE

You are the ship planner. You will load a model ship with twelve weighted “containers” bound for three ports, float it, and then sail it from port to port, unloading as you go. Your goal is a ship that floats level and never needs a restow. It is harder than it sounds, because the rules fight each other.

You will need

- A rectangular plastic food-storage tub or foil loaf pan about 20 cm by 10 cm (8 by 4 inches): the ship
- Twelve identical blocks (wooden cubes, small boxes, or Lego 2×4 bricks stacked in pairs): the containers
- About 40 coins and masking tape (to add weight), a marker
- A sink, bathtub or large basin with 10 cm (4 inches) of water
- A ruler, graph paper and a pencil; a kitchen scale if you have one

Steps

1. Make the cargo. Label four blocks A (the first port), four B (the second port) and four C (the last port). Tape coins to each block to make it light (0 coins), medium (2 coins) or heavy (4 coins), and write the weight on the label, such as “A-4.” Give each port a mix of light and heavy boxes.
2. Draw the ship on graph paper as a grid: 2 bays (front and back) by 3 rows (left, center, right), stacked 2 tiers high. That is 12 slots. Write the bay, row and tier for each slot.
3. Write your stowage plan. Rules: no A box may sit under a B or C box, and no B box under a C box; heavy boxes go on the bottom tier when possible; left and right sides should hold about the same number of coins, and so should front and back.
4. Load the ship exactly as planned and float it. Measure how high the side of the tub stands above the water (the freeboard) at all four corners. Record any lean to one side (list) or tip toward one end (trim).

5. Sail to Port A. Unload every A box. If you must lift another box to reach one, set it aside, unload the A box, put the other box back, and count one restow. Measure the freeboard again. Is the ship still level?
6. Sail to Port B and then Port C, unloading and measuring each time. Score your voyage: start with 10 points, lose 1 point for each restow, and lose 1 point for every 5 mm (about 1/4 inch) difference between the highest and lowest corner at any port.
7. Late booking: your parent hands you two extra heavy A boxes at the last minute. Re-plan and reload. Then write a paragraph: which rules conflicted, and how did you choose between them?

Tips

- First-port-on-top and heavy-on-the-bottom can clash: a heavy A box wants to go low, but it must come off first. Real planners solve this by spreading heavy boxes across rows and bays and by using ballast.
- Balance the coins around the center of the ship, not just the number of blocks. A heavy box near the side tips the ship more than the same box near the middle.

Check your work

- I can write a stowage plan by bay, row and tier.
- I can load a model ship so it floats nearly level and needs no restows.
- I can explain why the rules of stowage sometimes conflict and how a planner decides.

MAP NOTEBOOK

1. Draw the terminal diagram from memory and label the quay, ship-to-shore cranes, apron, container yard, rail yard and truck gate.
2. On a blank world map, plot and label the twenty busiest container ports from this lesson's maps. Number the top ten in order.
3. Draw a cross-section of a ship (looking from the stern) with six containers, and write the weight in each box so that the ship balances.

From history. Dock work has given English two old words. A **longshoreman** was first an "alongshore man," a worker who labored along the shore. A **stevedore** comes from the Spanish *estibador*, one who packs or stows cargo in a ship's hold. In the age of break-bulk, a good stevedore was a skilled craftsman who knew how to fit thousands of odd-shaped pieces into a hold so tightly that nothing could shift at sea. Today's stowage planners do the same job with computers and boxes.

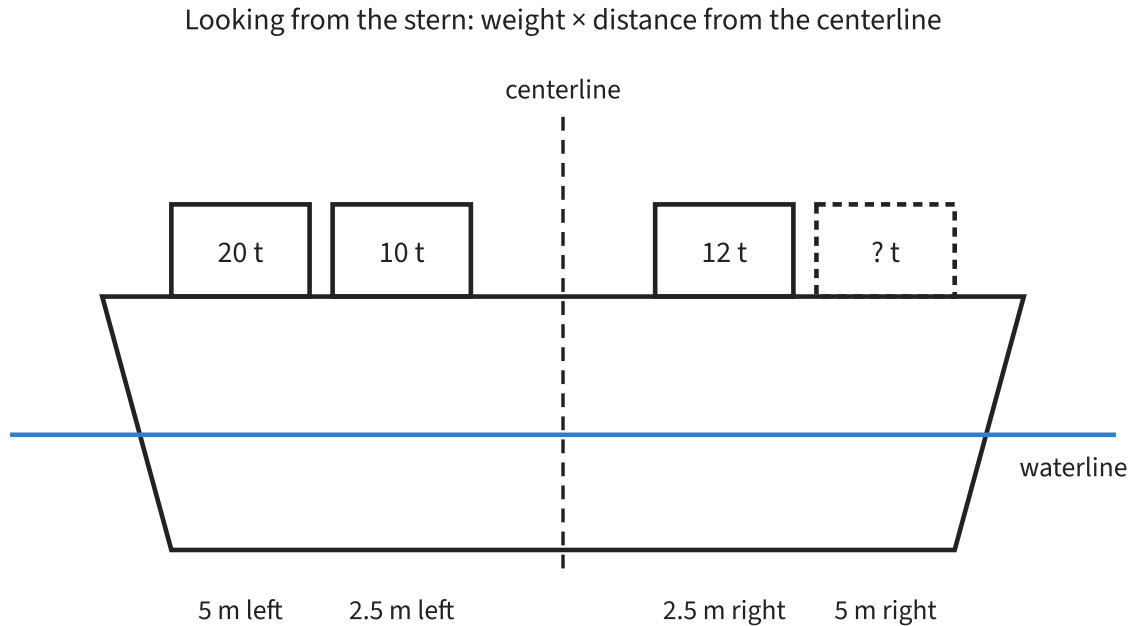
WORKED EXAMPLES

Example 1. A large ship must have 6,000 containers lifted off or on at Rotterdam. Six cranes work the ship, each making 30 moves an hour. How long will the work take?

1. Moves per hour for all cranes: $6 \times 30 = 180$ moves per hour.
2. Time: $6,000 \div 180 = 33.3$ hours.
3. 33.3 hours = 1 day and 9.3 hours, about a day and a half at the berth.
4. Note: a move is one box, whether it is 20 or 40 feet long, so 6,000 moves may be many more than 6,000 TEU.

Answer: About 33 hours, or about a day and a half.

Example 2. Looking at a ship from the stern, containers sit in four rows: 5 m left of the centerline, 2.5 m left, 2.5 m right and 5 m right. The rows hold 20 t (5 m left), 10 t (2.5 m left) and 12 t (2.5 m right). What weight must go in the row 5 m right so the ship does not lean? (Each side balances when the sum of weight $\times$ distance is equal.)



Balance the ship: weight $\times$ distance on each side of the centerline.

1. Left side: $20 \text{ t} \times 5 \text{ m} + 10 \text{ t} \times 2.5 \text{ m} = 100 + 25 = 125$ tonne-meters.
2. Right side so far: $12 \text{ t} \times 2.5 \text{ m} = 30$ tonne-meters.
3. Still needed on the right: $125 - 30 = 95$ tonne-meters.
4. The box sits 5 m from the centerline: $95 \div 5 = 19 \text{ t}$.

Answer: A 19-tonne container (this is a simplified model; real ships also use ballast tanks).

Example 3. Use the two maps of the twenty busiest container ports. How many of the twenty lie in East and Southeast Asia? What percent is that? How many of the top ten lie there?

(Use the map or drawing “Count the ports on this map.” shown earlier in this lesson.)

1. Count the ports on the Asia map: Shanghai, Singapore, Ningbo-Zhoushan, Shenzhen, Qingdao, Guangzhou, Busan, Tianjin, Hong Kong, Port Klang, Xiamen, Tanjung Pelepas, Kaohsiung and Laem Chabang. That is 14.
2. Percent: $14 \div 20 = 0.70 = 70$ percent.
3. Of the top ten, only number 9, Jebel Ali in Dubai, is outside East and Southeast Asia, so 9 of the top 10 are there.

Answer: 14 of 20 (70 percent); 9 of the top 10.

PRACTICE

1. **EASY** What is the name of the tall crane on the quay that lifts containers on and off ships? What part of it grips the box?
2. **EASY** Name three rules a ship planner follows when making a stowage plan.
3. **EASY** What is a reefer, and what kinds of cargo travel in one?
4. **MEDIUM** A ship needs 4,800 moves. Four cranes work it at 30 moves an hour each. How long will it take?
5. **MEDIUM** A terminal gate handles 3,600 trucks in an 18-hour day. How many trucks is that per hour, and about how many per minute?
6. **MEDIUM** A 12-tonne container sits 5 m left of a ship’s centerline. What weight must sit 2.5 m right of the centerline to balance it?
7. **MEDIUM** A container is marked ABCU 123456 0. What does each part of the number mean?
8. **HARD** Use the world map. Which two of the twenty busiest ports are in Europe? Which port lies closest to the Strait of Gibraltar?
(Use the map or drawing “Look for the ports in Europe and near Gibraltar.” shown earlier in this lesson.)
9. **HARD** One stack on a ship holds four containers. From top to bottom they are marked B, A, C, A, where A is the next port, B the port after that and C the last. How many restows are needed at port A? How should the stack be ordered from top to bottom to need none?
10. **CHALLENGE** In 2023 Shanghai handled about 49 million TEU and Rotterdam about 13.4 million. How many times more did Shanghai handle? Then explain in two or three sentences why fourteen of the twenty busiest container ports are in East and Southeast Asia.

COMMON MISTAKES

- Confusing moves with TEU. A crane move lifts one box; a 40-foot box is one move but 2 TEU.
- Always putting heavy boxes on the bottom. A heavy box for the first port may have to ride higher, or a restow will be needed; planners balance the rules against each other.
- Thinking a port works only by day. Big terminals work around the clock, because a ship waiting at the berth earns nothing.

Make it a game · Restow!. Shuffle a deck of cards and deal twelve face down into three stacks of four. Hearts are for Port A, diamonds for Port B, and clubs and spades for Port C. Turn the stacks face up without changing their order. Now “sail” to Port A: take off every heart, but any other card on top of a heart must be moved to another stack first, and each move counts as one restow. Then do Port B and Port C. Next, play again, but this time you may arrange the twelve cards before sailing. Can you reach zero restows? Race a parent to see who plans a perfect ship fastest.

Scripture. “Let all things be done decently and in order.” (1 Corinthians 14:40, KJV)

Paul wrote these words about worship in the church at Corinth, a busy port city. Order is a good gift in every kind of work. A container terminal runs only because thousands of boxes, machines and people move in careful order, and a well-planned ship is safe for its crew.

Practice answers

1. The ship-to-shore (STS) gantry crane. The spreader grips the box by locking twistlocks into its corner fittings.
2. Any three of: heavy boxes low; boxes for the next port on top; weight balanced left and right; weight balanced front and back; reefers where there is power; dangerous goods kept apart.
3. A refrigerated container with its own cooling unit, plugged into power. It carries fruit, meat, fish, dairy foods, flowers and medicines.
4. $4 \times 30 = 120$ moves per hour; $4,800 \div 120 = 40$ hours.
5. $3,600 \div 18 = 200$ trucks per hour; $200 \div 60 =$ about 3.3 trucks per minute.
6. $12 \times 5 = 60$ tonne-meters; $60 \div 2.5 = 24$ tonnes.
7. ABC is the owner code, U means a freight container, 123456 is the serial number, and 0 is the check digit used to catch mistakes in copying the number.
8. Rotterdam and Antwerp-Bruges are in Europe. Tanger Med, in Morocco, lies on the Strait of Gibraltar.
9. To reach the first A, lift off B (1 restow). To reach the bottom A, lift off C (2nd restow). So 2 restows. A better order, top to bottom: A, A, B, C.
10. $49 \div 13.4 =$ about 3.7 times. Sample explanation: East and Southeast Asia have many of the world’s factories and a large share of its people, so huge numbers of containers of manufactured goods are shipped out from there. The main sea roads between Asia, Europe and America pass through the Strait of Malacca and the South China Sea, so hub ports like Singapore, Port Klang and Tanjung Pelepas transship millions of boxes, and each transshipped box is counted twice.

UNIT 4 REVIEW

Answer each question. Show your work for calculations, include units (and both kilometers and miles where asked), and use complete sentences for explanations. The review is worth 60 points.

1. (5 pts) Explain why Rotterdam is called the gateway to Europe. Use the words situation and hinterland.
2. (5 pts) Put these Rhine cities in order from upstream (nearest the Alps) to the sea: Cologne, Rotterdam, Basel, Mainz, Duisburg, Strasbourg.
3. (5 pts) A barge carries 3,000 tonnes and a truck carries 25 tonnes. How many truck loads does one barge replace? A barge moves at 9 km/h upstream over a 180 km stretch of river. How long does it take, and how far is that in miles?
4. (5 pts) Who was Pieter Caland, and what did he build? Why was it needed?
5. (5 pts) Compare how Britain gained Singapore (1819) and Hong Kong (1841-1842). What did each place offer as a port?
6. (5 pts) What is a transshipment hub? A hub unloads 5,000 TEU, of which 80 percent are loaded onto feeder ships. Counting every lift off and on, how many TEU does the port record?
7. (5 pts) The sea route from Singapore to Hong Kong is about 1,450 nautical miles. How long does it take at 18 knots? Give the distance in kilometers (1 nautical mile = 1.852 km).
8. (5 pts) Describe the first voyage of the *Ideal X*: date, ports and cargo. Then explain how break-bulk loading worked and why the container was so much cheaper.
9. (5 pts) A ship carries 2,000 forty-foot containers and 1,500 twenty-foot containers. How many boxes and how many TEU?
10. (5 pts) Why did containers have to be standardized? Give the standard width and the two standard lengths in feet and meters.
11. (5 pts) A ship needs 5,400 moves. Five cranes each make 30 moves an hour. How long will it take? Then: a 16-tonne box sits 5 m left of the centerline; what weight 2.5 m right of the centerline balances it?
12. (5 pts) Name four of the top ten container ports in the world and the country of each. Then explain the restow rule: in what order should boxes be stacked for a ship that will call at ports A, B and C in that order?

UNIT PROJECT: PORT PLANNER'S PORTFOLIO

Show what you have learned about modern ports by assembling a three-part portfolio. First, a large hand-drawn world map of the twenty busiest container ports, with the top ten numbered, the main sea roads drawn between Asia, Europe and North America, and the Strait of Malacca, the Rhine and the Pearl River labeled. Second, your container-ship loading puzzle: the stowage plan on graph paper, your freeboard measurements at each port, your score, and the re-plan after the late booking. Third, a one-page "port profile" of Rotterdam,

Singapore or Hong Kong explaining its site, situation and hinterland, how it began, and one way technology helped it overcome geography.

- **Map accuracy:** All twenty ports are placed correctly and labeled clearly; the top ten are numbered; sea roads, straits and rivers are correct.
- **Stowage plan and records:** The plan gives every box a bay, row and tier; measurements and restows are recorded at each port; the re-plan follows the rules.
- **Port profile:** The profile uses site, situation and hinterland correctly, tells the port's real history accurately, and explains one clear example of technology overcoming geography.
- **Care and clarity:** The work is neat, the writing is in complete sentences, and the numbers include units.

Answer key

1. Rotterdam's situation is at the mouth of the Rhine and Maas, where Europe's busiest river meets the North Sea, with a short, deep channel (the New Waterway) to the sea. Its hinterland, the region it serves, includes the Netherlands, Germany's Rhine valley and Ruhr, and lands as far as Switzerland. Ocean ships unload there, and barges, trains, trucks and pipelines carry the cargo inland.
2. Basel, Strasbourg, Mainz, Cologne, Duisburg, Rotterdam.
3. $3,000 \div 25 = 120$ truck loads. Time: $180 \div 9 = 20$ hours. $180 \text{ km} \div 1.609 = \text{about } 112 \text{ miles}$.
4. A Dutch waterways engineer who designed the New Waterway (Nieuwe Waterweg), dug from 1863 and opened in 1872, a straight new channel from Rotterdam through the dunes at Hook of Holland to the North Sea. It was needed because the old river mouths were silting up and larger steamships could not reach Rotterdam.
5. Singapore: Stamford Raffles signed a treaty with local Malay rulers in 1819 and made it a free port; it offered a harbor at the southern end of the Strait of Malacca on the sea road between India and China. Hong Kong: Britain took it after the First Opium War, fought to protect British merchants' smuggling of opium into China, a wrong cause; the Treaty of Nanking (1842) ceded it. It offered Victoria Harbour, deep and sheltered, at the mouth of the Pearl River, the trade road to southern China.
6. A port where containers change from one ship to another without entering the country, as travelers change planes at a hub airport. Transshipped: $0.80 \times 5,000 = 4,000 \text{ TEU}$. Recorded: $5,000 + 4,000 = 9,000 \text{ TEU}$.
7. $1,450 \div 18 = \text{about } 80.6 \text{ hours}$ (about 3 days 9 hours). $1,450 \times 1.852 = \text{about } 2,685 \text{ km}$ (about 1,670 miles).
8. On 26 April 1956 the *Ideal X*, a converted wartime tanker, sailed from Port Newark, New Jersey, to Houston, Texas, with 58 containers. In break-bulk shipping, longshoremen loaded each sack, crate and barrel by hand, so ships waited in port for days and cargo was damaged or stolen. Containers were packed at the factory and lifted aboard whole by crane in minutes. In 1956 loose cargo cost about \$5.83 a ton to load, the *Ideal X* about 16 cents.
9. Boxes: $2,000 + 1,500 = 3,500$. TEU: $2,000 \times 2 + 1,500 \times 1 = 5,500 \text{ TEU}$.
10. So that every crane, ship, truck and railcar in the world can handle every box, and boxes can move between companies and countries without repacking. Width 8 feet (2.44 m); lengths 20 feet (6.1 m) and 40 feet (12.2 m).

11. $5 \times 30 = 150$ moves per hour; $5,400 \div 150 = 36$ hours. Balance: $16 \times 5 = 80$ tonne-meters; $80 \div 2.5 = 32$ tonnes.
12. Any four, for example: Shanghai (China), Singapore (Singapore), Ningbo-Zhoushan (China), Shenzhen (China), Qingdao (China), Guangzhou (China), Busan (South Korea), Tianjin (China), Jebel Ali (United Arab Emirates), Hong Kong (China). Boxes for A go on top, then B, with C on the bottom, so no box must be lifted off and put back to reach another.

STRAITS AND CHOKE POINTS

In the last unit you visited the great ports where ships load and unload. Now you will follow those ships to sea and discover that the ocean is not as open as it looks. Again and again, the sea lanes of the world squeeze through narrow gates between the continents: **straits**.

Whoever holds the shores of a strait can guard it, tax it or close it, so for thousands of years kings, admirals and merchants have fought to control these few narrow places. The Bible tells us that God “hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation” (Acts 17:26). The straits are among the bounds He set, and they still shape the history and the trade of the nations.

You will stand with Xerxes at the Hellespont and with the Greeks at Salamis, watch the Spanish flagship explode at Gibraltar in 1607, and see Mehmed II build a fortress to cut the throat of the Bosphorus. You will follow Albuquerque to Malacca and Hormuz and learn why a fifth of the world’s oil passes through one narrow sea, and you will see why twenty miles of water protected Britain from Philip II, Napoleon and Hitler, until airplanes and a tunnel finally crossed it. Along the way you will measure in nautical miles and knots, read the currents of a strait, and run your own choke-point traffic game with toy boats.

BEFORE YOU BEGIN

- Can read latitude and longitude on a map (taught in Grade 5)
- Can use a map scale to find distance
- Can compute speed, distance and time (distance = speed × time)
- Knows the great ports of Unit 4, especially Singapore and Rotterdam

MASTERY CHECKLIST

- I can define a strait and a choke point and explain why a strait is both a crossing place and a gate.
- I can locate the world’s eight great straits and name the waters and lands each one joins and divides.
- I can convert between nautical miles, kilometers and miles, and use knots to find travel times.
- I can explain the two-layer currents of Gibraltar and the Bosphorus.
- I can explain why Malacca and Hormuz matter to world trade and how the two are linked.
- I can tell how the English Channel protected Britain and how technology finally crossed it.

OPTIONAL BOOKS AND RESOURCES

- **MarineTraffic live ship map** (<https://www.marinetraffic.com/>): Free to view without an account (with a parent). Zoom in on the Strait of Dover, Singapore and the Strait of Hormuz to see real ships moving through the lanes right now. Count the ships in each strait for your portfolio.
- **Rijksmuseum collection** (<https://www.rijksmuseum.nl/>): Free. Search for “Battle of Gibraltar” to see Cornelis Claesz. van Wieringen’s painting of the Spanish flagship exploding in 1607 in high resolution, and zoom in on the details.
- **Library of Congress maps collection** (<https://www.loc.gov/maps/>): Free. Search for old maps of the Strait of Gibraltar, Constantinople, the Strait of Malacca or the English Channel and compare them with a modern map.

5.1 WHAT IS A STRAIT? ★

OBJECTIVES

- Define a strait and a choke point and explain why a strait is both a crossing place for land travelers and a gate for sea travelers.
- Use nautical miles and knots, and explain territorial seas, transit passage and traffic separation schemes.
- Locate the world's eight great straits on a world map and name the waters each one joins.

Warm-up. Pour a cup of dried beans or rice into a funnel held over a bowl and time how long it takes to run through. Now pour the same amount straight into the bowl from the cup. Which is faster? Put your finger over half of the funnel's spout and try again. Talk about it: what happens to anything that has to pass through a narrow place, and who has power over it?

Watch. *Battle of Salamis 480 BC (Persian Invasion of Greece) DOCUMENTARY* (Kings and Generals, 11:06). <https://www.youtube.com/watch?v=7uhoDZtA9PQ>

With the story: the Battle of Salamis in 480 BC, fought in a narrow strait.

Note: Kings and Generals uses animated maps and battle scenes, and it opens with a short sponsor message.

Backup video. *Global Chokepoints Explained* (Ticket To Know, 6:10).

<https://www.youtube.com/watch?v=nPfofGLVe7o>

With the big idea: the world's great choke points and why they matter.

KEY TERMS

strait

A narrow natural channel of water that joins two larger bodies of water and separates two pieces of land.

choke point

A narrow place on a route that much traffic must pass through, so it can easily be crowded, guarded or blocked.

nautical mile

The sailor's mile: one minute of latitude, about 1.852 km or 1.15 ordinary (statute) miles.

knot

A speed of one nautical mile per hour.

territorial sea

The band of sea, up to 12 nautical miles wide, that a coastal nation may claim along its shore.

traffic separation scheme

A set of one-way shipping lanes with a buffer zone between them, like a divided highway at sea.

CORE IDEAS

The story. In the spring of 480 BC, Xerxes, the Great King of Persia, brought the largest army the Greeks had ever seen to the shore of the Hellespont, the narrow strait we now call the Dardanelles. On one side lay Asia; on the other, Europe. The Greek historian Herodotus tells how the king's engineers lashed hundreds of ships side by side and laid a road across their decks to make two floating bridges from Abydos to the European shore, a crossing of less than a mile. When a storm tore the first bridges apart, Xerxes was so angry that he ordered the water itself to be given three hundred lashes. The bridges were rebuilt, and Herodotus says the army marched across for seven days and seven nights without a pause.

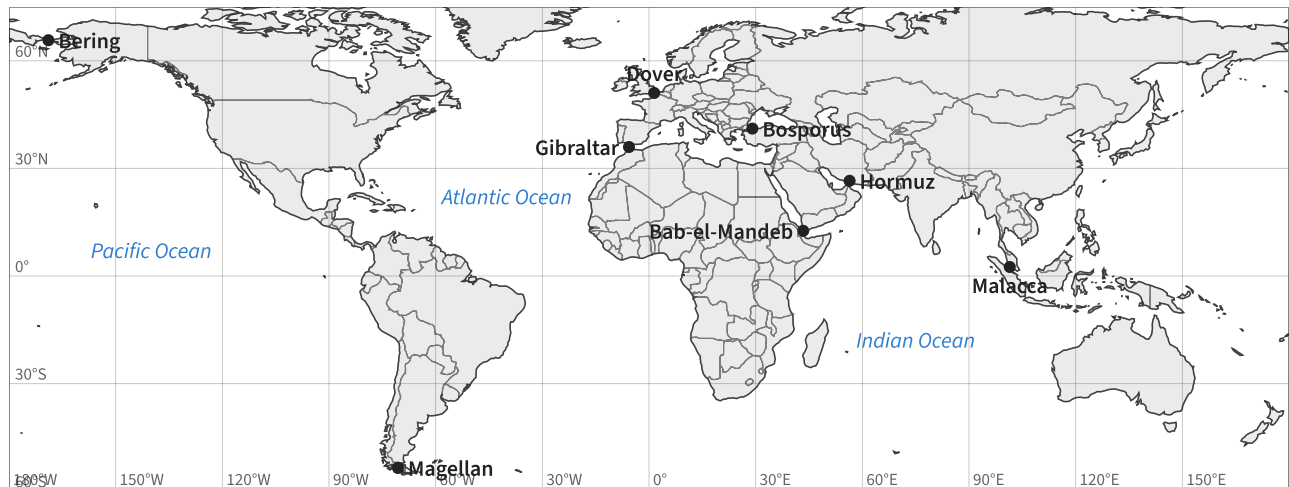
The same strait, the other way. A few months later, in September 480 BC, a narrow sea turned against the Great King. The Athenian general Themistocles persuaded the Greek fleet to fight in the strait between the island of Salamis and the mainland of Attica, a channel only about a mile wide. The Persian fleet was much larger, but in those tight waters its ships could not spread out. They crowded together, fouled one another's oars and were rammed by the Greek triremes. Xerxes watched from a seat on the slope of Mount Aegaleos as his fleet was broken. A narrow sea had cancelled the advantage of numbers.

The big idea. A **strait** is a narrow natural channel of water that joins two larger bodies of water and separates two pieces of land. Every strait has two faces. To people traveling by land, it is a *crossing place*, the shortest hop over the water, as it was for Xerxes. To people traveling by sea, it is a *gate*, a **choke point** that many ships must pass because the way around is very long or does not exist at all. Whoever holds the shores of a strait can watch the traffic, protect it, tax it or block it. That is why forts and cities gather at straits: Istanbul on the Bosphorus, Gibraltar, Singapore, Dover. Mountains and seas change very slowly, so the same straits that mattered to Phoenician and Greek sailors still matter to the captains of container ships and oil tankers today.

How it works. At sea, distance is measured in **nautical miles**. One nautical mile is one minute of latitude, about 1.852 km or 1.15 ordinary miles, so 60 nautical miles equal one degree of latitude. A ship's speed is given in **knots**, nautical miles per hour. Under the United Nations Convention on the Law of the Sea (1982), a coastal nation may claim a **territorial sea** up to 12 nautical miles from its shore. That means any strait narrower than 24 nautical miles lies entirely inside the territorial waters of the nations on its shores. To keep world trade moving, the convention gives ships of every nation a right of *transit passage* through straits used for international navigation: they may pass through without stopping, as long as they keep moving and do no harm. In the busiest straits, ships follow a **traffic separation scheme**: one-way lanes, each with a buffer zone between them, so that ships going opposite ways never meet head on. One of the first was set up in the Strait of Dover in 1967.

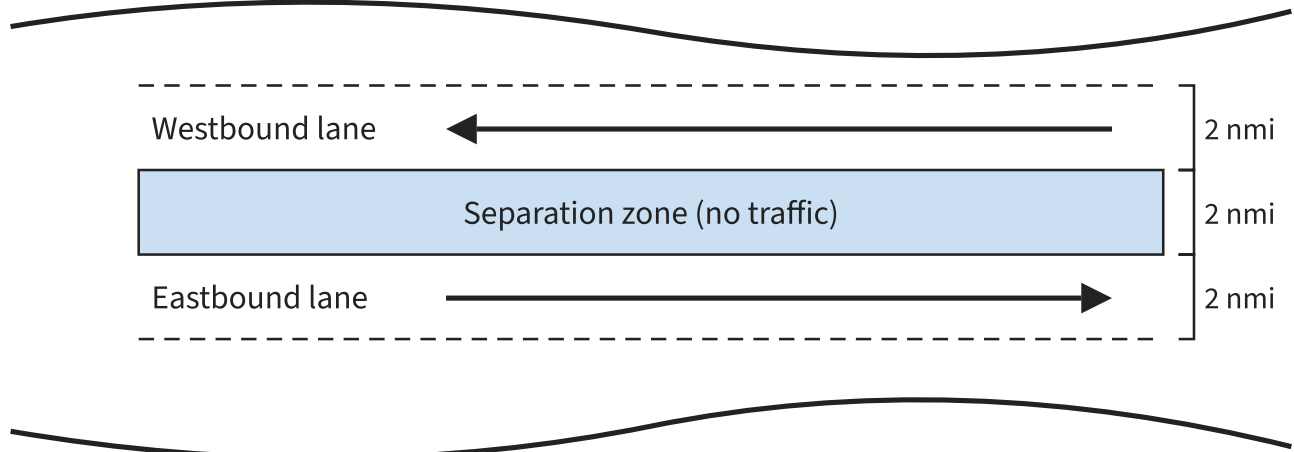
On the map. Find the world's eight great straits on the map. The **Strait of Dover** joins the English Channel and the North Sea. The **Strait of Gibraltar** joins the Atlantic and the Mediterranean. The **Bosporus**, with the Dardanelles, joins the Mediterranean world to the Black Sea. The **Bab-el-Mandeb**, about 20 miles (32 km) wide, joins the Red Sea and the Gulf of Aden. The **Strait of Hormuz** is the only sea door of the Persian Gulf. The **Strait of Malacca** joins the Indian Ocean and the South China Sea. Far to the south, the **Strait of Magellan** winds about 350 miles (560 km) through the tip of South America. Far to the north, the **Bering Strait**, about 51 miles (82 km) wide, separates Russia from Alaska and joins the Pacific to the Arctic Ocean.

Technology overcoming geography. People have fought the narrowness of straits in two ways. To cross them, they build ferries, bridges and tunnels, from Xerxes' ships to the bridges over the Bosporus and the tunnel under the English Channel. To get around them, they dig canals, which are really man-made straits, like Suez and Panama (Unit 6), and lay pipelines that carry oil overland. Yet no machine has made the narrow places wide. The gates God set in the seas still decide where much of the world's trade must go.



The world's eight great straits.

North shore



South shore

A traffic separation scheme: ships keep to the right, like cars on a divided highway. West is to the left, east to the right.

PICTURE STUDY



The Battle of Salamis, Wilhelm von Kaulbach, 1868 · Oil on canvas · Maximilianeum, Munich

Wilhelm von Kaulbach was a German painter of the 1800s who loved grand scenes from history. King Maximilian II of Bavaria asked artists to paint great moments of world history for the Maximilianeum in Munich, and Kaulbach chose the day in 480 BC when the small Greek fleet beat the Persians in the narrow strait of Salamis.

Kaulbach was not there, of course. He built his picture from Herodotus and from his own imagination, so it is a painting of what the battle *meant* as much as of what it looked like.

Look closely

- Look at how crowded the picture is. How does the painter make you feel that there is no room to move?
- Find the oars and the bows of the ships. Which ships seem to be winning?
- Look at the light. Where does the painter want your eye to go first?
- Herodotus says Xerxes watched from a seat on the shore. Look for anyone who seems to be watching rather than fighting.

Talk about it

1. Why would a narrow strait help a smaller fleet against a bigger one?
2. What does Kaulbach seem to think about the victory of the Greeks? How can you tell?
3. If you painted a strait, would you show it as a crossing place or as a gate? Why?

PROJECT: THE CHOKE-POINT TRAFFIC GAME

You will build a strait on the floor or a table and run toy boats through it. By timing and counting, you will see for yourself why narrow seas slow ships down, why one-way lanes help, and why whoever guards a strait has power over the trade that passes through it.

You will need

- 12 to 20 toy boats (bath toys, building-block boats, folded paper boats or bottle caps)
- Masking tape or painter's tape
- A stopwatch or phone timer
- A ruler or tape measure
- Map notebook and pencil
- Two or more players (a parent or siblings)

Steps

1. Make the seas. With tape, mark out two "seas" about 3 feet (1 m) square, one at each end of a table or a stretch of floor, joined by a channel 2 feet (60 cm) long. This channel is your strait.
2. Round 1, a wide strait. Make the channel 4 boat-widths wide. Put half the boats in the west sea and half in the east sea. Each player owns one side. On "Go," players push their boats, one at a time, through the strait to the other sea. Boats may not touch; if two touch, both go back to start. Count how many boats get through in 1 minute.
3. Round 2, a narrow strait. Move the tape so the channel is only 2 boat-widths wide. Play again and count.
4. Round 3, a traffic separation scheme. Keep the channel 2 boat-widths wide, but tape a line down the middle. Each side must keep to its right-hand lane. Play again and count.
5. Round 4, the guard. One player becomes the keeper of the strait. Each boat must stop at a tape line in the middle and wait while the keeper counts to three (an inspection) before going on. Count how many pass in 1 minute.

6. Round 5, the detour. Close the strait with tape. Boats must now go the long way around the outside of the table or room. Measure the length of the detour and count how many get through in 1 minute.
7. Record all five rounds in a table: round, width or rule, boats through in 1 minute. Make a bar graph of your results.
8. Write three sentences: Which rule moved the most boats? What did the guard and the detour do to trade? Which real strait does each round remind you of?

Tips

- Run each round twice and use the larger count, since the first try is often slow while players learn.
- If you have only a few boats, let each boat go back and forth and count crossings instead of boats.
- Save your tape layout and your table. You will use them again in Lessons 5.3 and 5.4 and in the unit portfolio.

Check your work

- I can show with numbers how narrowing a strait slows traffic.
- I can explain why one-way lanes let more ships pass safely.
- I can explain what happens to trade when a strait is guarded or closed.

MAP NOTEBOOK

1. Draw a blank world map in your map notebook and mark the eight great straits with numbered dots. Make a key that names each strait and the two waters it joins.
2. Draw the Hellespont and the strait of Salamis side by side. Under each, write one sentence: was it used as a crossing place or as a gate?
3. Copy the traffic separation scheme diagram and add arrows for a ferry that must cross the lanes. (Ferries cross at a right angle, as quickly as they safely can.)

From history. Ferdinand Magellan's ships reached the eastern mouth of the strait that now bears his name on 21 October 1520. Steering through cold, twisting channels between high mountains, with one ship deserting and turning back to Spain, the fleet took 38 days to pass through. On 28 November 1520 they came out into a calm ocean, which Magellan named the Pacific, the "peaceful" sea.

WORKED EXAMPLES

Example 1. The Strait of Dover is about 21 miles (34 km) wide at its narrowest. How wide is that in nautical miles? Is any part of it outside the territorial seas of Britain and France?

1. One nautical mile is 1.852 km, so $34 \text{ km} \div 1.852 \approx 18.4$ nautical miles. (Check with miles: $21 \div 1.15 \approx 18.3$.)
2. Each nation may claim a territorial sea of 12 nautical miles, so two facing shores can claim $12 + 12 = 24$ nautical miles.
3. Since 18.4 is less than 24, the claims of the two shores meet in the middle, and no strip of open sea is left.

Answer: About 18 nautical miles. The whole strait lies inside British and French territorial waters, so ships from other nations pass by the right of transit passage.

Example 2. About 400 merchant ships pass through the Strait of Dover in a typical day. On average, how many minutes apart are they?

1. A day has $24 \times 60 = 1,440$ minutes.
2. Divide the minutes by the number of ships: $1,440 \div 400 = 3.6$ minutes.
3. 3.6 minutes is 3 minutes and $0.6 \times 60 = 36$ seconds.

Answer: About one ship every 3.6 minutes (3 minutes 36 seconds), day and night.

Example 3. Use the map of the eight great straits. An oil tanker loads in the Persian Gulf and sails to Rotterdam in the Netherlands by way of the Suez Canal. List, in order, the great straits it passes through.

(Use the map or drawing "Trace the tanker's route with your finger." shown earlier in this lesson.)

1. To leave the Persian Gulf, it must go through the Strait of Hormuz into the Gulf of Oman and the Arabian Sea.
2. To enter the Red Sea from the Gulf of Aden, it passes the Bab-el-Mandeb. It then goes north through the Suez Canal (a man-made channel, not a strait) into the Mediterranean.
3. To leave the Mediterranean for the Atlantic, it passes the Strait of Gibraltar.
4. To go from the English Channel into the North Sea, where Rotterdam lies, it passes the Strait of Dover.

Answer: Hormuz, Bab-el-Mandeb, (Suez Canal), Gibraltar, Dover.

PRACTICE

1. **EASY** What is a strait? Give one example.
2. **EASY** Name the two “faces” of a strait and tell who sees each one.
3. **EASY** Convert 30 nautical miles to kilometers and to ordinary miles.
4. **MEDIUM** A ship sails at 12 knots for 5 hours. How far does it go, in nautical miles, kilometers and miles?
5. **MEDIUM** The Strait of Gibraltar is about 13 km (8 miles) wide at its narrowest. How wide is that in nautical miles?
6. **MEDIUM** The Bab-el-Mandeb is about 20 miles (32 km) wide. Is it narrower than 24 nautical miles? What does that mean?
7. **MEDIUM** On the map of the eight great straits, which strait joins the Pacific Ocean to the Arctic Ocean? Which strait did Magellan sail through in 1520, and which two oceans does it join?
(Use the map or drawing “Use the map to answer.” shown earlier in this lesson.)
8. **HARD** Suppose 84,000 ships pass through a strait in a year. How many is that per day, and about how many minutes apart are they?
9. **HARD** In two or three sentences, explain why the narrow strait of Salamis helped the smaller Greek fleet against the larger Persian fleet.
10. **CHALLENGE** A container ship sails from Singapore to Rotterdam by way of the Suez Canal. Name, in order, the great straits it passes, and say which one it passes first after leaving port.

COMMON MISTAKES

- Calling a canal a strait. A strait is natural; a canal is dug by people (though a canal can do the same job).
- Mixing up nautical miles and ordinary miles. A nautical mile is longer: about 1.15 miles or 1.852 km.
- Thinking straits matter only in war. Every day, peaceful trade in food, fuel and goods depends on ships passing safely through them.

Make it a game · Name That Gate. Make eight cards, one for each great strait. On the back of each, write the two waters it joins and the lands on each side. A parent reads the back of a card; you name the strait and point to it on a world map. One point for the name, one for the correct spot. Then switch: you read, and the parent answers. Play until someone reaches 12 points.

Scripture. “And from thence we fetched a compass, and came to Rhegium: and after one day the south wind blew, and we came the next day to Puteoli.” (Acts 28:13, KJV)

On his voyage to Rome as a prisoner, Paul’s ship sailed from Syracuse in Sicily to Rhegium, on the narrow Strait of Messina between Sicily and Italy, and waited there for a south wind to carry it through. Even an apostle traveled by the gates and winds God had set in the sea.

Practice answers

1. A narrow natural channel of water that joins two larger bodies of water and separates two pieces of land. Examples: the Strait of Gibraltar, the Bosphorus, the Strait of Dover.
2. It is a crossing place for people traveling by land (the shortest way over the water), and a gate or choke point for people traveling by sea (a narrow passage ships must go through).
3. $30 \times 1.852 \approx 55.6$ km; $30 \times 1.15 \approx 34.5$ miles.
4. $12 \times 5 = 60$ nautical miles, which is about 111 km or 69 miles (exactly one degree of latitude).
5. $13 \div 1.852 \approx 7.0$ nautical miles.
6. $32 \div 1.852 \approx 17.3$ nautical miles, which is less than 24. The whole strait lies inside the territorial seas of the nations on its shores, so foreign ships pass by the right of transit passage.
7. The Bering Strait joins the Pacific and the Arctic. Magellan sailed through the Strait of Magellan, which joins the Atlantic and the Pacific.
8. $84,000 \div 365 \approx 230$ ships a day. $1,440 \div 230 \approx 6.3$ minutes apart.
9. In the narrow water the Persians could not spread out or use their greater numbers; their ships crowded, collided and fouled their oars. The Greeks could meet them only a few at a time and ram them, so the narrowness cancelled the Persian advantage.
10. Strait of Malacca (first, heading northwest from Singapore), Bab-el-Mandeb, then the Suez Canal (man-made), Strait of Gibraltar, Strait of Dover.

5.2 GIBRALTAR AND THE BOSPORUS

OBJECTIVES

- Locate the Strait of Gibraltar and the Turkish Straits (Bosporus and Dardanelles) and name the seas, lands and cities on each.
- Explain the two-layer currents of Gibraltar and the Bosporus using differences in saltiness and evaporation.
- Tell the stories of the Battle of Gibraltar (1607) and Mehmed II's fortress on the Bosporus (1452) and explain what each shows about the power of a strait.

Warm-up. Fill a clear glass halfway with tap water. Stir 2 tablespoons of salt and a few drops of food coloring into a second cup of water. Very slowly pour the salty water down the side of the glass, or over the back of a spoon. Where does the colored salty water go? Make a guess: if a salty sea and a less salty sea were joined by a narrow strait, which way would each kind of water move?

Watch. *Fall Of Constantinople 1453 - Ottoman Wars DOCUMENTARY* (Kings and Generals, 12:02). <https://www.youtube.com/watch?v=8W0OTGOEY8E>

With the story of the Bosporus: the fall of Constantinople in 1453.

Note: Kings and Generals tells a battle story with animated fighting. Watch with your student.

Backup video. *Why Does Britain Own Gibraltar? (Short Animated Documentary)* (History Matters, 4:04). https://www.youtube.com/watch?v=LMTJW_eEYDs

With the story of Gibraltar: why Britain took the Rock in 1704 and has kept it through every siege since.

KEY TERMS

Pillars of Hercules

The ancient name for the two great rocks that guard the Strait of Gibraltar: the Rock of Gibraltar in Europe and a mountain on the African shore.

evaporation

Water turning to vapor and rising into the air; it leaves the salt behind, so the sea that remains gets saltier.

density

How heavy something is for its size. Salty water is denser than fresh water, so it sinks beneath it.

sill

An underwater ridge across the floor of a strait that makes it shallower than the seas on either side.

Turkish Straits

The Bosphorus, the Sea of Marmara and the Dardanelles together: the only sea passage between the Black Sea and the Mediterranean.

CORE IDEAS

The story. On 25 April 1607, a Dutch fleet of about twenty-six warships sailed into the Bay of Gibraltar. The Dutch had been fighting for their independence from Spain for nearly forty years, and their admiral, Jacob van Heemskerck, had come to strike the Spanish fleet where it guarded the entrance to the Mediterranean. (Ten years earlier, Heemskerck had survived a winter frozen in the Arctic ice of Novaya Zemlya with the explorer Willem Barentsz.) The Spanish ships, under Admiral Juan Álvarez de Ávila, lay at anchor under the guns of the Rock. Early in the battle a cannonball took off Heemskerck's leg, and he died, but his captains fought on. The powder of the Spanish flagship caught fire and the ship blew apart, the very moment shown in our picture study. By evening the Spanish squadron was destroyed. Two years later Spain agreed to the Twelve Years' Truce with the Dutch.

The door of the Mediterranean. Why fight there? Because every ship sailing between the Atlantic and the Mediterranean must pass through the **Strait of Gibraltar**, about 36 miles (58 km) long and only about 8 miles (13 km) wide at its narrowest. The ancient Greeks called the rocks on either side the **Pillars of Hercules** and thought of them as the edge of the known world. The Rock of Gibraltar rises about 1,400 feet (426 m) on the European side; the African shore belongs to Morocco, with the Spanish city of Ceuta on a point of land beside it. The name *Gibraltar* comes from the Arabic *Jabal Tariq*, "Mount of Tariq," after Tariq ibn Ziyad, who crossed here from Africa in 711 and began the Muslim conquest of Spain. Britain captured Gibraltar in 1704, and Spain gave it up by the Treaty of Utrecht in 1713. It is still British, though Spain has long asked for it back.

How it works. The sun beats down on the Mediterranean, and more water evaporates from it than its rivers and rain can replace. Evaporation leaves salt behind, so the Mediterranean is saltier, and therefore denser, than the Atlantic. The result is a two-way flow through the strait. Lighter Atlantic water pours *in* eastward along the surface, while heavier Mediterranean water slides *out* westward along the bottom, spilling over an underwater ridge called the Camarinal Sill, about 300 meters (1,000 feet) deep. For sailing ships this meant that entering the Mediterranean was easy, but leaving it westward against the surface current and the wind could be slow work, and captains sometimes waited in Gibraltar Bay for an east wind, the *levanter*, to carry them out.

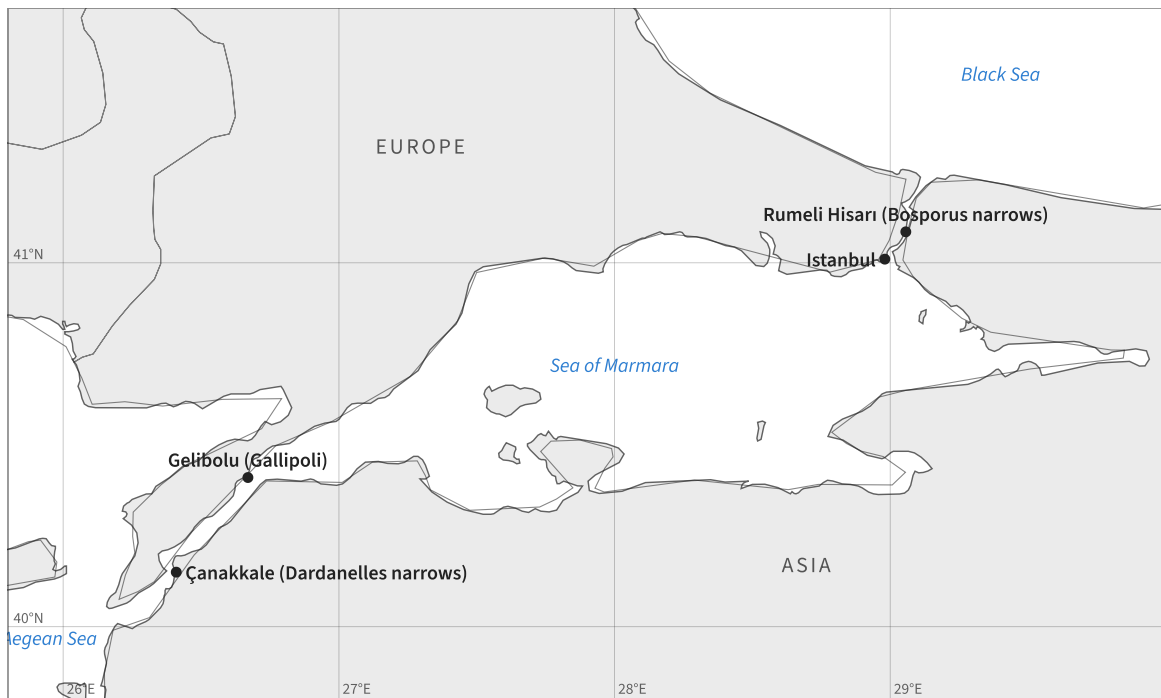
The door of the Black Sea. At the other end of the Mediterranean world lie the **Turkish Straits**. From the Aegean Sea, ships enter the Dardanelles, about 38 miles (61 km) long, cross the little Sea of Marmara, and then pass the **Bosphorus**, about 19 miles (31 km) long and less than a kilometer (about half a mile) wide at its narrowest. Here the flow runs the opposite way. The Black Sea is filled by great rivers such as the Danube, the Dnieper and the Don, so it is *less* salty. Its light surface water flows south through the Bosphorus, while salty Mediterranean water creeps north beneath it. On the Bosphorus stands Istanbul, once Constantinople, the only great city that lies on two continents.

The fortress that cut the throat. In 1452 the young Ottoman sultan Mehmed II built a fortress, Rumeli Hisari, at the narrowest point of the Bosphorus, across the water from an older Ottoman castle on the Asian shore. The Turks called it *Boğazkesen*, which can mean “cutter of the strait” or “throat-cutter.” Its cannons could reach ships passing below, and when a Venetian ship refused to stop that November, it was sunk. Constantinople was cut off from the grain ships of the Black Sea, and on 29 May 1453 the city fell. Ever since, whoever holds the Bosphorus has held the key to the Black Sea. Russia long wanted free passage to warm waters through it; in 1915 British and French fleets tried and failed to force the Dardanelles. Since 1936 the Montreux Convention has let merchant ships pass freely in peacetime while limiting the warships of nations outside the Black Sea.

Technology overcoming geography. The Bosphorus once divided Istanbul into two halves joined only by boats. The first bridge across it opened in 1973, two more followed in 1988 and 2016, and since 2013 the Marmaray railway tunnel has carried trains under the strait from Europe to Asia. At Gibraltar, fast ferries cross from Spain to Morocco in about an hour. Yet the water still rules: roughly 40,000 ships a year thread the narrow, winding Bosphorus right through the middle of a city of millions.



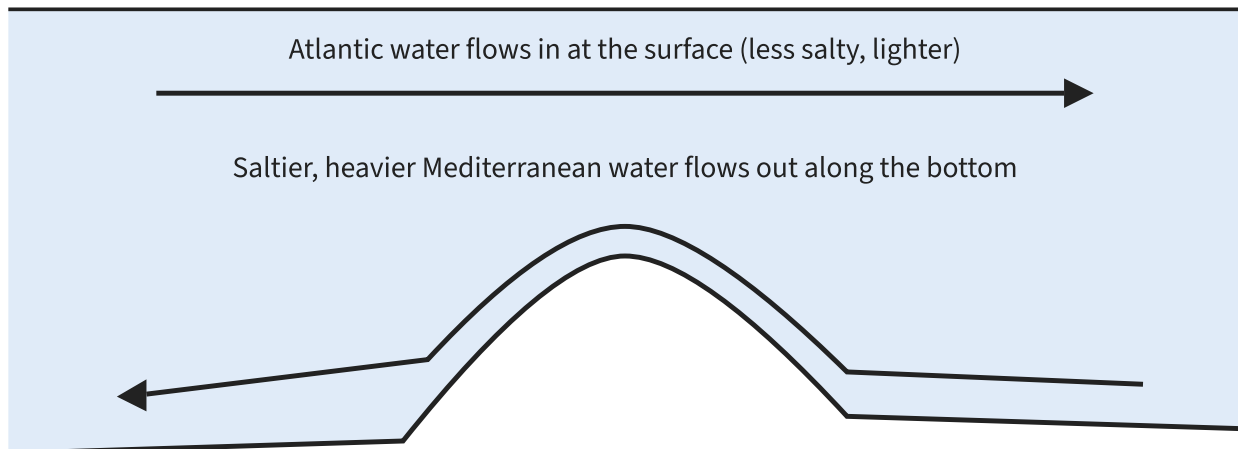
The Strait of Gibraltar, the door of the Mediterranean.



The Turkish Straits: the Dardanelles, the Sea of Marmara and the Bosphorus.

ATLANTIC OCEAN (west)

MEDITERRANEAN SEA (east)



Camarinal Sill, about 300 m deep

The two-layer flow at Gibraltar (not to scale). At the Bosphorus the same thing happens, but the less salty water comes from the Black Sea.

PICTURE STUDY



The Explosion of the Spanish Flagship during the Battle of Gibraltar, 25 April 1607, Cornelis Claesz. van Wieringen, about 1621 · Oil on canvas · Rijksmuseum, Amsterdam

Cornelis Claesz. van Wieringen was a Dutch painter from Haarlem who painted ships and sea battles. About fourteen years after the battle, he painted the moment when the Spanish flagship blew up in the Bay of Gibraltar. For the Dutch, the victory was a proud memory of the long struggle for their independence, and paintings like this hung where people could see and remember.

Notice that the painter does not show a quiet map of the strait. He shows the strait as a place where nations fought for control of the door between the ocean and the Mediterranean.

Look closely

- Find the exploding ship. What is flying through the air around it?
- Look at the flags on the ships. How can you tell the Dutch ships apart?
- Look at the background behind the battle. Can you find land, a town or the Rock?
- Find the smoke from the cannons. Which way does it seem to be blowing?

Talk about it

1. Why would the Dutch want to fight the Spanish fleet at Gibraltar instead of somewhere in the open ocean?
2. The painter shows the battle as both terrible and glorious. Which parts of the picture make you feel each one?
3. Admiral Heemskerck died early in the battle. Why might his captains have fought on anyway?

PROJECT: A TWO-LAYER STRAIT IN A BOX

Oceanographers call this a lock-exchange experiment. You will join a “salty sea” and a “fresh sea” through a gate and watch the salty water slide out along the bottom while the fresh water rushes in along the top, just as at Gibraltar and the Bosphorus.

You will need

- A clear plastic storage box or a glass baking dish, at least 12 inches (30 cm) long
- A piece of stiff plastic or cardboard wrapped in plastic wrap, cut to fit snugly across the box as a divider
- Modeling clay
- Salt (about 1/4 cup) and two colors of food coloring
- Two pitchers of room-temperature water
- A flashlight and a phone camera (optional)

Steps

1. Seal the divider across the middle of the box with a rim of modeling clay so water cannot leak past it.
2. In one pitcher, stir about 1/4 cup of salt into 1 quart (1 liter) of water until it dissolves, and color it blue. This is the salty Mediterranean.
3. Color the other pitcher of plain water yellow. This is the fresher Atlantic (or, for the Bosphorus, the Black Sea).
4. Fill both sides of the box at the same time to the same height.
5. Hold the flashlight behind the box. Lift the divider straight up and out in one smooth motion.
6. Watch from the side. Sketch what you see after 5 seconds, 15 seconds and 1 minute. Which color goes along the bottom? Which along the top? Which way does each move?
7. Empty, rinse and set up again. This time, before filling, press a low ridge of clay across the bottom where the divider stands, about one-quarter as high as the water. This is the sill. Repeat and compare.
8. Label your sketches with Atlantic and Mediterranean (or Black Sea and Marmara) and with arrows for the direction of each current.

Tips

- Make the salty water really salty and the colors strong; the stronger the difference, the clearer the result.
- Lift the divider gently. A fast jerk stirs the water and blurs the layers.
- A phone video in slow motion makes a fine record for your portfolio.

Check your work

- I can explain why salty water slides beneath fresher water.

- I can draw the two-layer flow of Gibraltar and of the Bosphorus with arrows in the right directions.
- I can explain what a sill does to the flow.

MAP NOTEBOOK

1. Trace the Strait of Gibraltar. Label Spain, Morocco, Gibraltar, Ceuta, Tarifa, Tangier, the Atlantic and the Mediterranean, and draw the surface current with an arrow.
2. Draw the Turkish Straits from the Aegean to the Black Sea. Label the Dardanelles, the Sea of Marmara, the Bosphorus and Istanbul, and mark Rumeli Hisarı at the narrows.
3. Draw a cross-section of the Bosphorus like the Gibraltar diagram, with arrows showing which way the surface and bottom water flow.

From history. In 1915, during the First World War, Britain and France tried to force the Dardanelles with battleships so they could reach Constantinople and open a sea route to their ally Russia. On 18 March 1915 the fleet steamed in, but mines laid across the narrow strait sank three battleships and damaged others. The Allies then landed soldiers on the Gallipoli peninsula, including many Australians and New Zealanders, but after eight months of hard fighting they withdrew in January 1916. A narrow strait, well defended, had beaten the strongest navies in the world.

WORKED EXAMPLES

Example 1. On a map with a scale of 1:500,000, how many centimeters would the 13 km narrows of the Strait of Gibraltar measure?

1. Change kilometers to centimeters: $13 \text{ km} = 13 \times 1,000 \text{ m} \times 100 \text{ cm} = 1,300,000 \text{ cm}$.
2. At 1:500,000, every 500,000 cm of ground is 1 cm on the map.
3. $1,300,000 \div 500,000 = 2.6 \text{ cm}$.

Answer: 2.6 cm.

Example 2. Gibraltar lies at about 36.14°N and Ceuta at about 35.89°N , at nearly the same longitude. About how far apart are they, north to south?

(Use the map or drawing “Find Gibraltar and Ceuta on the map.” shown earlier in this lesson.)

1. Difference in latitude: $36.14 - 35.89 = 0.25^\circ$.
2. One degree of latitude is 60 nautical miles, or about 111 km (69 miles).
3. $0.25 \times 60 = 15$ nautical miles; $0.25 \times 111 \approx 28 \text{ km}$; $0.25 \times 69 \approx 17 \text{ miles}$.

Answer: About 15 nautical miles (28 km, or 17 miles). Ceuta is almost due south of Gibraltar.

Example 3. A ship that makes 12 knots through still water sails the Bosphorus, about 31 km (16.7 nautical miles) long. Suppose the surface current runs south at 4 knots. How long does the trip take going north against the current, and going south with it?

1. Going north, the current subtracts from the ship's speed: $12 - 4 = 8$ knots over the ground.
2. Time north: $16.7 \div 8 \approx 2.1$ hours (about 2 hours 5 minutes).
3. Going south, the current adds: $12 + 4 = 16$ knots. Time south: $16.7 \div 16 \approx 1.04$ hours (about 1 hour 3 minutes).

Answer: About 2.1 hours northbound and about 1.0 hour southbound. The same strait takes twice as long one way as the other.

PRACTICE

1. **EASY** Which two continents does the Strait of Gibraltar separate? Which two does the Bosphorus separate?
2. **EASY** Where does the name "Gibraltar" come from?
3. **EASY** Name, in order, the three waters a ship passes from the Aegean Sea to the Black Sea.
4. **MEDIUM** The Bosphorus is about 31 km long. How long would it be on a map with a scale of 1:250,000?
5. **MEDIUM** The Rock of Gibraltar is about 426 m high. How high is that in feet? ($1 \text{ m} \approx 3.28 \text{ ft}$)
6. **MEDIUM** Tarifa, Spain, is at about 36.0°N and Tangier, Morocco, at about 35.8°N . What is the north-south distance between them in nautical miles and kilometers?
(Use the map or drawing "Find Tarifa and Tangier." shown earlier in this lesson.)
7. **MEDIUM** Why does Atlantic water flow into the Mediterranean along the surface at Gibraltar?
8. **HARD** Why does the surface current in the Bosphorus flow south, the opposite of what you might guess from Gibraltar?
9. **HARD** A ship that makes 10 knots in still water sails 16.7 nautical miles north up the Bosphorus against a 3-knot current. How long does it take?
10. **CHALLENGE** In three or four sentences, explain why Mehmed II built Rumeli Hisarı at the narrowest point of the Bosphorus, and what it did to Constantinople.

COMMON MISTAKES

- Thinking water flows only one way through a strait. At Gibraltar and the Bosphorus, two currents flow in opposite directions, one on top of the other.
- Mixing up the Bosphorus and the Dardanelles. The Bosphorus is at Istanbul and opens to the Black Sea; the Dardanelles opens to the Aegean.

- Thinking the whole African shore of the strait is Spanish. Morocco holds the African shore; Ceuta is a small Spanish city on it, and Gibraltar on the European shore is British.

Make it a game · Keeper of the Straits. Set up your tape strait from Lesson 5.1 and name it the Bosphorus. One player is Mehmed, keeper of the strait; the others are merchants. Each merchant boat carries a card: grain, wine, timber or soldiers. As each boat reaches the narrows, Mehmed may ask one question about this lesson. A right answer lets the boat pass; a wrong answer means it must turn back. Merchants score a point for each boat that reaches the far sea. Switch keepers after every five boats.

Scripture. “But Jonah rose up to flee unto Tarshish from the presence of the LORD, and went down to Joppa; and he found a ship going to Tarshish: so he paid the fare thereof, and went down into it, to go with them unto Tarshish from the presence of the LORD.” (Jonah 1:3, KJV)

Many scholars think Tarshish lay in the far west, perhaps in southern Spain near the Strait of Gibraltar, at the very end of the known sea. Jonah tried to sail to the edge of the world to escape God, but no sea gate is beyond His reach.

Practice answers

1. Gibraltar: Europe and Africa. Bosphorus: Europe and Asia.
2. From the Arabic *Jabal Tariq*, “Mount of Tariq,” after Tariq ibn Ziyad, who crossed from Africa into Spain there in 711.
3. The Dardanelles, the Sea of Marmara, the Bosphorus.
4. $31 \text{ km} = 3,100,000 \text{ cm}$; $3,100,000 \div 250,000 = 12.4 \text{ cm}$.
5. $426 \times 3.28 \approx 1,397$ feet, about 1,400 feet.
6. $0.2^\circ \times 60 = 12$ nautical miles; $0.2 \times 111 \approx 22 \text{ km}$.
7. More water evaporates from the Mediterranean than its rivers and rain replace, so its level is kept up by inflow from the Atlantic. Evaporation also leaves the Mediterranean saltier and denser, so its heavy water flows out along the bottom while the lighter Atlantic water flows in on top.
8. The Black Sea receives huge rivers (the Danube, Dnieper and Don), so it has extra, less salty water. That light water flows south at the surface into the Sea of Marmara, while saltier, heavier Mediterranean water flows north underneath.
9. Speed over the ground is $10 - 3 = 7$ knots; $16.7 \div 7 \approx 2.4$ hours (about 2 hours 23 minutes).
10. At the narrows, every ship had to pass close to the shore, within reach of the fortress’s cannons, and the older castle on the Asian side covered the other bank. Together they could stop or sink any ship, as they did a Venetian ship in 1452. This cut Constantinople off from help and grain coming from the Black Sea, weakening the city before the siege that ended with its fall on 29 May 1453.

5.3 MALACCA AND HORMUZ

OBJECTIVES

- Locate the Strait of Malacca and the Strait of Hormuz and name the lands, seas and ports around each.
- Explain how the monsoon winds made Malacca a great market and why so much of the world's oil passes through Hormuz.
- Calculate transit times, oil volumes and widths in nautical miles, kilometers and miles, and explain why these two straits are linked.

Warm-up. Find three things in your house that came from far away: look for “Made in” labels on a toy, a shirt or an electronic gadget. On a world map or globe, put your finger on the country each came from and trace the shortest sea route to your home. How many of your routes squeeze between Sumatra and the Malay Peninsula?

Watch. *The Strait of Hormuz Explained* (Ticket To Know, 6:41).

<https://www.youtube.com/watch?v=udtVdDmSSoo>

With the Strait of Hormuz: why so much of the world's oil passes through it.

Note: Explains the strait plainly; it mentions the 2019 attacks on tankers near the strait.

Backup video. *Time-lapse (60x): transit Malacca Strait / arrival Port Klang (Malaysia) [4K / UHD]*. (SeaTube, 3:20). <https://www.youtube.com/watch?v=pkOHd0Q6SOw>

With the Strait of Malacca: a time-lapse from the bridge of a ship transiting the strait to Port Klang. Note: Ship's-bridge footage with no narration.

KEY TERMS

monsoon

A seasonal wind that blows from one direction for about half the year and then reverses; in the Indian Ocean it set the calendar of trade.

entrepôt

A trading port where goods from many places are brought, stored, traded and shipped on again.

barrel

The standard measure for oil: 42 U.S. gallons, about 159 liters.

supertanker (VLCC)

A “very large crude carrier,” an oil tanker that carries about 2 million barrels.

draft

How deep a ship's hull reaches below the waterline; a ship cannot pass where the water is shallower than its draft.

pipeline

A long pipe that carries oil or gas over land, sometimes used to go around a choke point.

CORE IDEAS

The story. In the summer of 1511, Afonso de Albuquerque, the Portuguese governor in India, arrived off the city of Malacca with a fleet of about eighteen ships. Malacca was the richest market in Asia. Ships from India, Arabia and China came there to trade spices, cloth, porcelain and gold. After weeks of fighting, the city fell to the Portuguese in August 1511. Albuquerque had a plan: Portugal did not need to conquer the whole Indian Ocean, only its gates. He took Goa in India for a base, attacked Aden at the mouth of the Red Sea (and failed), and in 1515 took the island of Hormuz at the mouth of the Persian Gulf. A Portuguese apothecary named Tomé Pires, who lived in Malacca soon after the conquest, wrote: “Whoever is lord of Malacca has his hand on the throat of Venice.” He meant that the spices sold in Venice came through Malacca, so whoever held the strait could squeeze the trade of Europe. The Portuguese held Malacca by force for 130 years, until the Dutch took it in 1641.

How the winds made a market. The **Strait of Malacca** runs about 500 miles (800 km) between the Malay Peninsula and the Indonesian island of Sumatra. It is the shortest sea road between the Indian Ocean and the South China Sea. In the days of sail, the **monsoon** winds decided when ships could move. From about June to September the southwest monsoon blew ships from India eastward; from about December to March the northeast monsoon blew ships from China southward. Neither fleet could go all the way and back in one season, so they met halfway, at the strait, and waited for the wind to change. Around 1400 a prince named Parameswara founded Malacca as a port for them, and it became a great **entrepôt**. Today Singapore, at the southern end of the strait, plays the same part (Unit 4).

On the map. The strait narrows as it runs southeast. In the Singapore Strait, the Phillip Channel is only about 1.7 miles (2.8 km) wide, and the water is shallow enough that the largest, most deeply loaded tankers must take care or go another way, through the Sunda or Lombok Straits in Indonesia, adding days to the voyage. Tens of thousands of ships pass Malacca every year, carrying oil to China, Japan and Korea and bringing back manufactured goods. Piracy once troubled these waters, but since 2004 the navies of Indonesia, Malaysia and Singapore, later joined by Thailand, have patrolled the strait together.

The oil strait. Far to the west, the **Strait of Hormuz** is the only sea door of the Persian Gulf. On its north shore is Iran; on its south shore is the Musandam peninsula, which belongs to Oman. At its narrowest it is about 21 nautical miles (39 km, or 24 miles) across. The ships keep to a traffic separation scheme: an inbound lane and an outbound lane, each about 2 miles wide, with a 2-mile buffer between them. Around the Gulf lie some of the largest oil fields on earth, in Saudi Arabia, Iraq, Kuwait, Iran, the United Arab Emirates and Qatar. In 2024 about 20 million barrels of oil a day passed through Hormuz, roughly one-fifth of all the oil the world uses, along with much of the world’s shipped natural gas. Most of it goes east to Asia, which means that much of the oil that passes Hormuz must pass Malacca too. The two straits are links in one chain.

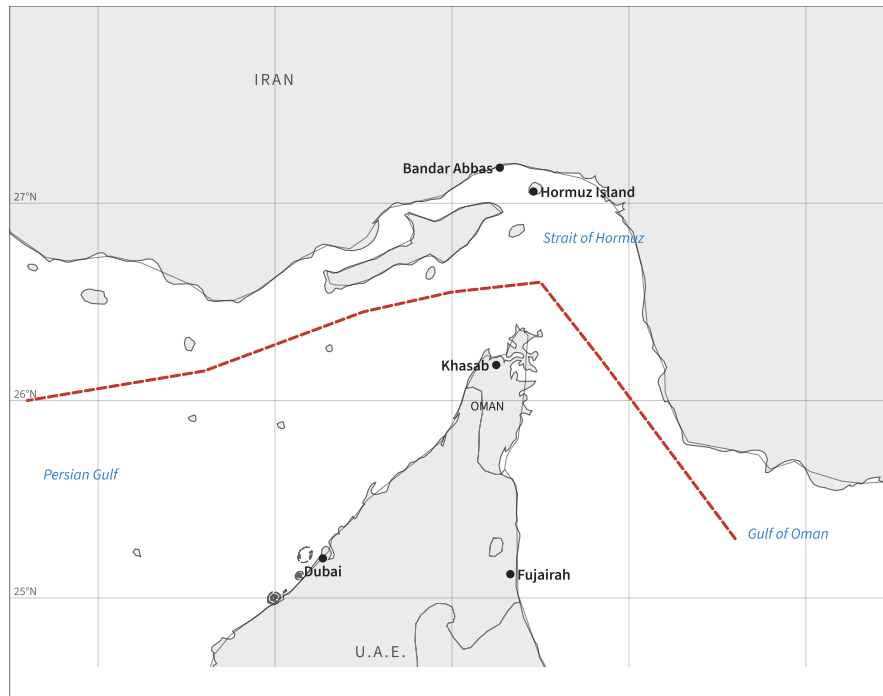
A strait under watch. Hormuz has long been a trading crossroads; Marco Polo visited the busy market of Hormuz in the 1200s, when the town still stood on the mainland shore (it

moved to the island around 1300). In modern times it has also been a place of danger. During the war between Iran and Iraq (1980–1988), both sides attacked tankers in the Gulf, and in 1987 and 1988 the United States Navy escorted Kuwaiti tankers through the strait. Iran has at times threatened to close the strait, and many nations whose trade depends on it keep ships in the region. To lessen the risk, Saudi Arabia built a pipeline across the desert to Yanbu on the Red Sea, and the United Arab Emirates built one to Fujairah on the Gulf of Oman, beyond the strait. Together they can carry only part of the oil, so the strait remains vital.

Technology overcoming geography. A supertanker can carry about 2 million barrels of oil and is about as long as three football fields. Satellites now track every large ship by its radio signal, so anyone with a computer can watch the traffic in both straits. Pipelines carry some oil around Hormuz. Yet the giant ships have made the straits matter more, not less: the bigger the ship, the fewer the passages deep and wide enough for it.



The Strait of Malacca, from the Andaman Sea to Singapore.



The Strait of Hormuz, the only sea door of the Persian Gulf. The route is simplified.

PICTURE STUDY



Portrait of Afonso de Albuquerque, Unknown Portuguese painter, about 1545–1550 · Oil on wood panel · Museu Nacional de Arte Antiga, Lisbon

This portrait was painted some thirty years after Afonso de Albuquerque died in 1515, so the painter probably worked from earlier pictures and from what people remembered.

Albuquerque was famous for his long white beard and his iron will. He was a brilliant planner who saw the Indian Ocean as a map of gates to be held, and he was also a hard and often cruel conqueror. When Malacca fell, his men sacked the city.

Look at the portrait as the Portuguese of the 1500s did: as the face of the man who built their empire in the East, and remember also the people of Malacca, Goa and Hormuz who paid the price of his conquests.

Look closely

- Look at his face and his eyes. What kind of man does the painter want you to see?
- Look at his beard and his clothing. Do they suggest a courtier, a scholar or a soldier?
- Look at the background and any writing or emblems in the picture. What do they add to what we learn about him?

Talk about it

1. Albuquerque saw that holding a few straits could control a whole ocean. Was he right? Use the map to explain.
2. How should we judge a man who was both a brilliant planner and a harsh conqueror?
3. If you painted a portrait of a strait instead of a man, what would you put in it?

PROJECT: MEASURING THE OIL ROAD WITH STRING

You will measure the sea road from the Persian Gulf to Japan on a map with a piece of string, turn it into real distance with the map scale, and then work out how many days a tanker needs. Then you will measure the detour a giant tanker might take around Malacca and see what the strait saves.

You will need

- A printed map of the Indian Ocean and East Asia with a scale bar (from an atlas or printed from the Library of Congress or a free online map)
- A piece of thin string about 3 feet (1 m) long
- A ruler, a fine marker and a calculator
- Your tape strait and toy boats from Lesson 5.1
- Map notebook

Steps

1. On the map, find Ras Tanura (on the Saudi coast of the Persian Gulf, about 26.6°N, 50.2°E) and Yokohama, Japan.
2. Lay the string along the sea route: through the Strait of Hormuz, across the Arabian Sea, around the south of India and Sri Lanka, through the Strait of Malacca and Singapore, then northeast through the South China Sea to Japan. Mark the string where it reaches Yokohama.
3. Lay the marked string along the map's scale bar, a piece at a time, and find the distance in kilometers. Convert it to nautical miles by dividing by 1.852, and to miles by dividing by 1.609.
4. Work out the time: divide nautical miles by 14 knots to get hours, then by 24 to get days.

5. Now measure the detour: from Sri Lanka, go south of Sumatra, through the Lombok Strait (between Bali and Lombok), then north to Japan. Find the distance and the time the same way.
6. Subtract to find what the Strait of Malacca saves in distance and in days.
7. Go back to your floor strait. Run Round 1 again, but now make two of your boats “supertankers” that take up the whole width of the strait. How many boats get through in a minute now?
8. Write a short report: the two distances, the two times, the difference, and one sentence on why the shorter route is worth its crowding.

Tips

- Keep the string tight but not stretched, and follow the curves of the coasts the way a ship would, a safe distance offshore.
- Different maps will give slightly different answers. That is fine; show your work so the reader can follow it.
- Real voyages of this kind take a few weeks. If your answer is a few days or several months, check your scale.

Check your work

- I can measure a sea route on a map with string and a scale bar.
- I can turn a distance and a speed into a travel time in days.
- I can explain how much a strait saves compared with going around.

MAP NOTEBOOK

1. Draw the Strait of Malacca. Label Sumatra, the Malay Peninsula, Singapore, Malacca, the Andaman Sea and the South China Sea. Add two arrows for the monsoons and label their months.
2. Draw the Strait of Hormuz. Label Iran, Oman (Musandam), the Persian Gulf, the Gulf of Oman, Bandar Abbas and the two shipping lanes with their buffer zone.
3. Draw a chain of two links labeled Hormuz and Malacca, and under it write in your own words why trouble in one strait matters to the other.

From history. Between 1405 and 1433, the Chinese admiral Zheng He led seven great voyages into the Indian Ocean with fleets of large ships. He used Malacca as a base and storehouse, and the Ming emperors took the young port under their protection. In 1411 Malacca’s ruler, Parameswara, sailed to China himself to visit the emperor’s court. With Chinese favor and the monsoon winds, the little port grew within a few decades into the busiest market of Southeast Asia.

WORKED EXAMPLES

Example 1. The Strait of Malacca is about 800 km (500 miles) long. How long does a tanker sailing at 15 knots take to pass through it?

(Use the map or drawing “Follow the route from the Andaman Sea to Singapore.” shown earlier in this lesson.)

1. Convert to nautical miles: $800 \div 1.852 \approx 432$ nautical miles.
2. Time = distance $\div$ speed = $432 \div 15 \approx 28.8$ hours.
3. 28.8 hours is 1 day and 4.8 hours, about 1 day and 5 hours.

Answer: About 29 hours, a little more than a day.

Example 2. About 20 million barrels of oil a day passed through the Strait of Hormuz in 2024. How many U.S. gallons is that? How many supertanker loads of 2 million barrels each?

1. One barrel is 42 U.S. gallons: $20,000,000 \times 42 = 840,000,000$ gallons.
2. Supertanker loads: $20,000,000 \div 2,000,000 = 10$.
3. (In real life the oil travels in tankers of many sizes, so the number of ships is larger.)

Answer: About 840 million gallons a day, the same as about 10 full supertankers every day.

Example 3. The Strait of Hormuz is about 21 nautical miles wide at its narrowest. Convert this to kilometers and miles. Is any part of it outside the territorial seas of Iran and Oman?

(Use the map or drawing “Find the narrows between Iran and the Musandam peninsula.” shown earlier in this lesson.)

1. $21 \times 1.852 \approx 38.9$ km; $21 \times 1.15 \approx 24.2$ miles.
2. Two territorial seas of 12 nautical miles each would cover 24 nautical miles.
3. Since 21 is less than 24, the territorial waters of Iran and Oman meet; there is no open sea at the narrows.

Answer: About 39 km (24 miles). The whole narrows lies in Iranian and Omani waters, so foreign ships pass by the right of transit passage, using the lanes on the Omani side.

PRACTICE

1. **EASY** Which two lands border the Strait of Malacca? Which two nations hold the shores of the Strait of Hormuz?

2. **EASY** How many U.S. gallons are in one barrel of oil? About how many liters?
3. **EASY** Use the Malacca map. Which great port city stands at the southern end of the strait?
(Use the map or drawing "Use the map to answer." shown earlier in this lesson.)
4. **MEDIUM** The Phillip Channel near Singapore is about 2.8 km wide. How wide is that in miles and in nautical miles?
5. **MEDIUM** The shipping lanes at Hormuz are each about 2 miles wide with a 2-mile buffer between them. How wide is the whole traffic separation scheme in miles and in kilometers?
6. **MEDIUM** A merchant in the 1400s wants to sail from India to Malacca. In which season should he sail, and why?
7. **MEDIUM** What did Tomé Pires mean when he wrote that whoever is lord of Malacca has his hand on the throat of Venice?
8. **HARD** If 20 million barrels a day pass Hormuz, how many barrels is that in a year (365 days)? How many supertanker loads of 2 million barrels?
9. **HARD** A tanker leaves the Persian Gulf for Japan. Name the two great straits it will most likely pass, in order, and explain why the two straits are called links in one chain.
10. **CHALLENGE** Saudi Arabia and the United Arab Emirates have built pipelines that go around the Strait of Hormuz. In three or four sentences, explain how these pipelines help, and why the strait is still important.

COMMON MISTAKES

- Placing Hormuz at the Red Sea. Hormuz is at the mouth of the Persian Gulf; the Red Sea's gate is the Bab-el-Mandeb.
- Thinking a barrel of oil is the same as a 55-gallon drum. An oil barrel is a measure of 42 gallons.
- Thinking the monsoon is just heavy rain. In geography it is a seasonal reversal of the wind, which brings the rainy and dry seasons with it.

Make it a game • Monsoon Market. Two players are captains: one from India, one from China. A third is the merchant of Malacca. Each captain may sail only when the parent calls his wind: "Southwest monsoon!" lets the Indian captain sail east; "Northeast monsoon!" lets the Chinese captain sail south. Each captain carries cards for goods (cloth and pepper from India; silk and porcelain from China). When both reach Malacca, they trade through the merchant, who keeps one card as his fee. A captain who sails on the wrong wind loses a turn. The first captain to carry four new goods home wins; then ask who got rich without sailing at all.

Scripture. "They that go down to the sea in ships, that do business in great waters; These see the works of the LORD, and his wonders in the deep." (Psalm 107:23-24, KJV)

The merchants who waited at Malacca for the monsoon, and the crews who steer supertankers through Hormuz today, do "business in great waters." The winds that turn with

the seasons are among the works of the Lord they see.

Practice answers

1. Malacca: the Malay Peninsula (Malaysia) and the island of Sumatra (Indonesia). Hormuz: Iran and Oman.
2. 42 gallons, about 159 liters.
3. Singapore.
4. $2.8 \div 1.609 \approx 1.7$ miles; $2.8 \div 1.852 \approx 1.5$ nautical miles.
5. $2 + 2 + 2 = 6$ miles; $6 \times 1.609 \approx 9.7$ km.
6. During the southwest monsoon, about June to September, because that wind blows from the southwest toward the east and carries ships from India toward Malacca.
7. The spices that Venice bought and sold in Europe came from the East through the Strait of Malacca. Whoever controlled the strait could choke off that trade and so had power over Venice's wealth.
8. $20,000,000 \times 365 = 7,300,000,000$ barrels (7.3 billion). $7,300,000,000 \div 2,000,000 = 3,650$ supertanker loads.
9. First the Strait of Hormuz, then the Strait of Malacca (with the Singapore Strait). Most oil from the Gulf goes east to Asia, so the same cargoes pass both straits; trouble in either one would hold up the oil supply of East Asia.
10. The pipelines carry oil overland to ports beyond the strait, at Yanbu on the Red Sea and Fujairah on the Gulf of Oman, so some oil could still be shipped if Hormuz were closed. But together they can carry only part of the oil that normally passes through the strait, and other Gulf producers such as Kuwait, Iraq and Qatar have no such route. So most Gulf oil and gas must still go through Hormuz, and the strait remains one of the most important in the world.

5.4 THE ENGLISH CHANNEL

OBJECTIVES

- Locate the English Channel and the Strait of Dover and name the ports and headlands on each side.
- Explain why a strait only about twenty miles wide protected Britain from invasion for centuries, using the Armada (1588), Napoleon (1803–1805) and 1940.
- Calculate speeds and times for crossings of the Channel, from swimmers to airplanes to trains, and draw a scale cross-section with vertical exaggeration.

Warm-up. Set a large bowl of water on the table and float a small plastic lid in it as a “ship.” Ask someone to make waves by gently rocking the bowl while you try to land a coin on the lid from 1 foot away. Now try in still water. Talk about it: why would an army want calm water and good weather to cross even a short stretch of sea?

Watch. *The Channel Tunnel: Building the World's Longest Undersea Link* (The B1M, 9:31). <https://www.youtube.com/watch?v=gAPahZAapMQ>
With Technology overcoming geography: how the Channel Tunnel was built under the strait.

Note: The B1M opens with a sponsor message for an art-investment company; skip it.

Backup video. *25th July 1909: Louis Blériot makes the first powered cross-Channel flight* (HistoryPod, 3:15). <https://www.youtube.com/watch?v=ThIC41uEhSg>
With the history note: Louis Blériot flies across the Channel in 1909.

KEY TERMS

English Channel

The arm of the Atlantic Ocean between southern England and northern France, called *La Manche* (“the sleeve”) by the French.

Strait of Dover

The narrowest part of the Channel, about 21 miles (34 km) wide, between Dover in England and Calais in France.

invasion

An army entering another country by force to conquer or occupy it.

fireship

An old ship filled with things that burn, set on fire and sent drifting into an enemy fleet.

vertical exaggeration

Stretching the up-and-down scale of a cross-section more than the side-to-side scale so that low hills and shallow seas can be seen.

CORE IDEAS

The story. In late July 1588, English lookouts on the cliffs of Cornwall saw the sails of the Spanish Armada, about 130 ships under the Duke of Medina Sidonia. King Philip II of Spain had sent it up the English Channel to meet the Duke of Parma's army in Flanders and carry it across the narrow sea to invade England. For a week the English ships under Lord Howard of Effingham and Sir Francis Drake chased and harried the Spanish fleet up the Channel. When the Armada anchored off Calais, the English sent eight burning fireships drifting into it on the night of 7 August. The Spanish cut their anchor cables and scattered, and the next day the English attacked them off Gravelines. Meanwhile Parma's barges could not get out at all, for Dutch ships blockaded the shallow coast. A strong wind drove the Armada north into the North Sea, and it limped home around Scotland and Ireland, where storms wrecked many ships. About a third of the fleet never came home.

On the map. The English Channel is about 350 miles (560 km) long. At its western end it is about 150 miles (240 km) wide, but it narrows like a funnel to the **Strait of Dover**, only about 21 miles (34 km) across between the South Foreland near Dover and Cap Gris-Nez near Calais. The white chalk cliffs of Dover face matching chalk cliffs in France; the same rock runs under the sea. On a clear day you can see France from Dover. The Strait of Dover joins the Channel to the North Sea, and it is one of the busiest shipping lanes in the world. Ships heading northeast keep to a lane on the French side and ships heading southwest to a lane on the English side, while ferries cut across between them.

The big idea. Why could twenty miles of water protect a nation? Because an army is strong on land and helpless at sea. To invade, it must gather hundreds of boats, load men, horses and guns, cross in calm weather and land on a guarded shore, all while the enemy's navy tries to sink it. Tides and currents in the Channel are strong and its weather changes quickly. So whoever controls the sea controls the crossing. No invading army has conquered England across the Channel since William the Conqueror in 1066. (When William of Orange landed with an army in 1688, he came at the invitation of many English leaders.) Napoleon gathered a great army at Boulogne from 1803 to 1805 and built flat-bottomed boats to cross, but he could never win command of the Channel. Admiral Lord St Vincent is said to have told the lords of Parliament that he did not say the French could not come; he only said they could not come by sea. After Nelson's victory at Trafalgar in October 1805, the danger was over.

1940 and 1944. In the spring of 1940, Hitler's armies swept through France to the Channel coast. Between 26 May and 4 June, navy ships and hundreds of small civilian boats carried about 338,000 British and French soldiers from the beaches of Dunkirk to England. Hitler planned an invasion, but he knew he needed command of the air over the Channel first. When the Royal Air Force won the Battle of Britain that summer and fall, he put off the invasion and never tried it. Four years later the Allies crossed the other way. On 6 June 1944, D-Day, thousands of ships carried soldiers to the beaches of Normandy, where the Channel is about 100 miles wide, and the engineers even towed two artificial harbors, the Mulberries, across the sea to unload supplies. The Channel works both ways: it is a moat for whoever holds it and a highway for whoever commands it.

Technology overcoming geography. In 1785 the Frenchman Jean-Pierre Blanchard and the American John Jeffries crossed in a hydrogen balloon. In 1875 Captain Matthew Webb became the first person to swim across, in 21 hours and 45 minutes. On 25 July 1909 Louis Blériot flew a small monoplane from near Calais to Dover in about 37 minutes, and newspapers declared that Britain was no longer an island. Finally, on 6 May 1994, Queen Elizabeth II and President François Mitterrand opened the Channel Tunnel, about 31 miles (50 km) long, with about 24 miles (38 km) of it under the sea, the longest undersea stretch of any tunnel in the world. Trains now run from London to Paris in a little over two hours. Yet the sea is still the sea: the strait remains crowded with ships, and storms still stop the ferries.



The English Channel and the Strait of Dover, with the route of the Armada in 1588 and the Channel Tunnel (1994).

PICTURE STUDY



The Armada Portrait of Elizabeth I, Unknown English painter (once attributed to George Gower), about 1588
· Oil on oak panel · Royal Museums Greenwich (the Queen's House), London

This famous portrait was painted soon after the defeat of the Spanish Armada. Three versions survive; this one hangs in the Queen's House at Greenwich, beside the Thames, close to where the Tudor navy was built and supplied.

The painting is full of symbols. It is less a picture of how the queen looked on one day than a statement of what the English believed the victory meant for their country and its future on the seas.

Look closely

- Find the globe. Where is the queen's hand resting? What part of the world is under her fingers?
- Look at the window on the left. What is happening to the Spanish fleet there?
- Look at the window on the right. How is the weather different, and what has happened to the ships?
- Find the crown. Where has the painter placed it, and why might that matter?

Talk about it

1. Why would the painter put a globe in a picture about a battle in the English Channel?
2. The two windows show the English fireships and then the storm. Which do you think the English believed won the victory, their ships or the wind?
3. How does this painting show the idea that the Channel protected England?

PROJECT: A SCALE CROSS-SECTION OF THE STRAIT OF DOVER

A strait looks wide on a map but is surprisingly shallow. You will draw a cross-section of the Strait of Dover from England to France at true horizontal scale, then stretch the depth so you can see it, and mark the Channel Tunnel running through the rock beneath the seabed.

You will need

- A strip of paper at least 40 cm (16 inches) long and 15 cm (6 inches) tall (tape two sheets end to end)
- Ruler, pencil, colored pencils
- A map of the Strait of Dover (the lesson map or an atlas)
- Your floor strait and toy boats from Lesson 5.1 (for the last step)

Steps

1. Draw a straight sea-level line across the strip, about 5 cm from the top. Mark England at the left end and France at a point 34 cm to the right. Horizontal scale: 1 cm = 1 km.
2. Vertical scale: 1 cm = 10 m. Draw the cliffs at each end: the white chalk cliffs at Dover rising about 10 cm (100 m) above sea level, and the lower cliffs of Cap Gris-Nez in France about 5 cm (50 m).
3. The seabed of the Strait of Dover is mostly between about 35 and 55 meters (120 to 180 feet) deep. Draw the seabed as a gently wavy line between 3.5 and 5.5 cm below sea level, sloping up to meet the cliffs at each shore.
4. Color the sea blue and the chalk white or pale gray. Below the seabed, draw a darker band for the chalk marl, the firm, watertight rock the tunnel builders followed.
5. Draw the Channel Tunnel as a line inside the chalk marl, below the seabed all the way across, and label it "Channel Tunnel, opened 1994."
6. Write on the strip: "Vertical exaggeration 100 times," and explain in one sentence what that means.
7. Below the drawing, make a timeline of crossings: balloon 1785, swim 1875, airplane 1909, tunnel 1994, with the time each took.
8. Return to your floor strait. Add a "ferry" that must cross the two shipping lanes at a right angle while boats pass. Count how long it waits for a safe gap.

Tips

- If you drew the depth at the same scale as the width, the whole sea would be a line thinner than a pencil mark. That is why vertical exaggeration is needed.
- Keep the tunnel in the rock below the sea. It does not lie on the seabed.
- Use a long ruler or a yardstick to keep your sea-level line straight.

Check your work

- I can draw a cross-section using two different scales.
- I can calculate and explain vertical exaggeration.

- I can tell the story of crossing the Channel from 1785 to 1994.

MAP NOTEBOOK

1. Trace the English Channel. Label England, France, Plymouth, Portsmouth, Dover, Calais, Boulogne, Le Havre, Cherbourg, the Strait of Dover and the North Sea. Draw the route of the Armada with arrows.
2. Draw a small sketch of the two shipping lanes in the Strait of Dover. Show with arrows which lane goes northeast and which goes southwest, and draw a ferry crossing them.
3. Make a three-column table titled “The Channel as a Moat”: Invader, Year, Why he could not cross. Fill it in for Philip II, Napoleon and Hitler.

From history. On 7 January 1785, the French balloonist Jean-Pierre Blanchard and his American companion, Dr. John Jeffries, rose in a hydrogen balloon from Dover Castle and set out for France. Halfway across, the balloon began to sink toward the sea. They threw out their sandbags, their equipment and even much of their clothing to stay aloft, and at last they drifted over the French coast and came down safely in the forest of Guînes, near Calais. It was the first crossing of the Channel by air, 124 years before Blériot.

WORKED EXAMPLES

Example 1. Louis Blériot crossed the Channel in about 37 minutes in 1909. If he had flown straight across the narrowest part, 21 miles (34 km), what would his average speed have been in miles per hour and in kilometers per hour?

1. 37 minutes = $37 \div 60 \approx 0.617$ hours.
2. Miles per hour: $21 \div 0.617 \approx 34$ mph.
3. Kilometers per hour: $34 \div 0.617 \approx 55$ km/h.

Answer: About 34 mph (55 km/h), about as fast as a car on a country road.

Example 2. Matthew Webb swam the Channel in 21 hours and 45 minutes in 1875. If he had swum straight across the 21-mile (34 km) narrows, what would his average speed have been? How many times faster was Blériot?

1. 21 hours 45 minutes = 21.75 hours.
2. Speed: $21 \div 21.75 \approx 0.97$ mph ($34 \div 21.75 \approx 1.6$ km/h).
3. Compare: $34 \div 0.97 \approx 35$. (Or compare times: 21.75 hours = 1,305 minutes, and $1,305 \div 37 \approx 35$.)

Answer: About 1 mph (1.6 km/h). Blériot was about 35 times faster. (In fact the tides pushed Webb back and forth, so he swam much farther than 21 miles.)

Example 3. In your cross-section of the Strait of Dover, the horizontal scale is 1 cm = 1 km and the vertical scale is 1 cm = 10 m. What is the vertical exaggeration? How deep would a 50 m seabed be drawn if there were no exaggeration?

1. Write both scales in the same units: horizontal 1 cm = 1,000 m; vertical 1 cm = 10 m.
2. Vertical exaggeration = $1,000 \div 10 = 100$. Heights and depths are drawn 100 times larger than widths.
3. Without exaggeration, 50 m would be drawn at the horizontal scale: $50 \text{ m} \div 1,000 \text{ m per cm} = 0.05 \text{ cm}$, only half a millimeter.

Answer: A vertical exaggeration of 100. Without it, the 50 m seabed would be only 0.05 cm (0.5 mm) deep on the drawing, too thin to see.

PRACTICE

1. **EASY** How wide is the Strait of Dover at its narrowest, in miles and kilometers? Which two towns face each other across it?
2. **EASY** What was the Spanish Armada trying to do in 1588, and what stopped Parma's army from crossing?
3. **EASY** When was the Channel Tunnel opened, and about how long is it?
4. **MEDIUM** The western end of the English Channel is about 150 miles wide. Convert this to kilometers and to nautical miles.
5. **MEDIUM** About 38 km of the 50 km Channel Tunnel lies under the sea. What percent is that?
6. **MEDIUM** Suppose a train runs through the 50 km Channel Tunnel at 160 km/h. How many minutes does it spend in the tunnel?
7. **MEDIUM** Use the Channel map. Which French port is nearest to Dover? In which compass direction is it from Dover?
(Use the map or drawing "Use the map to answer." shown earlier in this lesson.)
8. **HARD** Dover is at about 51.1°N. The D-Day beaches in Normandy are at about 49.35°N. How far apart are they north to south, in nautical miles, kilometers and miles?
9. **HARD** In the Strait of Dover, ships keep to the right, as on a road. A ship heading northeast toward the North Sea: does it use the lane nearer France or nearer England? Explain.
10. **CHALLENGE** In four or five sentences, explain why the Strait of Dover, only 21 miles wide, protected England from Philip II, Napoleon and Hitler, and what the Allies needed in 1944 to cross it the other way.

COMMON MISTAKES

- Thinking England was never invaded. It was conquered in 1066; the point is that no invader has conquered it across the Channel since.

- Thinking the Channel Tunnel lies on the seabed. It was bored through rock well below the seabed.
- Measuring the Channel at its widest when people speak of “twenty miles.” That is the Strait of Dover, the narrow eastern end.

Make it a game · Cross the Channel. Make a timeline game on the floor with six index cards in a row: 1066, 1588, 1785, 1805, 1909, 1994. Shuffle six clue cards (William the Conqueror lands; the Armada is scattered; Blanchard and Jeffries fly a balloon; Nelson wins at Trafalgar; Blériot lands at Dover; the tunnel opens). Race a parent or sibling to lay each clue on the right year, then cross the “Channel” by telling one fact about each event. Fastest correct crossing wins.

Scripture. “Thou rulest the raging of the sea: when the waves thereof arise, thou stillest them.” (Psalm 89:9, KJV)

The English and Dutch of 1588 gave thanks to God for the wind that scattered the Armada, and many soldiers at Dunkirk in 1940 remembered the calm seas that let small boats carry them home. Navies and engineers matter, but the winds and waves are ruled by the Lord.

Practice answers

1. About 21 miles (34 km). Dover in England and Calais in France.
2. It was sailing up the Channel to meet the Duke of Parma’s army in Flanders and carry it across to invade England. English attacks (including fireships at Calais and the fight off Gravelines), the Dutch blockade of Parma’s barges, and the wind that drove the Armada north stopped the crossing.
3. On 6 May 1994. About 31 miles (50 km), with about 24 miles (38 km) under the sea.
4. $150 \times 1.609 \approx 241$ km; $241 \div 1.852 \approx 130$ nautical miles.
5. $38 \div 50 = 0.76$, so 76 percent.
6. $50 \div 160 = 0.3125$ hours; $0.3125 \times 60 \approx 19$ minutes.
7. Calais. It lies to the southeast (east-southeast) of Dover.
8. $51.1 - 49.35 = 1.75^\circ$. $1.75 \times 60 = 105$ nautical miles; $1.75 \times 111 \approx 194$ km; $1.75 \times 69 \approx 121$ miles.
9. The lane nearer France. Facing northeast, your right hand points southeast, toward the French coast, so northeast-bound ships keep to the French side and southwest-bound ships keep to the English side.
10. An army is strong on land but helpless at sea; to cross, it must load men and supplies onto boats, wait for calm weather and land under fire, while the enemy navy and air force try to destroy it. Philip II’s Armada never won control of the Channel, Napoleon could never gain command of the sea long enough to cross, and Hitler could not win control of the air in the Battle of Britain. In 1944 the Allies crossed because they held command of both the sea and the air, gathered thousands of ships, planned carefully for weather and tides, and even brought their own artificial harbors.

UNIT 5 REVIEW

Answer each question. Show your work for calculations, give both metric and U.S. units where asked, and use complete sentences for explanations. Use 1 nautical mile = 1.852 km = 1.15 miles. The review is worth 60 points.

1. (5 pts) Define a strait and a choke point. Explain the two “faces” of a strait with one example of each.
2. (5 pts) A strait is 30 km wide. How wide is it in nautical miles? Do the territorial seas of the two shores cover all of it? Explain.
3. (5 pts) Name the eight great straits of this unit (shown on the map in Lesson 5.1), and for each, the two bodies of water it joins.
4. (5 pts) A ship sails at 14 knots for 6 hours. How far does it go in nautical miles, kilometers and miles?
5. (5 pts) Draw or describe the two currents in the Strait of Gibraltar. Which way does each flow, and why?
6. (5 pts) Why did Mehmed II build Rumeli Hisarı in 1452, and why at that spot?
7. (5 pts) On a map at 1:500,000, the narrows of a strait measure 2.6 cm. How wide is the strait in kilometers and miles? Which strait could this be?
8. (5 pts) Why did Malacca become a great market around 1400? Use the word monsoon in your answer.
9. (5 pts) A tanker at 12 knots sails the 432-nautical-mile length of the Strait of Malacca. How many hours does it take? If about 20 million barrels of oil a day pass Hormuz, how many 2-million-barrel supertanker loads is that in a week?
10. (5 pts) Explain in two or three sentences why trouble in the Strait of Hormuz would matter to Japan or Korea, even though they are thousands of miles away.
11. (5 pts) Louis Blériot crossed the Channel in about 37 minutes in 1909. If the crossing was 21 miles (34 km), what was his average speed in mph and km/h?
12. (5 pts) Give two reasons the English Channel protected Britain from invasion, and name the invader stopped in 1588, in 1805 and in 1940.

UNIT PROJECT: MY ATLAS OF THE GREAT STRAITS

Make a large world map that shows the eight great straits, each with a numbered marker and a small inset drawing of the strait with its lands, seas and chief ports. For each strait, write a card with its width (in km, miles and nautical miles), the waters it joins, and one real story from history. Add the results of your choke-point traffic game (your table and bar graph), your two-layer strait sketches, your oil-road calculation and your scale cross-section of the Strait of Dover. Finish with a paragraph explaining why a few narrow seas have so much power over the trade of the whole world, and one way technology has tried to overcome them.

- **Accuracy:** All eight straits are placed correctly, with the right seas, lands and ports labeled, and widths given correctly in three units.

- **Investigation:** The traffic game table and graph, the two-layer experiment sketches, the oil-road measurement and the cross-section are complete, with work shown.
- **Explanation:** The paragraph clearly explains choke points, uses at least two real stories from the unit, and names a technology that crossed or bypassed a strait.
- **Care:** The atlas is neat, colorful, easy to read and has a clear key and title.

Answer key

1. A strait is a narrow natural channel of water joining two larger bodies of water and separating two pieces of land. A choke point is a narrow place that much traffic must pass, so it can be crowded, guarded or blocked. To land travelers a strait is a crossing place (Xerxes bridging the Hellespont); to sea travelers it is a gate or choke point (ships passing Gibraltar into the Mediterranean).
2. $30 \div 1.852 \approx 16.2$ nautical miles. Yes: two territorial seas of 12 nautical miles each can reach 24 nautical miles, which is more than 16.2, so the whole strait lies in territorial waters (ships pass by the right of transit passage).
3. Dover: English Channel and North Sea. Gibraltar: Atlantic and Mediterranean. Bosphorus: Black Sea and Sea of Marmara (with the Dardanelles, to the Mediterranean). Bab-el-Mandeb: Red Sea and Gulf of Aden. Hormuz: Persian Gulf and Gulf of Oman. Malacca: Indian Ocean (Andaman Sea) and South China Sea. Magellan: Atlantic and Pacific. Bering: Pacific and Arctic.
4. $14 \times 6 = 84$ nautical miles; $84 \times 1.852 \approx 156$ km; $84 \times 1.15 \approx 97$ miles.
5. Less salty Atlantic water flows east into the Mediterranean along the surface; saltier, denser Mediterranean water flows west out into the Atlantic along the bottom, over the sill. The Mediterranean loses more water to evaporation than rivers and rain replace, which makes it saltier and draws Atlantic water in.
6. To control the Bosphorus and cut Constantinople off from ships and grain coming from the Black Sea before his siege. He built it at the narrowest point, where every ship had to pass within reach of the fortress's cannons, opposite an older Ottoman castle on the Asian shore.
7. $2.6 \times 500,000 = 1,300,000$ cm = 13 km; $13 \div 1.609 \approx 8$ miles. This matches the Strait of Gibraltar.
8. The monsoon winds reverse with the seasons: the southwest monsoon carried ships from India east, and the northeast monsoon carried ships from China south. Neither could make the whole round trip in one season, so they met halfway at the Strait of Malacca and waited there for the wind to change, which made Malacca a great entrepôt.
9. $432 \div 12 = 36$ hours (1.5 days). $20,000,000 \times 7 = 140,000,000$ barrels; $140,000,000 \div 2,000,000 = 70$ supertanker loads.
10. Much of the oil and gas that Japan and Korea buy comes from the Persian Gulf, and the Strait of Hormuz is the Gulf's only sea door. The same tankers then pass Malacca on the way to East Asia, so if Hormuz were blocked, much of their fuel supply would be cut off or would cost far more.
11. $37 \div 60 \approx 0.617$ h. $21 \div 0.617 \approx 34$ mph; $34 \div 0.617 \approx 55$ km/h.
12. Any two: an army must cross by sea and is helpless in boats; the invader needs command of the sea (and later the air); tides, currents and sudden storms make the crossing dangerous; landing on a guarded shore is very hard. 1588: Philip II of Spain (the Armada). 1805: Napoleon. 1940: Hitler.

CANALS THROUGH CONTINENTS

God laid out the continents and the seas, and the shape of the land decides where ships can go. For thousands of years a ship that wanted to go from Europe to India had to sail around Africa, and a ship from New York to San Francisco had to round the stormy tip of South America. Rivers in China ran east when the rice needed to go north, and the Great Lakes sat on a staircase of waterfalls and rapids that no ocean ship could climb. In this unit you will see how people studied that geography and then cut through it. “And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;” (Acts 17:26). The canals in this unit changed which nations traded with which, and how fast.

You will follow grain barges up China’s Grand Canal and meet Qiao Weiyue, who built the first pound lock in 984. You will stand at Port Said in 1869 as the Suez Canal opens, and learn why it needs no locks. You will fight yellow fever with William Gorgas and dig the Culebra Cut with George Goethals at Panama. Finally you will ride the St. Lawrence Seaway from Montreal up a staircase of lakes to Duluth. In every lesson you will measure: lock lifts, water volumes, distances saved and days saved.

With your own hands you will tow a barge of rice, cut a sea-level canal in a sand tray, build a working lock from plastic bottles and draw the Great Lakes staircase to scale. Your portfolio map will show all four canals and the voyages they shorten.

BEFORE YOU BEGIN

- Can read latitude and longitude on a map and convert degrees of latitude to distance (about 111 km or 69 miles per degree)
- Can convert between kilometers and miles and between meters and feet
- Can find the volume of a box ($\text{length} \times \text{width} \times \text{height}$) and work with percents
- Knows what a strait and a choke point are (Unit 5)

MASTERY CHECKLIST

- I can explain why China’s Grand Canal was dug and trace it from Hangzhou to Beijing across five river systems.
- I can explain how a pound lock raises and lowers a boat using only gravity, and calculate the water it uses.
- I can explain why Suez is a sea-level canal and Panama is a lock canal.
- I can tell how Gorgas defeated yellow fever and why that made the Panama Canal possible.
- I can read the staircase of the Great Lakes and explain how the Welland Canal bypasses Niagara Falls.
- I can calculate the distance and time a canal saves on a real voyage.

OPTIONAL BOOKS AND RESOURCES

- **Panama Canal Authority** (<https://pancanal.com/en/>): Free. The official site of the canal, with facts, history and live webcams of the Miraflores and Gatun locks, where students can watch ships rise and fall in real time.
- **Great Lakes St. Lawrence Seaway System** (<https://greatlakes-seaway.com/en/>): Free. The official site of the Seaway, with maps, lock facts and information about the ships and cargo that use it.
- **UNESCO World Heritage: The Grand Canal** (<https://whc.unesco.org/en/list/1443>): Free. UNESCO's page for the Grand Canal of China, with a description, maps and photographs of its locks, towns and bridges.

6.1 THE GRAND CANAL OF CHINA ★ ⚙️

OBJECTIVES

- Explain why China's rulers dug a canal to carry rice from the warm, wet south to capitals in the dry north.
- Trace the Grand Canal from Hangzhou to Beijing and name the five river systems it joins.
- Describe how Qiao Weiye's pound lock of 984 lifted barges, and calculate the water a lock uses.

Warm-up. Fill a baking dish with water and float a small plastic tub loaded with a cup of rice. Tie a string to it and tow it gently across the water with one finger. Now set the same loaded tub on the table and drag it by the string. Which was easier? Talk about why a ruler who needed to move mountains of rice might want water roads instead of dirt roads.

Watch. *The Grand Canal - UNESCO World Heritage Site* (World Heritage Journey, 3:26).
<https://www.youtube.com/watch?v=-O19SeNgauA>

With the story: China's Grand Canal, the longest canal of the old world.

Backup video. *The Surprising Efficiency of Canal Locks* (Practical Engineering, 10:37).
<https://www.youtube.com/watch?v=SBvclVcesEE>

With How it worked: why a pound lock saves so much water.

KEY TERMS

canal

A waterway dug by people to carry boats or water, often joining rivers, lakes or seas that nature left apart.

pound lock

A chamber with a gate at each end. Water is let in or out to raise or lower a boat between two water levels. Qiao Weiye built the first known one in China in 984.

summit level

The highest stretch of a canal, where it crosses a rise in the land. Water must be brought to it from streams or lakes, because water runs away downhill from both ends.

tribute grain

Rice and other grain sent as taxes from the provinces to feed the capital, the court and the army.

barge

A flat-bottomed boat for carrying heavy cargo on rivers and canals, often towed by people or animals walking on the bank.

towpath

A path along a canal bank where people or animals walked, pulling boats with ropes.

CORE IDEAS

The story. In the year 984, during the Song dynasty, an official named Qiao Weiyue was in charge of grain transport on a busy stretch of canal in the Huai River country. Every year thousands of barges loaded with rice passed his way, heading north to feed the capital. Where the canal changed level, the barges had to be hauled up and over sloping ramps of earth and stone called double slipways. Boats were often strained and broken on the ramps, and when they broke, the grain spilled and thieves carried it off. Qiao Weiyue had a better idea. He built two gates across the canal about fifty paces apart. A barge floated into the space between them, the gate behind it was shut, and water was let in until the barge rose gently to the next level. It was the first **pound lock** we know of in the world. Europe's first pound locks came about four hundred years later.

Why a canal at all? China's geography sets a puzzle. Its great rivers, the Yellow River and the Yangtze, flow from the mountains of the west to the sea in the east. But China's richest rice land lay in the warm, rainy south around the lower Yangtze, while its capitals often stood in the dry north, close to the frontier where the armies watched the steppe. Food grew in the south; soldiers and officials ate in the north. Hauling grain overland by cart was slow and costly. A river road running *north and south* would solve the problem, but nature had not made one. So people dug it. The oldest pieces go back to the 400s B.C. Between 605 and 610, Emperor Yang of the Sui dynasty joined many old canals and new ones into a single system, using the forced labor of enormous numbers of men and women, many of whom died at the work. Later, after Kublai Khan made Beijing his capital, the Yuan dynasty cut a straighter route north across Shandong (opened in 1289) and on into Beijing (1293). In 1411 the Ming engineer Song Li rebuilt the Shandong section and brought water to its summit so that it would stay full all year.

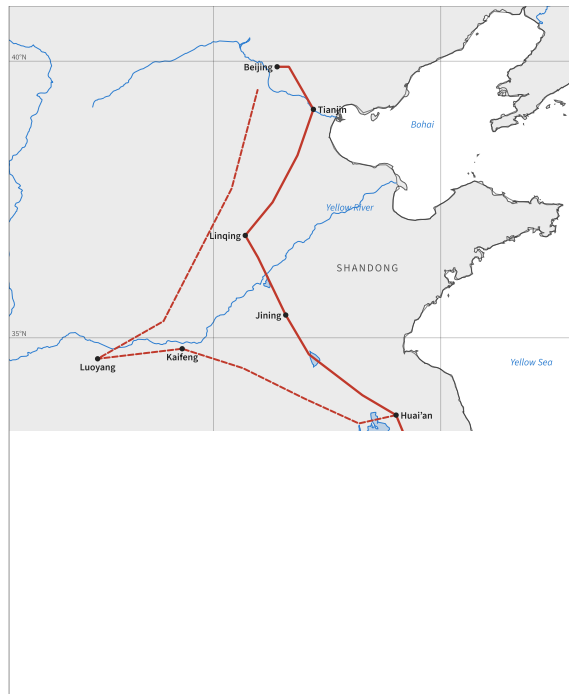
How it worked. A canal that climbs over high ground has a hard problem: water runs downhill away from the top in both directions. The highest stretch, the **summit level**, crossed the uplands of western Shandong. The Ming engineers dammed and diverted the Wen River so that its water reached the summit at Nanwang and divided there, part flowing north and part south, keeping both slopes full. Along the way, gates and locks held the water in steps. Barges were towed by teams of men called trackers who walked the **towpath** with ropes over their shoulders. Under the Ming and Qing dynasties, thousands of grain barges, crewed by soldiers, moved the **tribute grain** north every year. In 1600 the Jesuit missionary Matteo Ricci traveled north on the canal toward Beijing and was struck by the great crowds of boats he saw on it.

The big idea. The Grand Canal is a river turned sideways. It runs north and south across the grain of China's land and ties together five east-flowing river systems: from north to south, the **Hai**, the **Yellow**, the **Huai**, the **Yangtze** and the **Qiantang**. Cities grew wherever the canal crossed a great river or met a busy road: Yangzhou at the Yangtze crossing, Huai'an near the Huai, Jining and Linqing in Shandong, Tianjin near the sea. Just as the fall

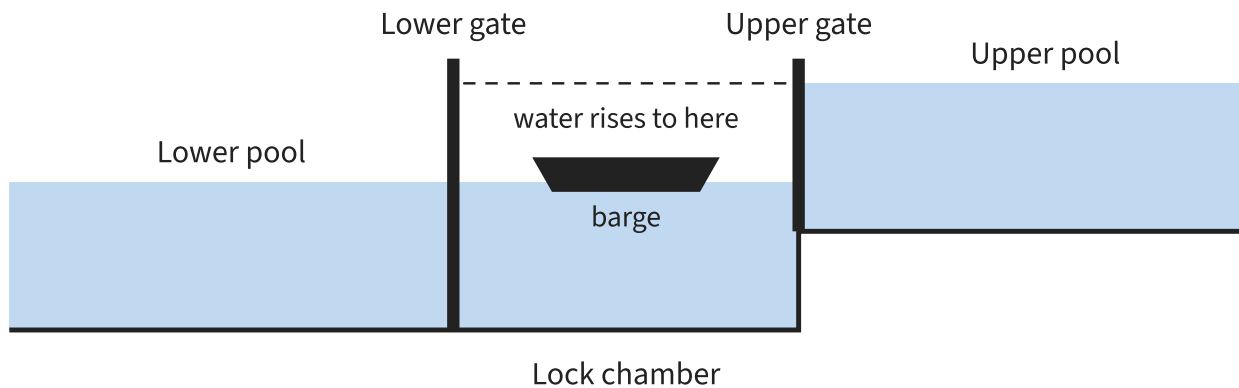
line and the confluence decided where American cities stood, the canal decided where many Chinese cities would prosper.

On the map. From Hangzhou, about 30°N, to Beijing, about 40°N, the Grand Canal runs about 1,770 km (1,100 miles). That is roughly three times the length of the Erie Canal in New York. A straight line between the two cities is only about 1,130 km (700 miles); the canal wanders to reach rivers, lakes and cities on the way. In 2014 UNESCO named the Grand Canal a World Heritage Site, and its southern half still carries a steady stream of barges loaded with coal, sand and building stone.

Technology overcoming geography. For a thousand years the canal beat China's geography, but geography fought back. In 1855 the Yellow River broke its banks and swung north to a new mouth, cutting the canal in Shandong and silting it up. By then steamships could carry rice up the coast by sea, and in the early 1900s a railroad from Tianjin to the Yangtze took the grain trade. One technology replaced another, but the lesson stayed: when people build a road of water across the land, they can feed a capital and join a nation together.



The Grand Canal (Yuan and Ming route) from Hangzhou to Beijing, and the older Sui route through Luoyang.



A pound lock. Shut the lower gate, let water in from the upper pool, and the barge rises to the upper level.

PICTURE STUDY



Along the River During the Qingming Festival, Zhang Zeduan, early 1100s (Northern Song dynasty) · Handsroll, ink and color on silk, about 25 cm tall and more than 5 m long · Palace Museum, Beijing

Zhang Zeduan painted this famous scroll at Kaifeng, the capital of the Northern Song dynasty. The river in the painting is the Bian River, the canal that carried grain and goods from the Huai and Yangtze country up to the capital. It was part of the great canal system that Emperor Yang of the Sui had joined together five hundred years earlier.

A handscroll is meant to be unrolled a little at a time, from right to left, so the viewer travels along the river from the quiet countryside into the bustle of the city. Historians love it because it shows boats, bridges, shops and workers of the Song dynasty in astonishing detail.

Look closely

- Find the great wooden arched bridge (often called the Rainbow Bridge). Why would a canal city need a bridge that arches so high?
- Find the large boat passing under the bridge. What are the boatmen doing with the mast, the ropes and the poles?
- Look along the banks for men hauling boats with ropes. They are trackers on the towpath.
- Find boats being loaded or unloaded. What kinds of goods might they carry to the capital?

Talk about it

1. What does the painting tell you about how important the canal was to the life of the capital?

2. Compare the river traffic here with a highway near your home. What carries goods there, and what carried them here?
3. Why do you think the painter showed so many ordinary workers and not just officials?

PROJECT: WATER WINS: THE BARGE AND CART PULLING TEST

Why would emperors spend fortunes digging a canal when they could build roads? You will find out by measuring. You will pull the same load of rice across a table and through water, and compare how hard you have to pull. The difference explains a thousand years of Chinese history.

You will need

- A small plastic food container with a lid (your barge)
- Uncooked rice, 1 to 4 cups
- A rubber band and a ruler, or a small spring scale or luggage scale
- String, about 1 m (3 ft)
- A bathtub, a long plastic storage bin or a large baking dish of water
- Ledger notebook and pencil

Steps

1. Tie the string to one end of the container, and tie the other end of the string to the rubber band (or hook it to the spring scale).
2. Put 1 cup of rice in the container. Set it on a smooth table and pull it by the rubber band slowly and steadily. Have a partner measure how long the rubber band stretches while the box is moving. Record it.
3. Float the same loaded container in the water. Tow it slowly and steadily the same way and measure the stretch again. Record it.
4. Repeat both tests with 2, 3 and 4 cups of rice. Make a table with columns: Cups of rice, Stretch on table, Stretch on water.
5. Now tow the floating barge fast. What happens to the stretch? Canal barges moved at a walking pace. Why?
6. Draw a bar graph of your results. Write two sentences explaining why a canal can move far more grain than a road with the same number of workers.

Tips

- Pull at the same slow speed every time, or your comparison will not be fair.
- If the stretch on water is too small to measure, use a thinner rubber band or count how many cups you can tow before the stretch matches one cup dragged on the table.
- On real canals, one horse could tow a barge carrying many times the load it could pull in a wagon on a dirt road.

Check your work

- I measured and recorded the pull on land and on water for at least three loads.
- I made a graph and explained the difference.
- I can explain why water transport was the best way to feed a distant capital before railroads.

MAP NOTEBOOK

1. Draw the Grand Canal from Hangzhou to Beijing. Mark and label the five river systems it crosses and at least five canal cities.
2. Draw a three-step comic of a barge passing through a pound lock: entering, rising, leaving. Label the gates and the water levels.
3. Draw a double slipway and a pound lock side by side. Under each, write one advantage and one problem.

From history. In 1600 the Italian Jesuit Matteo Ricci set out north along the Grand Canal toward Beijing, carrying gifts for the Wanli Emperor, including clocks. At Tianjin a powerful court eunuch held his party for months, but in January 1601 Ricci finally reached the capital, where he lived and taught until his death in 1610. He studied Chinese learning deeply, made a world map in Chinese, and wrote about the endless boats he saw carrying grain and goods along the canal. His journey shows how the canal was not only a road for rice but also a road for people, news and ideas.

WORKED EXAMPLES

Example 1. The Grand Canal runs about 1,770 km from Hangzhou to Beijing. How long would it be on a map with a scale of 1 cm = 50 km? How many miles is it? How does it compare with the 584 km (363 mile) Erie Canal?

(Use the map or drawing “Use the canal line to picture the 1,770 km journey.” shown earlier in this lesson.)

1. Map length: $1,770 \text{ km} \div 50 \text{ km per cm} = 35.4 \text{ cm}$.
2. Miles: $1 \text{ km} \approx 0.621 \text{ mi}$, so $1,770 \times 0.621 \approx 1,099$, about 1,100 miles.
3. Compare: $1,770 \div 584 \approx 3.0$.

Answer: 35.4 cm on the map; about 1,100 miles; about three times as long as the Erie Canal.

Example 2. Hangzhou lies at about 30.3°N , 120.2°E , and Beijing at about 39.9°N , 116.4°E . One degree of latitude is about 111 km (69 miles). How far north of Hangzhou is Beijing? In what general direction does a barge travel from Hangzhou to Beijing?

1. Difference in latitude: $39.9^{\circ} - 30.3^{\circ} = 9.6^{\circ}$.
2. North-south distance: $9.6 \times 111 \text{ km} \approx 1,066 \text{ km}$; $9.6 \times 69 \text{ mi} \approx 662 \text{ mi}$.
3. Longitude goes from 120.2°E to 116.4°E , a decrease of 3.8° , so Beijing is also somewhat west of Hangzhou.
4. The move is mostly north and a little west: north-northwest.

Answer: About 1,070 km (660 miles) north; the barge travels north-northwest.

Example 3. Suppose a Song-dynasty lock chamber is 75 m long and 9 m wide. The water below the lock stands at 31.0 m above sea level and the water above it at 33.5 m. A grain barge going north enters from below. Describe the steps, find how high the barge rises, and find how much water must flow into the chamber.

(Use the map or drawing “Water flows in from the upper pool until the chamber matches it.” shown earlier in this lesson.)

1. Open the lower gate; the barge floats in at 31.0 m. Shut the lower gate.
2. Open the sluices in the upper gate; water flows in from the upper pool by gravity until the chamber reaches 33.5 m. Then open the upper gate and tow the barge out.
3. Rise: $33.5 - 31.0 = 2.5 \text{ m}$. In feet: $2.5 \times 3.28 \approx 8.2 \text{ ft}$.
4. Water: $75 \text{ m} \times 9 \text{ m} \times 2.5 \text{ m} = 1,687.5 \text{ m}^3$, about 1,700 cubic meters (about 1.7 million liters, or about 446,000 gallons).

Answer: The barge rises 2.5 m (about 8 ft), and about $1,700 \text{ m}^3$ of water flows from the upper pool into the chamber.

PRACTICE

1. **EASY** Who built the first known pound lock, in what year, and why?
2. **EASY** Name the cities at the southern and northern ends of the Grand Canal.
3. **EASY** List, from north to south, the five river systems joined by the Grand Canal.
4. **MEDIUM** The straight-line distance from Hangzhou to Beijing is about 1,130 km. The canal is about 1,770 km. How many times longer is the canal route? Give one reason it is longer.
5. **MEDIUM** Suppose a towed grain barge covers 25 km (about 15.5 miles) a day. About how many days would the whole trip from Hangzhou to Beijing take, without stops?
6. **MEDIUM** A lock chamber is 60 m long and 8 m wide. A barge must rise 3 m. How many cubic meters of water fill the chamber for one lift?

7. **MEDIUM** On the map, Yangzhou is at about 32.4°N, 119.4°E and Beijing at about 39.9°N, 116.4°E. In what direction is Beijing from Yangzhou?
(Use the map or drawing “Find Yangzhou and Beijing on the canal.” shown earlier in this lesson.)
8. **HARD** Linqing, a canal city in Shandong, is at about 36.9°N. Hangzhou is at about 30.3°N. How far north of Hangzhou is Linqing, in km and miles?
9. **HARD** In a short paragraph, explain why China’s rulers needed a north-south canal. Use the words *rice*, *capital* and *east-flowing rivers*.
10. **CHALLENGE** Suppose 10,000 barges each carry 25 tonnes of rice north in a year. How many tonnes is that? If an ox cart carried 1 tonne per trip, how many cart trips would do the same work? What two changes in the 1800s and early 1900s ended the canal’s great grain trade?

COMMON MISTAKES

- Thinking the Grand Canal was dug all at once. It was built in pieces over about two thousand years, joined by the Sui (605–610) and rerouted by the Yuan (1280s–1290s) and Ming (1411).
- Thinking canals must be flat. The Grand Canal climbs over the uplands of Shandong; locks and a carefully fed summit level carry boats over the rise.
- Thinking locks were a European invention. The first known pound lock was built in China in 984, centuries before Europe’s.

Make it a game · Barge Race to Beijing. Lay a strip of paper on the floor marked with the canal cities from Hangzhou to Beijing, with three “locks” drawn across it. Each player moves a bottle-cap barge by rolling a die. At each lock, the player must answer a question from this lesson (a date, a river, a direction or a quick calculation) to rise through it. A wrong answer means waiting one turn for the water to fill. First barge to deliver its rice to Beijing wins.

Scripture. “The king’s heart is in the hand of the LORD, as the rivers of water: he turneth it whithersoever he will.” (Proverbs 21:1, KJV)

Chinese emperors turned rivers of water wherever they wished, north and south across the land. Scripture reminds us that even the mightiest ruler’s heart is in God’s hand, the way a channel of water is in the hand of the one who digs it.

Practice answers

1. Qiao Weiye, a Song-dynasty transport official, in 984. Barges were being damaged on the double slipways, and the spilled grain was being stolen, so he built a two-gate lock to raise and lower them gently.
2. Hangzhou in the south; Beijing in the north.
3. Hai, Yellow, Huai, Yangtze, Qiantang.
4. $1,770 \div 1,130 \approx 1.6$ times longer. It bends to meet rivers, lakes, water supplies and cities and to follow low ground.
5. $1,770 \div 25 = 70.8$, about 71 days, more than two months.

6. $60 \times 8 \times 3 = 1,440 \text{ m}^3$.
7. North, and a little west (north-northwest): latitude increases by 7.5° while longitude decreases by 3° .
8. $36.9 - 30.3 = 6.6^\circ$. $6.6 \times 111 \approx 733 \text{ km}$; $6.6 \times 69 \approx 455 \text{ miles}$.
9. Sample: China's great rivers are east-flowing rivers, so they could not carry goods north and south. The best rice land was in the warm, wet lower Yangtze, but the capital and the frontier armies were in the dry north. Carts were slow and costly, so rulers dug a canal to float the rice north to feed the capital.
10. $10,000 \times 25 = 250,000$ tonnes, or 250,000 cart trips. The Yellow River changed course in 1855 and cut the canal in Shandong, and steamships on the coast and then the railroad from Tianjin to the Yangtze took over the grain trade.

6.2 THE SUEZ CANAL ⚙️

OBJECTIVES

- Tell the story of Ferdinand de Lesseps and the opening of the Suez Canal on 17 November 1869.
- Explain why Suez could be a sea-level canal without locks, and how a surveying mistake nearly kept it from being built.
- Compare the sea route from London to Bombay around Africa and through Suez, and calculate the distance and time saved.

Warm-up. On a globe or world map, put one finger on London and one on Mumbai (Bombay), India. Use a piece of string to trace the sea route around the southern tip of Africa, then trace a route through the Mediterranean and the Red Sea. Mark each string where it reaches Mumbai and lay them side by side. How much shorter is the second route? What thin strip of land is in the way?

Watch. *The History of the Suez Canal Explained* (FactSpark, 8:40).

<https://www.youtube.com/watch?v=bGdKAUhBctM>

After the story: the history of the Suez Canal from Napoleon to 1869.

Backup video. *25th April 1859: Construction begins on the Suez Canal at the Egyptian port town of Port Said* (HistoryPod, 2:35). <https://www.youtube.com/watch?v=weT17D0whC4>

As review: the Suez Canal opens on November 17, 1869.

KEY TERMS

isthmus

A narrow strip of land joining two larger land areas and separating two bodies of water, such as the Isthmus of Suez between Africa and Asia.

sea-level canal

A canal with no locks, cut down to the level of the seas at both ends so that ships float straight through.

concession

A grant from a government giving a person or company the right to build and run something, such as a canal, for a set number of years.

corvée

Forced, unpaid or poorly paid labor that a government demands from its people for public works.

dredger

A machine, usually on a boat, that scoops mud and sand from the bottom of a waterway to deepen it.

convoy

A group of ships traveling together in a line, as ships do through the narrow Suez Canal.

CORE IDEAS

The story. On 17 November 1869, cannons boomed across the flat sands of Port Said, a brand-new town on the Mediterranean coast of Egypt. A long line of ships, decked with flags, steamed slowly into a narrow channel cut through the desert. Leading the official procession was the French imperial yacht *L'Aigle*, carrying Empress Eugénie of France. Kings, princes, scholars and newspaper writers from all over Europe followed. That evening the ships anchored in Lake Timsah, beside another new town, Ismailia, where Khedive Ismail of Egypt held a grand ball. Three days later the procession reached Suez on the Red Sea. For the first time in history, a ship could sail from Europe to Asia without going around Africa. Standing proudly among the guests was the man who had made it happen, Ferdinand de Lesseps.

The man and the plan. De Lesseps was not an engineer. He was a French diplomat who had served in Egypt as a young man and dreamed of cutting the isthmus. In 1854 his old friend Said Pasha, the new ruler of Egypt, gave him a **concession** to form a company and build a canal. De Lesseps sold shares to thousands of ordinary French investors. Britain's government opposed the plan at first, fearing French power on the road to India. On 25 April 1859, at the spot that would become Port Said, de Lesseps struck the first blow of a pickaxe. The idea itself was ancient: Egyptian pharaohs and the Persian king Darius had once dug canals linking the Nile to the Red Sea, but those had long since filled with sand.

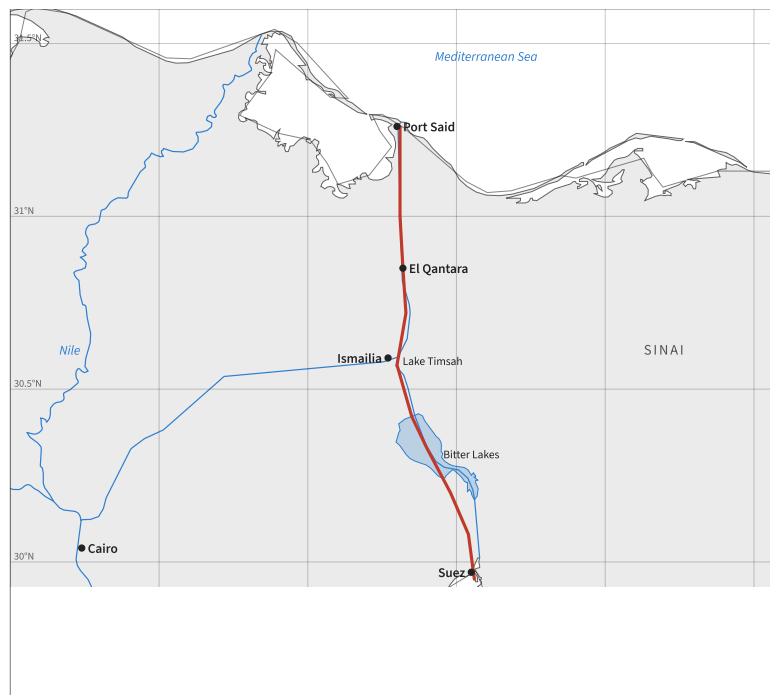
How they figured it out. Sixty years earlier, Napoleon's engineer Jacques-Marie Le Père had surveyed the isthmus in 1799 and reported that the Red Sea stood about 10 m (about 30 feet) higher than the Mediterranean. If that were true, a canal would need locks, or the Red Sea would pour through it. Later and better surveys in the 1840s showed that Le Père was wrong: the two seas stand at nearly the same level. That made a **sea-level canal** possible. The land helped too. The isthmus is low and flat, and a chain of shallow lakes and dry basins lay along the route: Lake Manzala near the Mediterranean, Lake Timsah in the middle and the Great and Little Bitter Lakes to the south. The engineers linked them with cuts through the sand.

The work. There was no fresh water in the desert, so the company first dug a Sweet Water Canal from the Nile to bring drinking water to the work camps. At first the digging was done by tens of thousands of Egyptian laborers sent by the government under the **corvée**, a system of forced labor. They dug with picks and baskets in great heat, and many died of disease and exhaustion. In 1864 the forced labor was ended. The company then turned to steam: huge **dredgers** and excavators built by the contractors Borel and Lavalley scooped the channel and swung the sand onto the banks on long chutes. Machines finished most of the canal.

On the map. The canal ran about 164 km (102 miles) from Port Said to Suez when it opened; with its approach channels it is about 193 km (120 miles) today. It marks the line between Africa and Asia, with the Sinai Peninsula on the east bank. Because it is narrow,

ships pass in **convoys**, taking about 12 to 16 hours. The great prize was the voyage to India and the Far East. A steamer from London to Bombay sailed about 19,800 km (12,300 miles) around the Cape of Good Hope, but only about 11,500 km (7,100 miles) through Suez, a saving of more than 40 percent.

Technology overcoming geography. The canal changed the world's map of trade almost overnight. Sailing ships struggled with the light, shifting winds of the Red Sea, so the canal especially favored steamships, and the age of sail began to end. Coaling stations sprang up along the new route. In 1875 Britain bought Egypt's shares in the canal company, and in 1888 the Convention of Constantinople declared the canal open to ships of every nation in peace and war. Egypt took over the canal in 1956, which led to an international crisis, and the canal was closed by war from 1967 to 1975. In March 2021 a single huge container ship, the *Ever Given*, ran aground across the channel and blocked it for six days, a reminder that a choke point made by people can be choked as easily as one made by nature.



The Suez Canal links the Mediterranean and the Red Sea through a chain of lakes.



Two routes from London to Bombay (Mumbai): around Africa, and through Suez.

PICTURE STUDY



The Inauguration of the Suez Canal at Port Said, 17 November 1869 (from the Empress's Album), Édouard Riou, 1869 · Watercolor (one of a series of watercolors from life, many later reproduced as lithographs) · Original watercolors (the 'Album of the Empress') held by the Association du Souvenir de Ferdinand de Lesseps et du Canal de Suez, Paris

Édouard Riou was a French illustrator famous for drawing the pictures in Jules Verne's adventure stories, such as *Journey to the Center of the Earth*. In 1869 he went to Egypt for the opening of the Suez Canal and made a series of views of the celebrations: the crowds and

pavilions at Port Said, the procession of ships, the new town of Ismailia and the desert banks of the canal. His pictures were printed in color so that people back in Europe could see the great event.

Look at these prints the way a newspaper reader in Paris would have in 1869. Very few people had ever seen the desert of Egypt. Riou wanted them to feel the wonder of ships sailing through the sand.

Look closely

- Find the ships. Which have sails, which have smokestacks, and which have both? What does that tell you about the year 1869?
- Look at the flags. Why would every ship be decorated with flags for this day?
- Look at how the ships are lined up. Why would ships entering a narrow canal need to go one behind another?
- Find the people on the shore and the tents or pavilions. Who do you think came to watch, and from how far away?

Talk about it

1. Why would the opening of a canal be celebrated like the crowning of a king?
2. What does Riou want the viewer to feel about the canal? How does he do it?
3. Whose work made this day possible, and how might the artist have shown them too?

PROJECT: A SEA-LEVEL CANAL IN A SAND TRAY

You will build an isthmus between two seas, cut a canal through it, and test what happens when the seas are level and when one sea stands higher, just as Le Père claimed. You will see why Suez needed no locks.

You will need

- A long shallow plastic storage box or a large baking pan
- Damp sand, or modeling clay or salt dough for the isthmus
- Water and two colors of food coloring (blue and green)
- Two cups, a ruler and a marker
- A spoon or craft stick for digging

Steps

1. Build a ridge of damp sand or clay across the middle of the box, about 5 cm (2 inches) high, to be your isthmus. Press it firmly so it does not leak. Scoop a shallow hollow in the middle of the ridge for the Bitter Lakes.
2. Pour blue water into one side (the Mediterranean) and green water into the other (the Red Sea) until both are 2 cm deep. Mark the level on the outside of the box.
3. With the spoon, cut a narrow canal through the isthmus, deep enough to reach below the water level, passing through your lake hollow. Watch the water meet. Does either

color rush through?

4. Float a small cork or bottle-cap ship from one sea to the other by blowing it gently.
5. Now rebuild the ridge to close the canal. Add water to the green side until it stands 2 cm higher than the blue side, like Le Père's mistaken survey. Cut the canal again. What happens?
6. Measure the time for the levels to even out. Write a paragraph comparing the two tests and explaining why surveyors had to measure the seas carefully before digging.

Tips

- Wet sand holds a shape better than dry sand. Clay or salt dough works best for the ridge.
- A sea-level canal still has gentle currents from tides and wind. Your level test shows why the currents at Suez are small.

Check your work

- I built an isthmus and cut a working canal through it.
- I tested level seas and unlevel seas and recorded what happened.
- I can explain why Suez is a sea-level canal and why Le Père's error mattered.

MAP NOTEBOOK

1. Draw the Isthmus of Suez. Label the Mediterranean, the Gulf of Suez, Port Said, Ismailia, Suez, Lake Timsah, the Bitter Lakes, the Nile and the Sinai Peninsula.
2. On a world outline, draw the London to Bombay route around Africa in one color and through Suez in another. Write the distance of each in km and miles.
3. Draw a steam dredger with a long chute dumping sand on the canal bank, and write a caption explaining how machines replaced forced labor after 1864.

From history. The night before the opening, the British warship HMS *Newport*, commanded by Captain George Nares, slipped through the crowded anchorage at Port Said in the dark with no lights and placed herself ahead of the French imperial yacht. In the morning the French found a British ship first in line, and it was too late to move her. The Royal Navy officially reprimanded Nares for his trick, but he was privately praised for his fine seamanship. Six years later he led a British expedition toward the North Pole.

WORKED EXAMPLES

Example 1. A steamer from London to Bombay sailed about 19,800 km (12,300 miles) around the Cape of Good Hope, or about 11,500 km (7,100 miles) through the Suez Canal. How much shorter is the Suez route, in km, in miles and as a percent?

(Use the map or drawing “Compare the two routes.” shown earlier in this lesson.)

1. Saving in km: $19,800 - 11,500 = 8,300$ km.
2. Saving in miles: $12,300 - 7,100 = 5,200$ miles.
3. Percent: $8,300 \div 19,800 \approx 0.42$, or about 42 percent.

Answer: About 8,300 km (5,200 miles) shorter, a saving of about 42 percent.

Example 2. A steamer of 1870 cruised at about 10 knots, which is about 18.5 km/h. How many days of steaming did the Suez route save on the London to Bombay voyage?

1. Distance per day: $18.5 \text{ km/h} \times 24 \text{ h} = 444$ km per day.
2. Days saved: $8,300 \text{ km} \div 444 \text{ km per day} \approx 18.7$ days.
3. So the voyage was shortened by nearly three weeks, and the ship needed far less coal.

Answer: About 19 days of steaming saved.

Example 3. Port Said is at about 31.26°N , 32.30°E and Suez at about 29.97°N , 32.55°E . Using 111 km (69 miles) per degree of latitude, find the north-south distance between them. Compare it with the 164 km canal of 1869, and give the direction a ship sails from Port Said to Suez.

(Use the map or drawing “Suez lies south and a little east of Port Said.” shown earlier in this lesson.)

1. Latitude difference: $31.26 - 29.97 = 1.29^\circ$.
2. Distance: $1.29 \times 111 \approx 143$ km; $1.29 \times 69 \approx 89$ miles.
3. The canal (164 km) is about 21 km longer, because it bends to use Lake Timsah, the Bitter Lakes and the easiest ground.
4. Latitude decreases (south) and longitude increases slightly (east).

Answer: About 143 km (89 miles) north to south, about 21 km less than the canal; a ship sails south, a little east.

PRACTICE

1. **EASY** On what date was the Suez Canal opened, and whose yacht led the procession?

2. **EASY** Which two bodies of water does the Suez Canal join, and which two continents does it separate?
3. **EASY** Why does the Suez Canal need no locks?
4. **MEDIUM** Convert the 1869 length of the canal, 164 km, to miles (1 km $\approx$ 0.621 mi).
5. **MEDIUM** Ships in the canal move slowly, about 14 km/h. How many hours would a ship take to steam the 193 km of today's canal without stopping?
6. **MEDIUM** Le Père reported in 1799 that the Red Sea was about 10 m higher than the Mediterranean. How many feet is that (1 m $\approx$ 3.28 ft)? What would such a difference have meant for a canal?
7. **MEDIUM** On the Suez map, name in order the towns and lakes a ship passes going from Port Said to Suez.
(Use the map or drawing "Follow the canal from north to south." shown earlier in this lesson.)
8. **HARD** Explain how the work of digging the canal changed in 1864, and why the change mattered both for the workers and for the speed of the work.
9. **HARD** Sailing ships gained much less from the Suez Canal than steamships did. Give one reason from the geography of the Red Sea.
10. **CHALLENGE** Suppose a modern ship burns 50 tonnes of fuel a day and sails at 30 km/h. It saves 8,300 km by using Suez instead of the Cape route. How many days and how many tonnes of fuel does it save?

COMMON MISTAKES

- Thinking Suez has locks like Panama. It is a sea-level canal with no locks at all.
- Thinking de Lesseps was an engineer. He was a diplomat and promoter; engineers and contractors designed and dug the canal.
- Forgetting the workers. The canal was begun largely with forced Egyptian labor, and many died before machines took over the digging.

Make it a game • Convoy Captain. Make a long, narrow canal on the floor with two pieces of string and a wide "Bitter Lake" in the middle. Players are northbound and southbound ships (toy boats or blocks). Ships may not pass each other in the narrow canal, only in the lake. Take turns planning a schedule so both convoys get through in the fewest moves. Then add a "stuck ship" card and see how long it takes to clear the jam.

Scripture. "Behold, I will do a new thing; now it shall spring forth; shall ye not know it? I will even make a way in the wilderness, and rivers in the desert." (Isaiah 43:19, KJV)

The Suez builders made a way of water through the desert and brought sweet water from the Nile across the sand. Isaiah speaks of God doing such things for His people. Every good thing people build in the wilderness uses the land, water and strength that God first made.

Practice answers

1. 17 November 1869; the French imperial yacht *L'Aigle* carrying Empress Eugénie led the procession.

2. The Mediterranean Sea and the Red Sea (by way of the Gulf of Suez); it separates Africa and Asia.
3. The Mediterranean and the Red Sea stand at nearly the same level, and the isthmus is low and flat, so the canal could be dug down to sea level.
4. $164 \times 0.621 \approx 102$ miles.
5. $193 \div 14 \approx 13.8$ hours, about 14 hours.
6. $10 \times 3.28 \approx 33$ ft. A canal would have needed locks, or the Red Sea would have poured through with a strong current.
7. Port Said, El Qantara, Lake Timsah at Ismailia, the Great Bitter Lake, the Little Bitter Lake, then Suez.
8. Before 1864 most digging was done by Egyptian peasants forced to work under the corvée, with hand tools, in harsh conditions where many died. In 1864 forced labor was ended, and the company turned to steam dredgers and excavators. Fewer people suffered, and the machines moved far more sand, finishing most of the canal.
9. The Red Sea is long and narrow with light, shifting and often contrary winds and dangerous reefs, so sailing ships had trouble making their way through, while steamships did not depend on the wind.
10. Distance per day: $30 \times 24 = 720$ km. Days saved: $8,300 \div 720 \approx 11.5$ days. Fuel saved: $11.5 \times 50 \approx 576$ tonnes (about 575 tonnes).

6.3 THE PANAMA CANAL

OBJECTIVES

- Tell how William C. Gorgas defeated yellow fever and George Goethals finished the Panama Canal between 1904 and 1914.
- Explain why Panama needed a lock canal, and how Gatun Lake and gravity lift ships 26 m (85 ft) over the isthmus.
- Build a working model lock and calculate lock lifts, water use and the distance a ship saves between New York and San Francisco.

Warm-up. Fill two clear cups with water to different heights. Connect them with a bent drinking straw full of water (hold your finger over one end while you place it). Watch what happens. When does the water stop flowing? You have just found the rule that makes every lock in the Panama Canal work without a single pump.

Watch. *The Engineering Marvel called Panama Canal* (Sabin Civil Engineering, 14:39).

<https://www.youtube.com/watch?v=jh79YSCC8mM>

After the story: how the Panama Canal was built, its locks and the dam that made Gatun Lake.

Backup video. *How Does the Panama Canal Work?* (The Panama Canal, 1:03).

<https://www.youtube.com/watch?v=hoQ7RHyG-EA>

As review: the Panama Canal Authority's one-minute look at how the locks work.

KEY TERMS

lock canal

A canal that uses locks to lift ships up over high ground and lower them down again on the other side.

yellow fever

A deadly disease caused by a virus and spread by the bite of the *Aedes aegypti* mosquito.

malaria

A disease that causes fever and chills, caused by a tiny parasite carried by *Anopheles* mosquitoes.

continental divide

The line of high ground that separates rivers flowing to one ocean from rivers flowing to another.

culvert

A large tunnel inside a lock wall that carries water in or out of the lock chamber.

spillway

A channel or gate in a dam that lets extra water flow out safely so the lake does not rise too high.

CORE IDEAS

The story. In the spring of 1905, yellow fever broke out among the canal workers in Panama. Men who felt well in the morning were dead within days. Panic spread, and hundreds of American workers boarded ships and fled home. Everyone remembered what had happened to the French: from 1881 to 1889, Ferdinand de Lesseps, the hero of Suez, had tried to dig a sea-level canal across Panama, and about 22,000 workers had died, most of them from yellow fever and malaria. The company went bankrupt. Now the Americans seemed doomed to fail the same way. But the chief sanitary officer, Colonel William Crawford Gorgas, an Army doctor from Alabama, believed he knew the enemy. It was not bad air or filth, as many still thought. It was a mosquito.

How they figured it out. In 1881 a Cuban doctor, Carlos Finlay, had proposed that a mosquito carried yellow fever. In 1900 an Army board led by Major Walter Reed tested the idea in Cuba, with brave volunteers who allowed themselves to be bitten. One of Reed's colleagues, Dr. Jesse Lazear, died of the fever. The tests proved Finlay right: the *Aedes aegypti* mosquito spread the disease. Gorgas then cleared yellow fever from Havana in 1901. In Panama he did it again on a grand scale. His crews fumigated every house in Panama City and Colón, put screens on windows, covered every water barrel and cistern, drained puddles, spread oil on standing water and laid piped water so people no longer kept open jars where mosquitoes bred. President Theodore Roosevelt backed him when others wanted him dismissed. By 1906 yellow fever was gone from the isthmus, and malaria was sharply reduced. Without that victory, there would have been no canal.

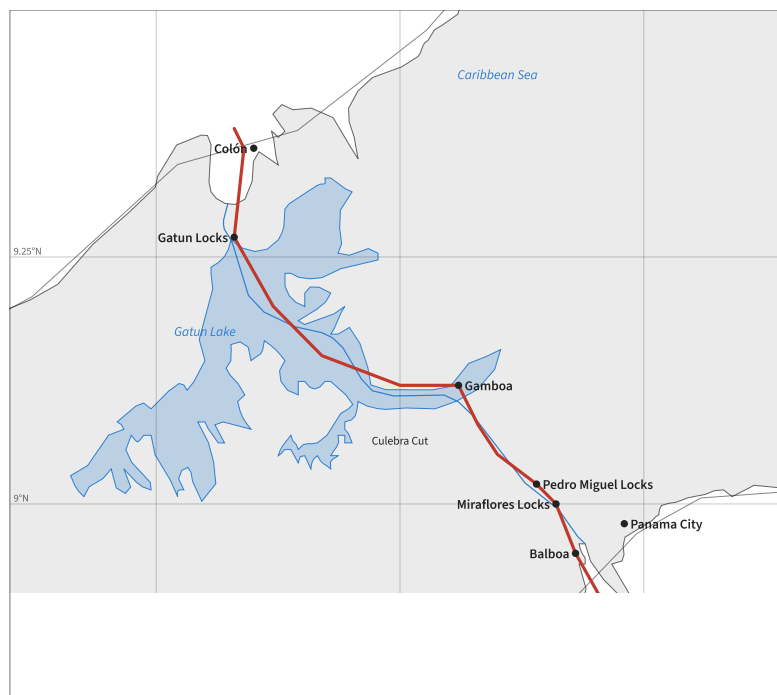
The engineers. The first American chief engineers struggled. John F. Stevens, a railroad builder, rebuilt the Panama Railroad to haul away dirt and persuaded Roosevelt to choose a **lock canal** instead of a sea-level one. When Stevens resigned in 1907, Roosevelt gave the job to an Army engineer, George Washington Goethals. Goethals ran the work like a general, and every Sunday morning he sat in his office and heard complaints from any worker who came. The hardest task was the Culebra Cut (later named the Gaillard Cut) through the **continental divide**. Steam shovels loaded rock into trains day and night, but the mountainsides kept sliding back into the cut. Altogether the builders dug out more than 200 million cubic yards (about 150 million cubic meters) of earth and rock. The workers came from many lands, most of all from Barbados and the other West Indian islands. They were paid on the "silver roll," in lower wages and with poorer housing than the white Americans on the "gold roll," a plain injustice of the time. About 5,600 workers died during the American years, most of them West Indians.

The big idea. Instead of cutting the mountains down to sea level, the builders raised the sea up to the mountains. They dammed the Chagres River at Gatun, creating Gatun Lake, then the largest lake ever made by people, about 26 m (85 feet) above the sea. Ships climb to the lake in three lock steps at Gatun, cross the lake and the Culebra Cut, then go down one step at Pedro Miguel and two steps at Miraflores to the Pacific. Each chamber is about 305 m long and 33.5 m wide (1,000 by 110 feet). The locks are filled and emptied by gravity alone: water flows from the lake through great **culverts** in the walls. No pumps are needed. But

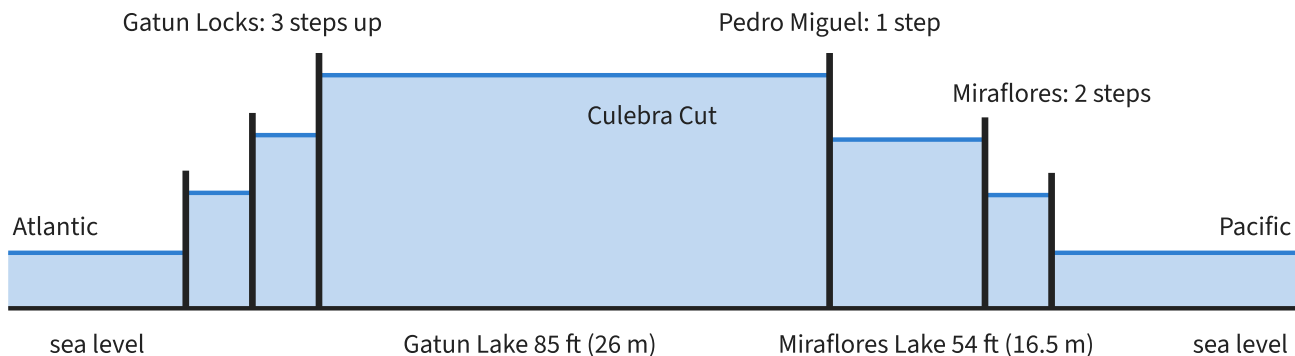
every ship that passes sends about 197,000 m³ (52 million gallons) of fresh lake water down to the sea. The heavy tropical rains of Panama, which fall for most of the year, refill the lake.

On the map. The canal is about 80 km (50 miles) long. It surprises most people: because the isthmus bends, the canal runs from northwest to southeast, so the Pacific end at Balboa lies *east* of the Atlantic end at Colón. On 15 August 1914 the steamship *Ancon* made the first official transit. A ship sailing from New York to San Francisco around South America covered about 20,900 km (13,000 miles); through Panama, only about 8,400 km (5,200 miles).

Technology overcoming geography. Steam shovels, railroads, dynamite, electric lock gates and science against disease together beat jungle, mountains and fever. The United States ran the canal until 31 December 1999, when Panama took full control under the treaties of 1977. In 2016 Panama opened a third, larger set of locks for the giant ships of today.



The Panama Canal runs from northwest (Colón) to southeast (Balboa).



Profile of the canal (not to scale). Ships climb three steps, cross the lake, and come down three steps.

PICTURE STUDY



President Theodore Roosevelt at the Controls of a Steam Shovel, Culebra Cut, Unknown photographer (the scene was also published as a stereograph by Underwood & Underwood), November 1906 · Photograph · Library of Congress, Prints and Photographs Division (Underwood & Underwood stereographs of the scene); copies in many archives

In November 1906 Theodore Roosevelt traveled to Panama, the first time a sitting American president had left the country. He chose to go in the rainy season so that he would see the work at its hardest. He tramped through the mud, visited the hospitals and work camps and talked with workers. At the Culebra Cut he climbed into the cab of a giant Bucyrus steam shovel and asked how it worked. A photographer caught the moment, and the picture appeared in newspapers across America.

Steam shovels like this one were the great machines of the canal. Each could scoop several tons of rock in one bite and load it onto railroad cars that ran right beside it.

Look closely

- Find the president. How is he dressed compared with the men around him?
- Look at the size of the steam shovel. Where is its bucket, and where does the engine sit?
- Find the ground. What clues show that this was the rainy season?
- Look at the faces of the workers. What do you think they thought of a president at the controls?

Talk about it

1. Why might Roosevelt have wanted this photograph published at home?
2. What does the photograph tell you about the machines that dug the canal?
3. How is a photograph different from a painting as a record of history?

Safety first. An adult should cut the bottles and make the holes, especially if a heated nail or a drill is used. Work over a sink, a bathtub or outdoors, and wipe up spills at once so no one slips.

PROJECT: A WORKING MODEL LOCK FROM PLASTIC BOTTLES

You will build a lock that really works, using the same rule as Panama: water flows from high to low until the levels are equal. A high bottle is your Gatun Lake, a middle bottle is your lock chamber, and a dishpan is the sea. Two pieces of tubing are your culverts, and two clips are your valves. A bottle-cap ship will rise and fall as you open and close them.

You will need

- Three clear 2-liter plastic bottles (one is a spare)
- A dishpan or large bowl (the sea)
- Clear vinyl tubing, about 6 mm (1/4 inch) across, two pieces about 40 cm (16 inches) long (from a hardware or aquarium store)
- Two binder clips or clothespins to pinch the tubing shut
- Hot glue, plumber's putty or waterproof modeling clay to seal the holes
- A stack of books, a ruler, a marker, scissors or a craft knife (adult use)
- A bottle cap or small cork for the ship, and food coloring

Steps

1. Have an adult cut the tops off two bottles so each becomes a tall open cylinder. Label one LAKE and one LOCK.
2. Have an adult make a hole near the bottom of the LAKE bottle and a hole near the bottom of the LOCK bottle, just big enough for the tubing. Make a second hole on the

other side of the LOCK bottle, also near the bottom.

3. Push one tube from the LAKE hole into one LOCK hole (the upper culvert). Push the second tube into the other LOCK hole and let its free end hang into the dishpan (the lower culvert). Seal every joint with glue or putty and let it set.
4. Stand the LOCK bottle in or beside the dishpan. Stand the LAKE bottle on a stack of books so its bottom is higher than the LOCK bottle's middle. Pinch both tubes shut with the clips.
5. Fill the dishpan with a few centimeters of plain water (the sea). Fill the LAKE bottle with colored water. Pour plain water into the LOCK to the same level as the sea and float your ship in it. Mark the water level on the LOCK with a marker.
6. Lock up: open the upper clip. Watch water flow from the lake into the lock and the ship rise. When it stops, mark the new level and measure the rise with a ruler. Close the clip.
7. Lock down: open the lower clip and let the lock drain into the sea. Measure how far the ship falls. Close the clip.
8. Repeat several lockages. Record the lake level each time. How many lockages can you make before the lake runs low and needs "rain" from a pitcher?

Tips

- If the water stops flowing before the levels match, there may be an air bubble in the tube. Squeeze the tube or tip it to let the bubble out.
- Notice that water always runs downhill from the lake toward the sea, just as at Panama. Each lockage costs the lake a little water.
- For a two-step flight like Miraflores, add a second LOCK bottle between the first lock and the sea, connected the same way.

Check your work

- My lock raises and lowers a floating ship using only gravity.
- I measured the rise and fall and recorded the lake level after each lockage.
- I can explain why Panama's lake needs heavy rainfall to keep the locks running.

MAP NOTEBOOK

1. Draw the Panama Canal from Colón to Balboa. Label the Caribbean Sea, the Pacific Ocean, Gatun Locks, Gatun Lake, the Culebra Cut, Pedro Miguel Locks, Miraflores Locks and Panama City. Add a compass rose.
2. Draw the side profile of the canal with its lock steps and write the elevations of Gatun Lake (26 m, 85 ft) and Miraflores Lake (16.5 m, 54 ft).
3. Draw an *Aedes aegypti* mosquito and around it list four things Gorgas did to stop it from breeding.

From history. Before the canal, the United States learned the hard way how far apart its two coasts were by sea. When war with Spain began in 1898, the battleship USS *Oregon*

was at San Francisco. She raced around the whole of South America, through the Strait of Magellan, to join the fleet in the Caribbean, a voyage of more than two months. Americans followed her journey in the newspapers, and many decided that a canal across Central America was a national necessity.

WORKED EXAMPLES

Example 1. Gatun Lake stands about 26 m (85 ft) above sea level. The Gatun Locks lift ships from the Atlantic to the lake in three equal steps. How high is each step?

(Use the map or drawing “Three steps up at Gatun.” shown earlier in this lesson.)

1. In meters: $26 \div 3 \approx 8.7$ m per step.
2. In feet: $85 \div 3 \approx 28.3$ ft per step.
3. Check: $3 \times 28.3 \approx 85$ ft.

Answer: About 8.7 m (28 ft) per step.

Example 2. A Panama lock chamber is about 305 m long and 33.5 m wide. How much water does it take to raise the water in it by one step of 8.7 m? How does this compare with the 197,000 m³ (52 million gallons) used for a whole transit?

1. Area of the chamber: $305 \times 33.5 = 10,217.5$ m².
2. Volume for one step: $10,217.5 \times 8.7 \approx 88,900$ m³.
3. In gallons: 1 m³ $\approx$ 264 gallons, so $88,900 \times 264 \approx 23.5$ million gallons.
4. A transit uses about 197,000 m³, a little more than twice one step, because water must be let down from the lake on both the Atlantic side and the Pacific side.

Answer: About 88,900 m³ (about 23.5 million gallons) for one step; a full transit uses a little more than twice that.

Example 3. A ship from New York to San Francisco sails about 20,900 km (13,000 miles) around South America, or about 8,400 km (5,200 miles) through Panama. At 25 km/h, how many days does Panama save?



The long way and the short way from New York to San Francisco.

1. Distance saved: $20,900 - 8,400 = 12,500$ km ($13,000 - 5,200 = 7,800$ miles).
2. Distance per day: $25 \times 24 = 600$ km.
3. Days saved: $12,500 \div 600 \approx 20.8$ days.

Answer: About 12,500 km (7,800 miles) and about 21 days saved.

PRACTICE

1. **EASY** Who was in charge of fighting disease at Panama, and who was the chief engineer from 1907 to 1914?
2. **EASY** Which mosquito spreads yellow fever, and which kind carries malaria?
3. **EASY** Why did the French attempt to build a canal at Panama fail?
4. **MEDIUM** Pedro Miguel Lock lowers ships from Gatun Lake (85 ft) to Miraflores Lake (54 ft). How many feet and about how many meters is that drop?
5. **MEDIUM** Miraflores Locks lower ships from Miraflores Lake (54 ft) to the Pacific in two equal steps. How high is each step?
6. **MEDIUM** Look at the map. Colón is at about 79.90°W and Balboa at about 79.57°W . Which end of the canal is farther east? In what direction does a ship travel from the Atlantic end to the Pacific end?

(Use the map or drawing “Compare the longitudes of the two ends.” shown earlier in this lesson.)

7. **MEDIUM** A ship moves through the 80 km canal at an average of 10 km/h including time in the locks. How long does the transit take? Give the length in miles too.
8. **HARD** Explain in three or four sentences why the Americans chose a lock canal instead of a sea-level canal.
9. **HARD** Name four things Gorgas's crews did in Panama to defeat yellow fever, and explain how they worked together.
10. **CHALLENGE** Gatun Lake covers about 425 km² (164 square miles). If one transit takes 197,000 m³ of water from the lake, how far does the lake surface fall per transit? How far would it fall in a day of 36 transits with no rain?

COMMON MISTAKES

- Thinking the Panama Canal runs east to west. It runs from northwest to southeast, and its Pacific end is east of its Atlantic end.
- Thinking the locks use pumps. They are filled and emptied by gravity, using water from Gatun Lake.
- Giving all the credit to engineers. Without Gorgas's victory over yellow fever and malaria, and without the tens of thousands of West Indian and other laborers, the canal could not have been built.

Make it a game • Lock Master. Draw the Panama profile on a long sheet of paper with six lock steps. One player is the Lock Master and calls out a lock ("Gatun step 2!"), and the other must tell whether the ship goes up or down there and by about how many feet. Correct answers move the ship one step. Add "mosquito cards": draw one and you must name one of Gorgas's weapons against mosquitoes or lose a turn.

Scripture. "Every valley shall be exalted, and every mountain and hill shall be made low: and the crooked shall be made straight, and the rough places plain:" (Isaiah 40:4, KJV)

At Panama, a valley was raised into a lake and a mountain was cut down at Culebra. Isaiah's words are a picture of the way being prepared for the Lord. The canal builders, with all their machines, did in one small place what God promises to do for His people.

Practice answers

1. Colonel William C. Gorgas led the fight against disease; George W. Goethals, an Army engineer, was chief engineer.
2. *Aedes aegypti* spreads yellow fever; *Anopheles* mosquitoes carry malaria.
3. Disease (yellow fever and malaria) killed about 22,000 workers; the sea-level plan through the mountains and the floods of the Chagres River were too hard, and the company went bankrupt in 1889.
4. $85 - 54 = 31$ ft, about 9.4 m (31×0.305).
5. $54 \div 2 = 27$ ft (about 8.2 m) per step, at average sea level.
6. Balboa, the Pacific end, is farther east (79.57°W is east of 79.90°W). A ship travels southeast from Colón to Balboa.
7. $80 \div 10 = 8$ hours; $80 \text{ km} \times 0.621 \approx 50$ miles.

8. A sea-level canal would have meant digging through the continental divide all the way down to sea level, which would have taken far more digging and time. The Chagres River floods could not be controlled in a sea-level channel. By damming the Chagres to make Gatun Lake, the builders raised ships 26 m to the lake and only had to cut down to the lake level, while the lake supplied the water for the locks and tamed the river.
9. They fumigated houses, screened windows, covered water barrels and cisterns, drained or oiled standing water and supplied piped water. Together they killed adult mosquitoes, kept them from biting the sick and spreading the virus, and took away the clean standing water where *Aedes aegypti* lays its eggs.
10. $425 \text{ km}^2 = 425,000,000 \text{ m}^2$. $197,000 \div 425,000,000 \approx 0.00046 \text{ m}$, about 0.46 mm per transit. $36 \times 0.46 \text{ mm} \approx 17 \text{ mm}$, about 1.7 cm (two-thirds of an inch) a day. Over a long dry season that adds up, which is why rainfall matters.

6.4 THE ST. LAWRENCE SEAWAY

OBJECTIVES

- Tell how Canada and the United States built the St. Lawrence Seaway (1954–1959) so that ocean ships could reach the Great Lakes.
- Read the “staircase” of the Great Lakes, from Montreal at about 6 m to Lake Superior at about 183 m (600 ft), and explain how the Welland Canal bypasses Niagara Falls.
- Compare the four great canals of this unit by length, lift and the voyages they shorten.

Warm-up. Stack five books of different thicknesses into a staircase on the table. Roll a marble up the stairs by lifting it one step at a time. Now imagine the marble is a ship 225 m (740 ft) long and each step is a lock. Which step on your staircase would be the hardest to build? On a map of North America, find the five Great Lakes and the river that drains them to the Atlantic.

Watch. *The Great Lakes-St. Lawrence Seaway Shipping System* (Great Lakes St. Lawrence Seaway Development Corp., 5:17). https://www.youtube.com/watch?v=po3fu_T14xo

With the story: the St. Lawrence Seaway, from the Seaway’s own channel.

Note: Ends with a line saying ships give off less carbon than other ways of moving freight. It is a government channel promoting the Seaway.

Backup video. “*The Story Of The St. Lawrence Seaway*”- 1959 (Canada 160 Archive, 12:51). <https://www.youtube.com/watch?v=FV9RWx1XlN0>

With the history note: newsreel of the Seaway’s opening in 1959.

KEY TERMS

seaway

A deep-water route, made of rivers, lakes, canals and locks, that lets ocean-going ships travel far inland.

rapids

A stretch of river where the water runs fast and rough over rocks because the riverbed drops steeply.

escarpment

A long, steep slope or cliff. Niagara Falls pours over the Niagara Escarpment.

flight of locks

Locks built one right after another like stairs, so a ship leaves one chamber and enters the next directly.

Seawaymax

The largest ship that fits the Seaway locks: about 225.5 m (740 ft) long and 23.8 m (78 ft) wide.

hydroelectric power

Electricity made by water falling through turbines at a dam.

CORE IDEAS

The story. On 26 June 1959, at the St. Lambert Lock across the river from Montreal, Queen Elizabeth II and President Dwight D. Eisenhower stood together to dedicate the St. Lawrence Seaway. Then the royal yacht *Britannia*, carrying the Queen and the President, steamed into the lock and was lifted toward the Great Lakes. Two months earlier, on 25 April, the Canadian icebreaker *D'Iberville* had led the first ships through. For the first time, large ocean ships from Europe, Africa and Asia could sail more than 3,700 km (2,300 miles) from the Atlantic to the heart of North America, all the way to Duluth, Minnesota, at the western tip of Lake Superior.

Why it was hard. The Great Lakes hold about a fifth of the world's fresh surface water, and their shores are lined with farms, mines, steel mills and cities: Chicago, Detroit, Cleveland, Toronto, Buffalo. But the lakes sit on a giant staircase. Lake Superior stands about 183 m (600 ft) above sea level, Lakes Michigan and Huron about 176 m (577 ft), Lake Erie about 174 m (571 ft) and Lake Ontario only about 75 m (246 ft). Between Erie and Ontario, the Niagara River plunges over the **escarpment** at Niagara Falls. Below Lake Ontario, the St. Lawrence River tumbled through **rapids** such as the Long Sault and the Lachine Rapids on its way down to Montreal, which lies only about 6 m (20 ft) above the sea. Small canals had been built around these obstacles long before: the Lachine Canal in 1825, and the first Welland Canal around Niagara, the project of William Hamilton Merritt, in 1829. But the canals along the St. Lawrence were only about 14 feet (4.3 m) deep, too shallow for ocean ships.

How they did it. For decades Americans argued about a deep seaway; railroads and East Coast ports feared the competition. In the early 1950s Canada declared that it would build the seaway alone if necessary, and in 1954 the United States Congress agreed to join. Work began that summer. Engineers built seven new locks between Montreal and Lake Ontario, two of them in the United States (the Snell and Eisenhower locks near Massena, New York), and dredged a channel 27 feet (8.2 m) deep. At the same time, the two countries built a great hydroelectric dam across the river between Cornwall, Ontario, and Massena. On 1 July 1958 its lake began to rise and flooded the Long Sault Rapids and several villages. About 6,500 people on the Canadian side were moved to new towns, and many houses were lifted onto trucks and carried away. These towns are remembered today as the Lost Villages. The Mohawk community of Akwesasne, which lies along the river there, also saw its river and shoreline changed.

The big idea. A seaway is a chain of lakes joined by locks. From Montreal to Lake Erie, a ship passes through 15 locks: seven on the St. Lawrence and eight on the Welland Canal, which runs 43 km (27 miles) across the Niagara Peninsula and lifts ships about 99.5 m (326 ft) around Niagara Falls. Three of its locks, at Thorold, form a **flight**, one chamber stepping straight into the next. Farther west, the Soo Locks at Sault Ste. Marie lift ships about 6 to 7 m (21 ft) from Lake Huron to Lake Superior. Every Seaway lock is about 233.5 m long and

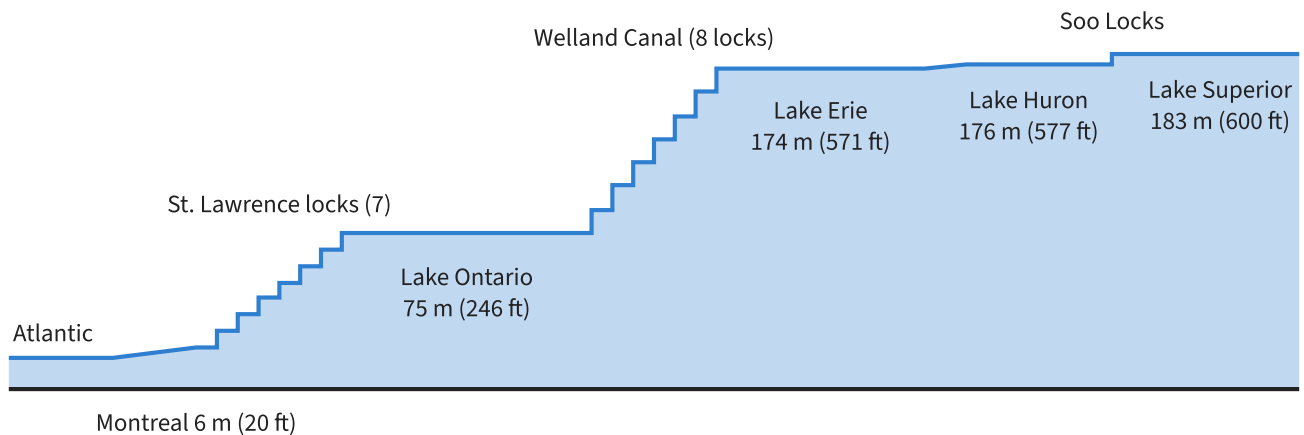
24.4 m wide (766 by 80 feet), so the largest ship that fits, the **Seawaymax**, is about 225.5 m by 23.8 m.

On the map. The Seaway carries grain from the prairies, iron ore from Minnesota and Quebec, steel, coal, salt and machinery. Because its locks are limited in size, the giant lake freighters about 305 m (1,000 ft) long can never leave the upper lakes; they are too long for the Welland locks. Most of today's huge container ships are too big as well. And geography still wins one round every year: ice closes the Seaway each winter, from about late December to late March.

Technology overcoming geography. The four canals of this unit each beat a different obstacle. The Grand Canal joined rivers that ran the wrong way. Suez cut a flat isthmus between two level seas. Panama lifted ships over a mountain range with a lake made by a dam. The Seaway climbed a staircase of lakes and a great waterfall. In every case, people studied the land God made, worked with its water and slope, and made a road where nature had left a wall.



The Great Lakes St. Lawrence Seaway from Montreal to Duluth.



The staircase of the Great Lakes (heights to scale, distances not to scale). The Welland Canal has eight locks; Lock 8 is a guard lock with a very small lift.

PICTURE STUDY



Niagara, Frederic Edwin Church, 1857 · Oil on canvas · National Gallery of Art, Washington, D.C. (Corcoran Collection)

Frederic Edwin Church, an American painter of the Hudson River School, studied Niagara Falls for months and then painted this huge canvas, more than 2 m (7 ft) wide. He left out any foreground, so the viewer seems to stand at the very brink of the Horseshoe Falls, with water rushing past. When it was shown in New York in 1857, crowds lined up and paid to see it, and critics praised it highly.

For a geographer, this is a picture of an obstacle. The Niagara River drops more than 50 m (160 ft) at the Horseshoe Falls, and much more in the rapids above and below it, on its way

from Lake Erie to Lake Ontario. No ship could ever pass here. That is why the Welland Canal was built a few miles to the west.

Look closely

- Find the edge of the falls. Where does Church put the viewer?
- Look at the color of the water as it curves over the brink. Why is it green and not white there?
- Find the rainbow in the spray. What does it add to the painting?
- Look at the horizon. How does the long, low line of the painting make the falls feel wide?

Talk about it

1. How does Church make you feel the power of the water? How would a ship captain have felt?
2. Why did people want to build a canal around the falls instead of trying to tame the falls?
3. Psalm 107 says sailors “see the works of the LORD.” What work of the Lord do you see in this painting?

PROJECT: THE STAIRCASE TO THE SEA: A SCALED ELEVATION PROFILE

You will draw the Great Lakes St. Lawrence Seaway as an elevation profile, with true heights to scale, and then add your bottle lock from Lesson 6.3 to show one step of the staircase. When you finish, you will be able to see at a glance where every lift happens and how much of the climb is done by the Welland Canal.

You will need

- A strip of paper about 1 m long and 30 cm wide (tape sheets together or use the back of a roll of paper)
- Ruler, pencil, blue and black markers
- Your model lock from Lesson 6.3
- Sticky notes or small cards for labels

Steps

1. Draw a horizontal line near the bottom of the paper for sea level. Use a vertical scale of 1 cm = 10 m.
2. Mark the water levels, from left to right, as flat lines at their heights: Atlantic 0 m, Montreal 6 m (0.6 cm), Lake Ontario 75 m (7.5 cm), Lake Erie 174 m (17.4 cm), Lake Huron 176 m (17.6 cm), Lake Superior 183 m (18.3 cm). Space them evenly across the paper; the horizontal is not to scale.
3. Join the levels with steps. Between Montreal and Lake Ontario draw 7 steps (the St. Lawrence locks). Between Lake Ontario and Lake Erie draw 7 big steps and 1 tiny one (the Welland Canal). Between Huron and Superior draw 1 step (the Soo Locks).

Between Erie and Huron draw a gentle slope (the Detroit and St. Clair rivers have no locks).

4. Draw Niagara Falls beside the Welland steps and the Lachine Rapids beside the first St. Lawrence steps.
5. Label each lake with its height in meters and feet, and each set of locks with its total lift.
6. Set your model lock beside the profile and run one lockage. Explain to a family member which step of the profile your model is acting out.

Tips

- Use a sharp pencil for the scale marks; 0.6 cm for Montreal is small but it matters.
- Real lake levels rise and fall a little with the seasons and years; these are long-term averages.

Check your work

- My profile shows all six levels at the correct scaled heights.
- I drew the right number of locks for each section.
- I can explain why the Welland Canal does more lifting than any other part of the Seaway.

MAP NOTEBOOK

1. Draw the Great Lakes and the St. Lawrence River. Label the five lakes, Montreal, Toronto, Buffalo, Cleveland, Detroit, Chicago, Sault Ste. Marie and Duluth, and draw the Seaway route.
2. Draw the Welland Canal beside Niagara Falls on the Niagara Peninsula, with Lake Ontario to the north and Lake Erie to the south.
3. Make a table comparing the four canals of this unit: country, year completed, length, locks and the voyage each one shortens.

From history. The first Welland Canal was the dream of William Hamilton Merritt, a mill owner near St. Catharines, Ontario, who needed a steady supply of water for his mills and saw that a canal could also carry ships around Niagara Falls. His wooden-lock canal opened in 1829 with 40 small locks. It was rebuilt and enlarged three times; the fourth Welland Canal, with its eight large locks, opened in 1932 and was deepened for the Seaway in the 1950s.

WORKED EXAMPLES

Example 1. A ship sails from Montreal (about 6 m, 20 ft above sea level) to Duluth on Lake Superior (about 183 m, 600 ft). How much is it lifted in all? How much of that lift happens on the Welland Canal (99.5 m)?

(Use the map or drawing “Compare the height of the Welland steps with the rest.” shown earlier in this lesson.)

1. Total lift: $183 - 6 = 177$ m; in feet: $600 - 20 = 580$ ft.
2. Share on the Welland: $99.5 \div 177 \approx 0.56$, or about 56 percent.
3. So more than half of the whole climb happens on one 43 km canal.

Answer: About 177 m (580 ft) in all; the Welland Canal does about 56 percent of it.

Example 2. On the Welland Canal, Locks 1 to 7 do nearly all of the 99.5 m (326 ft) lift; Lock 8 is a guard lock with a very small lift. About how much does each of Locks 1 to 7 lift a ship? Compare the total with the height of Lake Erie above Lake Ontario.

1. Lift per lock: $99.5 \div 7 \approx 14.2$ m; $326 \div 7 \approx 46.6$ ft.
2. Lake Erie minus Lake Ontario: $174 - 75 = 99$ m.
3. The canal’s lift matches the height difference of the two lakes, as it must.

Answer: About 14.2 m (46.6 ft) per lock; the 99.5 m total matches the 99 m difference between Lake Erie and Lake Ontario.

Example 3. A Seaway lock is about 233.5 m long and 24.4 m wide. (a) How much room is left around a Seawaymax ship 225.5 m long and 23.8 m wide? (b) Can a 305 m (1,000 ft) lake freighter pass through?

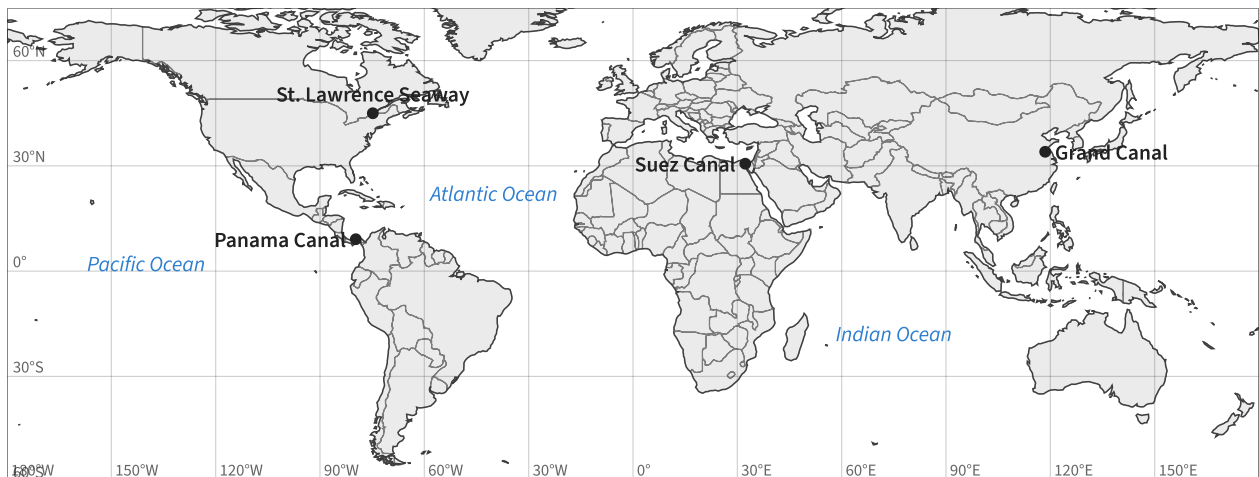
1. Length to spare: $233.5 - 225.5 = 8$ m (about 26 ft).
2. Width to spare: $24.4 - 23.8 = 0.6$ m, so only about 0.3 m (1 ft) on each side.
3. The freighter is 305 m long, which is $305 - 233.5 = 71.5$ m too long.

Answer: (a) 8 m of length and only 0.6 m of width to spare, about 30 cm on each side. (b) No; it is about 71.5 m too long, so the thousand-footers stay in the upper lakes.

PRACTICE

1. **EASY** When did the St. Lawrence Seaway open to ships, and who dedicated it at the St. Lambert Lock?
2. **EASY** Which two countries built the Seaway together?

3. **EASY** How many locks does a ship pass between Montreal and Lake Erie, and how are they divided?
4. **MEDIUM** The Seaway system reaches about 3,700 km from the Atlantic to Duluth. How many miles is that (1 km $\approx$ 0.621 mi)?
5. **MEDIUM** Montreal is at about 73.6°W and Duluth at about 92.1°W, both near 46°N. At that latitude one degree of longitude is about 77 km (48 miles). About how far west of Montreal is Duluth?
(Use the map or drawing "Find Montreal and Duluth." shown earlier in this lesson.)
6. **MEDIUM** How much do the seven St. Lawrence locks lift a ship from Montreal (6 m) to Lake Ontario (75 m)? Give meters and feet (1 m $\approx$ 3.28 ft).
7. **MEDIUM** Using the lake heights given in this lesson, about how much do the Soo Locks lift a ship from Lake Huron to Lake Superior?
8. **MEDIUM** On the world map of the four canals, list them from farthest north to farthest south.



The four canals of Unit 6.

9. **HARD** Give two reasons from geography or engineering why the Seaway carries far less traffic than the Suez or Panama canals.
10. **CHALLENGE** Rank the four canals by the total height a ship must climb from sea level (Grand Canal: leave out; Suez: 0 m; Panama: 26 m; Seaway to Lake Superior: about 183 m). Then compare the distance saved on the famous voyages: London to Bombay through Suez saves about 8,300 km; New York to San Francisco through Panama saves about 12,500 km. Which saves more, and by how much?

COMMON MISTAKES

- Thinking ships go over or near Niagara Falls. They use the Welland Canal, several miles west of the falls.
- Thinking the Seaway is open all year. Ice closes it each winter, roughly from late December to late March.
- Thinking any ship that can cross the ocean can reach Chicago. Only ships that fit the Seaway locks (Seawaymax) can enter the lakes.

Make it a game · Seawaymax Squeeze. Mark a lock on the floor with tape, 23 squares long and 2.5 squares wide (each square stands for about 10 m). Players draw ship cards with real lengths and widths (a Seawaymax 225 m by 24 m, a lake freighter 305 m by 32 m, a container ship 366 m by 49 m, a Great Lakes tug 30 m by 9 m) and must decide quickly whether each ship fits. Correct calls score a point; the first to five names one lake the ship can reach.

Scripture. “They that go down to the sea in ships, that do business in great waters; These see the works of the LORD, and his wonders in the deep.” (Psalm 107:23-24, KJV)

Sailors on the Seaway climb from salt water to fresh, past waterfalls and through a staircase of inland seas. Every canal in this unit leads its travelers past the works of the Lord, and good engineering helps us see them.

Practice answers

1. It opened on 25 April 1959; Queen Elizabeth II and President Eisenhower dedicated it on 26 June 1959.
2. Canada and the United States.
3. 15 locks: 7 on the St. Lawrence and 8 on the Welland Canal.
4. $3,700 \times 0.621 \approx 2,300$ miles.
5. $92.1 - 73.6 = 18.5^\circ$. $18.5 \times 77 \approx 1,425$ km; $18.5 \times 48 \approx 890$ miles.
6. $75 - 6 = 69$ m; $69 \times 3.28 \approx 226$ ft.
7. $183 - 176 = 7$ m; in feet, $600 - 577 = 23$ ft (the locks are usually given as about 21 ft, because lake levels vary).
8. St. Lawrence Seaway (about 45°N), Grand Canal (about 30° to 40°N), Suez Canal (about 30° to 31°N), Panama Canal (about 9°N).
9. Ice closes it every winter for about three months; its locks are too small for the largest modern ships (container ships and thousand-foot lake freighters); and it leads into a continent rather than joining two oceans on a main world shipping lane.
10. Climb: Seaway (183 m) > Panama (26 m) > Suez (0 m). Panama saves more: $12,500 - 8,300 = 4,200$ km (about 2,600 miles) more than Suez.

UNIT 6 REVIEW

Answer each question. Show your work for calculations, give units (km and miles, or m and ft) and use complete sentences for explanations. The review is worth 60 points.

1. (6 pts) Why did Chinese rulers need a canal running north and south? Name the cities at its two ends and two of the river systems it crosses.
2. (6 pts) A lock chamber is 70 m long and 10 m wide. A barge rises from 20.0 m to 23.0 m above sea level. How high does it rise in meters and feet, and how many cubic meters of water fill the chamber?
3. (6 pts) Who built the first known pound lock, and when? Explain in two sentences how it was better than a double slipway.
4. (6 pts) Why could the Suez Canal be built without locks? What mistake did Le Père make in 1799?
5. (6 pts) London to Bombay is about 19,800 km around Africa and about 11,500 km through Suez. Find the distance saved in km and miles, and the days saved for a ship making 444 km a day.
6. (6 pts) Port Said is at about 31.3°N and Suez at about 30.0°N. About how far apart are they north to south? Name one lake the canal passes through.
7. (6 pts) Explain how Gorgas defeated yellow fever in Panama. Whose discoveries did his work depend on?
8. (6 pts) Gatun Lake is 85 ft (26 m) above sea level. Ships rise to it in three equal steps at Gatun. How high is each step? Why is it said that the Pacific end of the canal is east of the Atlantic end?
9. (6 pts) Lake Erie is about 174 m above sea level and Lake Ontario about 75 m. How much does the Welland Canal lift a ship, in meters and feet? What natural obstacle does it bypass?
10. (6 pts) Give the year the St. Lawrence Seaway opened and two limits that geography or engineering still place on it.

UNIT PROJECT: FOUR CANALS THAT SHORTENED THE WORLD

Make a large world map that shows the four canals of this unit: the Grand Canal, the Suez Canal, the Panama Canal and the St. Lawrence Seaway. For Suez and Panama, draw the long voyage the ships made before the canal (London to Bombay around Africa; New York to San Francisco around Cape Horn) in one color and the short voyage through the canal in another, and write the distances in km and miles. For the Grand Canal and the Seaway, draw an inset map of each with its main cities.

Beside the map, display your working bottle lock and your scaled Great Lakes profile, and write a one-page comparison table: country, years built, length, number of locks, total lift, the geographic obstacle it overcame and the voyage or trade it changed. Finish with a paragraph on which canal you think changed the world most, and why.

- **Accuracy:** All four canals, the routes and the cities are placed correctly, and the distances, lifts and dates in the table are correct.
- **Working model:** The bottle lock raises and lowers a ship by gravity, and the student can explain each step of a lockage.
- **Explanation:** The paragraph compares the canals using geography (rivers, isthmuses, mountains, lake levels) and gives a clear, reasoned answer.
- **Care:** The map, profile and table are neat, labeled in km and miles, and easy to read.

Answer key

1. China's rivers flow east, but rice grew in the warm, wet south while the capital and frontier armies were in the north; a north-south canal floated the grain to the capital cheaply. Ends: Hangzhou (south) and Beijing (north). Rivers: any two of Hai, Yellow, Huai, Yangtze, Qiantang.
2. Rise: 3.0 m, about 9.8 ft (3×3.28). Water: $70 \times 10 \times 3 = 2,100 \text{ m}^3$.
3. Qiao Weiye, in 984, in Song-dynasty China. Instead of dragging barges up a ramp where they were strained, broken and robbed, the lock floated them gently up or down between two gates by letting water in or out.
4. The Mediterranean and the Red Sea stand at nearly the same level and the isthmus is low and flat, so a sea-level canal works. Le Père wrongly reported that the Red Sea was about 10 m (about 30 ft) higher than the Mediterranean.
5. Saved: 8,300 km, about 5,200 miles ($8,300 \times 0.621 \approx 5,150$). Days: $8,300 \div 444 \approx 18.7$, about 19 days.
6. $1.3^\circ \times 111 \text{ km} \approx 144 \text{ km}$ ($1.3 \times 69 \approx 90$ miles). Lakes: Lake Timsah, the Great Bitter Lake or the Little Bitter Lake (also Lake Manzala near Port Said).
7. He attacked the *Aedes aegypti* mosquito: fumigating houses, screening windows, covering water containers, draining or oiling standing water and supplying piped water so mosquitoes could not breed. His work built on Carlos Finlay's idea (1881) that mosquitoes spread yellow fever and on Walter Reed's Army board, which proved it in Cuba in 1900.
8. $85 \div 3 \approx 28.3 \text{ ft}$ ($26 \div 3 \approx 8.7 \text{ m}$) per step. The isthmus bends so the canal runs from northwest to southeast; Balboa on the Pacific (about 79.57°W) is east of Colón on the Atlantic (about 79.90°W).
9. $174 - 75 = 99 \text{ m}$, about 325 ft (the canal's lift is given as 99.5 m, 326 ft). It bypasses Niagara Falls and the rapids of the Niagara River.
10. 1959. Ice closes it each winter for about three months, and its locks (about 233.5 m by 24.4 m) are too small for the largest ships, such as 1,000 ft lake freighters and big container ships.

MAP SKILLS FOR REAL LIFE

All year you have studied why cities stand where they do, how ports and canals grew, and how ships thread the world's straits. In this unit you stop reading maps about other people's journeys and start using maps to make your own. You will learn the four map skills that people use in real life: taking a **bearing** with a compass, finding your way across country by **orienteering**, understanding how **GPS** satellites tell a phone where it is, and using a **GIS**, a computer map built in layers, to study your own county.

Every lesson begins with a real moment: James Clark Ross finding the North Magnetic Pole in 1831, Ernst Killander sending runners into the Swedish forest in 1919, two young physicists listening to Sputnik's beeps in 1957, and Dr. John Snow mapping the cholera deaths of Soho in 1854. Along the way you will walk a triangle by compass, build an orienteering course for your family, find a mystery city with string and pins, and stack tracing-paper layers into a map of your own county. The question running through the unit is the oldest one in geography: **Where am I, and how do I get where I am going?** These tools answer it, and they prepare you for the study of your own city in Unit 8.

BEFORE YOU BEGIN

- Can read a map scale and convert between map length and real distance
- Knows the cardinal and intermediate directions and can read a protractor in degrees
- Can multiply and divide decimals and use the formula $\text{distance} = \text{speed} \times \text{time}$
- Can read contour lines on a simple topographic map

MASTERY CHECKLIST

- I can take a bearing from a map with a baseplate compass, correct it for declination, and follow it on the ground.
- I can find a back bearing and use my pace count to walk a measured distance.
- I can read an orienteering map and choose a route using handrails, attack points and aiming off.
- I can explain how GPS finds a position by trilateration and why it needs four satellites and atomic clocks.
- I can explain what a GIS layer is, tell vector from raster data, and use a free online GIS map of my county.
- I can tell how John Snow's 1854 map helped show that cholera spread through water.

OPTIONAL BOOKS AND RESOURCES

- **NOAA Magnetic Field Calculators**
(<https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml>): Free, from the National Oceanic and Atmospheric Administration. Enter your zip code to find today's magnetic declination for your town (Lesson 7.1).

- **Orienteering USA** (<https://orienteeringusa.org/>): The national orienteering organization. Use its club finder to locate a beginner event near you; many clubs have permanent courses in public parks (Lesson 7.2).
- **GPS.gov** (<https://www.gps.gov/>): Free official U.S. government site explaining how GPS works, its satellites and its uses, with diagrams suitable for students (Lesson 7.3).

7.1 BEARINGS AND THE COMPASS ★

OBJECTIVES

- Tell how James Clark Ross found the North Magnetic Pole on June 1, 1831, and explain why a compass needle does not point exactly to true north.
- Name the parts of a baseplate compass and use it to take a bearing from a map and to follow a bearing on the ground.
- Compute back bearings, correct a bearing for magnetic declination, and use a pace count to walk a measured distance.

Warm-up. Stand in the middle of a room and point to where you think north is. Have everyone in the family point too, then check with a compass or a phone compass app. How close were you? Now turn until you face the window and estimate the direction you are facing as an angle, counting clockwise from north: 0° is north, 90° east, 180° south and 270° west.

Watch. *Compass 101 - How to Use a Baseplate Compass* (MRCAParks, 3:02).

<https://www.youtube.com/watch?v=7MQUIYsmQhc>

Before the project: how to use a baseplate compass to take a bearing.

Backup video. *Magnetic Declination Explained | Your Compass Needle Does NOT Point North!* (TheTautLine, 5:12). <https://www.youtube.com/watch?v=SStmBzQC7eI>

After the project: magnetic declination, the difference between magnetic north and true north.

KEY TERMS

bearing

A direction given as an angle in degrees, measured clockwise from north, from 0° to 360° . East is 90° , south 180° , west 270° .

back bearing

The direction straight back the way you came: the bearing plus or minus 180° .

true north

The direction toward the geographic North Pole, where all lines of longitude meet. Map grids usually point to true north.

magnetic north

The direction a compass needle points, toward the North Magnetic Pole, which lies in the far Arctic and slowly wanders.

magnetic declination

The angle between true north and magnetic north at a given place. It is named east or west depending on which side of true north the needle points.

pace count

The number of double steps (every time the same foot lands) you take to walk 100 meters. It lets you measure distance with your feet.

CORE IDEAS

The story. On June 1, 1831, a young British naval officer named **James Clark Ross** stood on the frozen west coast of the Boothia Peninsula in the Canadian Arctic. He and his uncle, Captain John Ross, had been trapped in the ice with their ship *Victory* through two winters. James had sledged west across the snow with a few men and an instrument called a dip needle, a compass needle hung so it could tilt up and down instead of swinging flat. As they traveled, the needle tilted more and more steeply. At last, at about 70° N and 97° W, it pointed almost straight down into the ground. Ross had found the **North Magnetic Pole**, the place where Earth's magnetism dives into the planet. His men built a pile of stones to mark it and raised the British flag. The geographic North Pole, where the lines of longitude meet, was still about 1,400 miles (2,200 km) farther north.

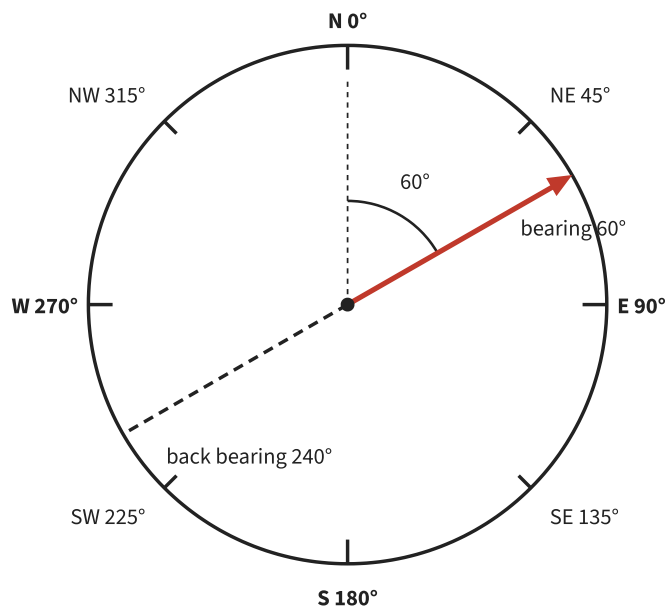
How it works. Earth behaves like a giant, weak magnet, because its outer core is a sea of molten iron in slow motion. A compass needle is a thin magnet balanced on a pivot, and its north-seeking end (usually painted red) swings to line up with Earth's magnetism. That means a compass points to **magnetic north**, not **true north**. The angle between them is the **magnetic declination**. In the mid-2020s it is about 15° east in Seattle and about 14° west in Boston, and close to zero along a line near the Mississippi valley. It also changes over time, because the magnetic pole wanders: since Ross's day it has moved more than 1,200 miles (2,000 km) and now lies near the middle of the Arctic Ocean, drifting toward Siberia. That is why careful maps print the declination and the year it was measured, and why you can look up today's value for your town at NOAA's free online calculator.

The baseplate compass. In Sweden in the early 1930s, engineer Gunnar Tillander and the three Kjellström brothers, who were orienteering racers, built a compass for people who travel on foot with a map: a liquid-filled needle housing set into a clear plastic plate with straight edges. Their company, Silva, began in 1933, and nearly every hiking compass today follows their idea. Learn its parts (see the diagram): the **baseplate** with its **direction-of-travel arrow**; the **rotating housing** with a dial marked from 0° to 360° ; the **orienting arrow** and **orienting lines** printed on the floor of the housing; the **magnetic needle**; and the **index line**, where you read your bearing.

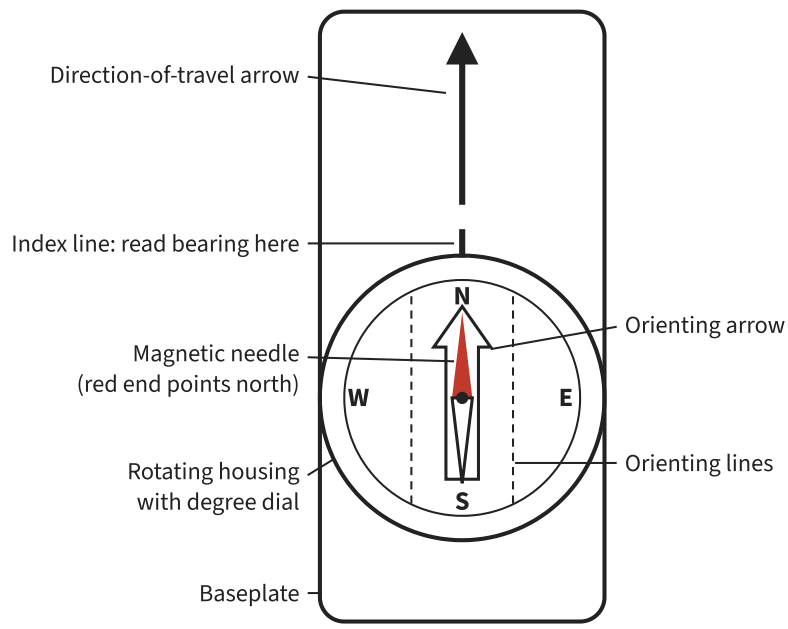
The big idea. A **bearing** is a direction measured clockwise from north in degrees. To *take a bearing from a map*, lay the edge of the baseplate from where you are to where you want to go, with the travel arrow pointing toward your goal. Turn the housing until its orienting lines run parallel to the map's north-south lines and the orienting arrow points to the top (north) of the map. Read the number at the index line. To *follow the bearing*, hold the compass flat at your waist with the travel arrow pointing straight ahead, then turn your whole body until the red end of the needle sits inside the orienting arrow. Orienteers say, "Red in the shed." Now walk where the travel arrow points, picking a tree or post on that line and walking to it, then picking another. To go back, use the **back bearing**: add 180° if your bearing is less than 180° , or subtract 180° if it is more.

Correcting for declination. A bearing measured on a map is a true bearing, but your needle points to magnetic north. Where declination is west, magnetic north lies to the left of true north, so every magnetic bearing is larger: *add* west declination when going from map to compass. Where declination is east, *subtract* it. A memory rhyme for map-to-compass is “East is least, west is best.” Ignoring a 10° error may not sound like much, but walking 1 kilometer on a bearing that is 10° off puts you about 175 meters (575 feet) to the side of your goal.

Technology overcoming geography. For most of history, travelers in fog, forest, desert or open sea had nothing to steer by but the sun and stars. The magnetic compass, first used for navigation in China and in Europe by about the 1100s and 1200s, let sailors hold a course under cloudy skies, and later portolan charts were drawn with compass directions on them. A compass and a **pace count** still work today when phone batteries die, and they are the foundation for orienteering in Lesson 7.2 and for understanding what GPS does for us in Lesson 7.3.



Bearings are measured clockwise from north. The back bearing of 60° is $60^\circ + 180^\circ = 240^\circ$.



The parts of a baseplate compass. Here the needle is “in the shed,” so the travel arrow points along the bearing set on the dial.

PICTURE STUDY



Carta Pisana (the Pisan Chart), Unknown chartmaker, probably of Genoa or Pisa, about 1275 to 1300 · Ink and color on parchment (animal skin) · Bibliothèque nationale de France, Paris

The Carta Pisana is the oldest nautical chart that survives in the Western world. It was found in the city of Pisa, which gave it its name, and it was probably drawn in Italy in the late 1200s. It is a **portolan chart**, a sailor’s chart of coasts and harbors. Its maker did not try to

show inland places at all. Instead, every harbor and cape along the shore is named, written at right angles to the coast so a sailor could turn the chart and read it.

The most striking thing about the chart is its web of straight lines. These are **rhumb lines**, lines of constant compass direction radiating from points spaced around circles. A pilot could lay a straightedge from his harbor to the next, find the rhumb line running parallel to it, and know which compass direction to steer. The coastlines are surprisingly accurate, probably because they were built up from many sailors' compass bearings and distance estimates. The fancy compass roses of later charts had not yet been invented; this is the bearing idea in its plainest form.

Look closely

- Find the Mediterranean Sea and the Black Sea. Which coasts look most accurate to you, and which look stretched or squeezed?
- Follow one rhumb line across the chart. Does it change direction, or stay straight the whole way?
- Look at how the place names are written. Why would writing them at right angles to the shore help a sailor?
- Find the parts of the chart that are blank. What did the chartmaker choose not to show, and why?

Talk about it

1. How is a rhumb line like a compass bearing you would follow with a baseplate compass?
2. Why would sailors on the Mediterranean, where land is often in sight, still need compass directions?
3. Which do you think was harder for these chartmakers to measure at sea: direction or distance? Why?

PROJECT: THE BEARING TRIANGLE

You will measure your own pace count, then walk a large triangle by compass bearings alone. If your bearings and paces are good, you will end up right back where you started. This is how surveyors and soldiers check their work, and it is the best practice there is for the orienteering course you will build in Lesson 7.2.

You will need

- A baseplate compass (an inexpensive hiking compass from a sporting goods store)
- A 100-foot or 30-meter tape measure, or a long string measured with a yardstick
- Three small markers (tent stakes, sticks with tape flags, or soda cans)
- Map notebook and pencil
- A large open yard, field or empty park lawn, away from cars, fences and power lines

Steps

1. Measure the pace course. Lay out 30 meters (about 98 feet) in a straight line on flat ground and mark both ends.
2. Walk the 30 meters at a normal stride, counting a pace each time your *left* foot lands. Walk it three times and average your count. Multiply by 100 and divide by 30 to get your pace count per 100 meters. Write it in your notebook.
3. Practice setting bearings. Set 0° at the index line, hold the compass flat at your waist, and turn until the red needle sits in the orienting arrow. You are facing magnetic north. Repeat for 90° , 180° and 270° .
4. Mark your starting point with a stake. Set the compass to 60° , put “red in the shed,” pick a target on that line, and walk 20 meters by pace count. Mark that corner.
5. Add 120° to your bearing ($60^\circ + 120^\circ = 180^\circ$). Set 180° , turn until the needle is in the shed, and walk another 20 meters. Mark the second corner.
6. Add 120° again (300°). Set 300° and walk 20 meters. Mark where you stop.
7. Measure how far your last mark is from your starting stake. Record the miss in your notebook. Then swap roles with a parent or sibling and compare.
8. Finally, take a bearing to a distant tree or pole: point the travel arrow at it, turn the housing until the needle is in the shed, and read the dial. Walk to it, turn around and check that the back bearing is 180° different.

Tips

- Keep the compass away from metal and magnets: belt buckles, car bodies, chain-link fences and phones can pull the needle several degrees.
- Always pick a target on your line and walk to it. Staring down at the compass while walking makes you drift.
- A miss of less than 2 meters on a 60-meter triangle is very good work.

Check your work

- I know my pace count for 100 meters.
- I can set a bearing on the dial and turn until the needle is in the shed.
- I walked a triangle by bearings and measured how close I came to my starting point.

MAP NOTEBOOK

1. Draw a large baseplate compass and label its seven parts from the diagram. Beside it, write the three steps for following a bearing.
2. Draw a compass rose with the 16 points (N, NNE, NE, ENE, E, and so on) and write the bearing for each one. (NNE is 22.5° .)
3. Draw a sketch map of the bearing triangle you walked, labeled with each bearing, each distance and how far you missed the start.

From history. Ross’s 1831 discovery came during one of the longest Arctic voyages of the age. The *Victory* left England in 1829 and was frozen in for three winters. The crew abandoned her in 1832, spent a fourth winter in the ice at Fury Beach, and escaped by

boat in 1833, rescued by the whaling ship *Isabella*. James Clark Ross later sailed to the Antarctic in 1839–1843 to search for the South Magnetic Pole. He did not reach it, but he discovered the Ross Sea and the great Ross Ice Shelf, both named for him.

WORKED EXAMPLES

Example 1. You walk from your tent to a spring on a bearing of 60° . What bearing will take you straight back to the tent?

(Use the map or drawing “ 60° out, 240° back.” shown earlier in this lesson.)

1. The way back is the opposite direction, half a circle around: 180° away.
2. Because 60° is less than 180° , add: $60^\circ + 180^\circ = 240^\circ$.
3. Check on the compass rose: 60° is between north and east (ENE), and 240° is between south and west (WSW), exactly opposite.

Answer: The back bearing is 240° .

Example 2. A hiker in Maine measures a bearing of 70° on a topographic map. The map margin says the magnetic declination is 15° west. What bearing should she set on her compass? And what if she were near Seattle, where the declination is about 15° east?

1. The map gives a true bearing. The compass reads magnetic bearings.
2. With west declination, magnetic north lies 15° to the left of true north, so the same direction measures 15° more from magnetic north: “west is best,” add. $70^\circ + 15^\circ = 85^\circ$.
3. With east declination, magnetic north lies to the right of true north, so subtract: “east is least.” $70^\circ - 15^\circ = 55^\circ$.

Answer: In Maine she sets 85° . Near Seattle she would set 55° .

Example 3. Your pace count is 64 double paces per 100 meters. Your map shows a footbridge 350 meters (about 1,150 feet) away on a bearing of 210° . How many paces should you count, and what is your back bearing for the trip home?

1. Paces per meter: $64 \div 100 = 0.64$.
2. Paces for 350 meters: $350 \times 0.64 = 224$ double paces.
3. Back bearing: 210° is more than 180° , so subtract: $210^\circ - 180^\circ = 30^\circ$.

Answer: Count about 224 double paces. Come home on a bearing of 30° .

PRACTICE

1. **EASY** Give the bearing in degrees for each direction: east, south, west, northeast, southwest.
2. **EASY** Find the back bearing of (a) 35° , (b) 160° , (c) 300° .
3. **EASY** What does “red in the shed” mean when you use a baseplate compass?
4. **EASY** What did James Clark Ross find on June 1, 1831, and how did he know he had found it?
5. **MEDIUM** The declination is 9° west. You measure a map bearing of 145° . What bearing do you set on your compass?
6. **MEDIUM** The declination is 12° east. You measure a map bearing of 8° . What bearing do you set on your compass?
7. **MEDIUM** Your pace count is 60 double paces per 100 meters. How many paces is 450 meters? How far have you walked after 150 paces? Give both answers in meters and feet (1 meter $\approx$ 3.28 feet).
8. **HARD** You walk 200 meters on a bearing of 90° , then 200 meters on a bearing of 180° . What bearing points straight back to your start, and about how far away is it?
9. **HARD** Surveyors use the “1-in-60 rule”: a 1° error puts you about 1 unit off for every 60 units you travel. If you follow a bearing that is 5° off for 1.2 km (about 0.75 mi), about how far to the side of your target will you be?
10. **CHALLENGE** In two or three sentences, explain why a map published in 1980 might give the wrong declination for your area today, and what you should do about it.

COMMON MISTAKES

- Reading the needle instead of the dial. The bearing is the number at the index line on the rotating housing, not wherever the needle happens to point.
- Letting the needle’s white (south) end sit in the orienting arrow. That sends you exactly 180° the wrong way. It must be the red end: “red in the shed.”
- Adding declination when it should be subtracted. Remember: going from map to compass, west declination is added and east declination is subtracted.

Make it a game • Bearing Call-Out. One player calls a bearing (“ 135° !”). Everyone else spins to face that direction as fast as they can, using a compass or just their sense of north. The caller checks with a real compass; anyone within about 20° scores a point. For a harder round, the caller says “back bearing of 135° ,” and players must face 315° . Play to ten points.

Scripture. “Trust in the LORD with all thine heart; and lean not unto thine own understanding. In all thy ways acknowledge him, and he shall direct thy paths.” (Proverbs 3:5-6, KJV)

A compass needle is useful, but it wanders and must be corrected against a fixed reference, true north. Our own understanding is like the needle. God’s Word is the fixed north by which

a life is set straight.

Practice answers

1. East 90° , south 180° , west 270° , northeast 45° , southwest 225° .
2. (a) $35^\circ + 180^\circ = 215^\circ$. (b) $160^\circ + 180^\circ = 340^\circ$. (c) $300^\circ - 180^\circ = 120^\circ$.
3. Turn your body (with the compass held flat) until the red, north end of the magnetic needle sits inside the orienting arrow in the housing. Then the direction-of-travel arrow points along the bearing set on the dial.
4. He found the North Magnetic Pole on the Boothia Peninsula in the Canadian Arctic. His dip needle, which can tilt up and down, pointed almost straight down into the ground.
5. West declination: add. $145^\circ + 9^\circ = 154^\circ$.
6. East declination: subtract. $8^\circ - 12^\circ = -4^\circ$, which is the same as $360^\circ - 4^\circ = 356^\circ$.
7. $450 \text{ m} \times 0.60 = 270$ paces. $150 \text{ paces} \div 0.60 = 250 \text{ m}$, about 820 feet.
8. You went 200 m east, then 200 m south, so the start is to the northwest: bearing 315° . The distance is the diagonal of a 200 m square: $200 \times 1.414 \approx 283$ meters (about 928 feet).
9. $1,200 \text{ m} \div 60 = 20 \text{ m}$ off for each degree. $5 \times 20 =$ about 100 meters (about 330 feet) to the side.
10. The North Magnetic Pole slowly wanders (it has moved more than 2,000 kilometers since 1831), so the declination at any place changes year by year. A 1980 value could be off by several degrees. Look up the current declination for your location, for example with NOAA's free magnetic field calculator, before you set bearings.

7.2 ORIENTEERING

OBJECTIVES

- Tell how orienteering grew from Scandinavian military training into a sport, and how Major Ernst Killander made it popular in Sweden in 1919.
- Read an orienteering map: its scale, colors, contour lines, magnetic north lines and course symbols.
- Plan and run a leg using map orientation, handrails, attack points and aiming off, and compute leg distances, climbs and times.

Warm-up. Lay a map of your house or neighborhood on the floor. Turn it until the kitchen on the map points the same way as the real kitchen, or the street on the map lines up with the real street. That is called *setting* the map. Now walk to the front door while keeping the map set, turning the paper as you turn. Was it easier or harder than reading it upside down?

Watch. *Start Orienteering // A Newcomer's Guide // Presented by Graham Gristwood* (South London Orienteers / On The Red Line, 5:30). <https://www.youtube.com/watch?v=26Zc5AVkFis>

Before the project: what orienteering is and how to start.

Note: Made by a British orienteering club; the map symbols are the same in America.

Backup video. *Orienteering - How To Read The Map* (Orienteering Australia, 2:35). <https://www.youtube.com/watch?v=LPw8rLTCiG4>

With How it works: how to read an orienteering map.

KEY TERMS

orienteering

A sport in which you navigate between control points marked on a map, using map and compass, usually racing against the clock.

control

A checkpoint on an orienteering course: an orange-and-white flag at a feature shown by a circle on the map, where you punch your card.

setting the map

Turning the map so that north on the map points to north on the ground and every feature on the map lines up with the real one.

handrail

A long feature such as a trail, fence, stream or edge of a field that you can follow toward your goal.

attack point

An easy-to-find feature close to a control, from which you navigate carefully the last short distance.

aiming off

Aiming deliberately to one side of a target on a line feature, so that when you reach the line you know which way to turn.

CORE IDEAS

The story. In the spring of 1919, a Swedish army officer and youth sports leader named **Major Ernst Killander** had a problem: the young runners of Stockholm were losing interest in track. Killander had served in the army, where officers had long been trained to cross unknown country with a map and compass. He thought: why not make that a race? Outside Stockholm he set out a course of checkpoints through the forest, handed each runner a map, and sent them off one by one against the clock. More than two hundred runners came. The new sport, called *orienteering*, spread through the schools and clubs of Sweden, and Killander is remembered as the father of orienteering. It was not quite the first event: a sports club near Oslo, Norway, had held a public map-and-compass race in 1897. But Killander gave the sport its shape.

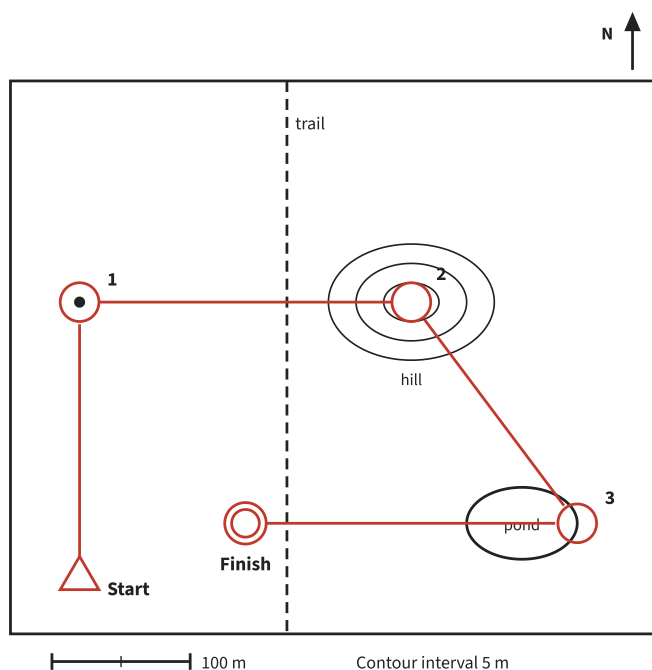
How it works. Every orienteer gets the same map with the course printed on it in purple or red. A **triangle** marks the start. Numbered **circles** mark the **controls**, which you must visit in order. A **double circle** marks the finish. At each control hangs an orange-and-white flag, and you prove you were there by punching a card or touching an electronic chip to a box. The circle is centered on a feature, and a list of **control descriptions** tells you exactly what it is: a boulder, a path junction, the east side of a pond. There is no set route between controls. The fastest runner is not always the strongest, but the one who chooses the best route and never gets lost.

Reading the map. Orienteering maps are drawn at large scales, usually 1:10,000 or 1:15,000, so 1 centimeter on the map is 100 or 150 meters on the ground. Their colors are standard around the world. **White** is open forest you can run through. **Yellow** is open land, like a field. **Green** is thick brush that slows you down: the darker the green, the slower. **Blue** is water. **Brown** is the shape of the land, mostly **contour lines**, usually 5 meters (about 16 feet) apart in height. **Black** is rock, trails, fences and buildings. Instead of a grid, the map is printed with lines pointing to **magnetic north**, so you can lay your compass on them with no declination to correct.

The big idea. Good orienteers break each leg into simple steps. First, **set the map** with your compass so the map matches the ground, and keep your thumb on the map where you are ("thumbing"). Next, look for a **handrail**, such as a trail or stream, that runs toward the control, and a **catching feature** beyond it, such as a fence, that will stop you if you overshoot. Near the control, find an **attack point**, an obvious feature like a trail bend, and from there go carefully by compass and pace count. If the control sits on a long line feature like a stream, **aim off**: steer a few degrees to one side on purpose. When you hit the stream, you know which way to turn. If you aimed straight at it and missed by a little, you would not know whether to turn left or right.

On the map. Look at the practice course in the figure. From the start triangle, leg 1 runs due north (0°) for 200 meters to a boulder. Leg 2 runs due east (90°) for 240 meters, crossing a trail and climbing three contour lines to a hilltop: a 15-meter climb. Leg 3 runs about 143° downhill for 200 meters to the east side of a pond. The straight line to the finish crosses the pond, so you must choose a route around it, north or south, and use the trail as a catching feature, because the finish lies just 30 meters beyond it. Choosing the route is the heart of the sport.

Technology overcoming geography. A forest with no roads, no signs and no view beyond fifty yards can stop a traveler cold. A good map, a compass and a trained mind overcome it. That is why armies have always trained officers in land navigation, and why searchers, foresters, surveyors and hunters still learn these skills. Orienteering is a family sport today, with courses for every age in public parks across America, and the habits it builds (knowing where you are, planning a route, checking your progress) are the same ones a pilot or ship's officer uses.



A practice orienteering course. Legs: 0° for 200 m, 90° for 240 m, 143° for 200 m, and 270° for 240 m. Contour interval 5 m.

PICTURE STUDY



The first Ordnance Survey map: An Entirely New and Accurate Survey of the County of Kent, The Ordnance Survey (surveyed under William Mudge; published by William Faden), 1801 · Engraved and printed map, scale one inch to one mile · British Library, London, and other map collections

In 1791 the British government's Board of Ordnance, which supplied the army, began a careful survey of the whole of Great Britain. Surveyors measured precise base lines and built a web of triangles from hilltop to hilltop. Britain was at war with Revolutionary France, and the army feared an invasion of the southern coast, so the first map they published, in 1801, was of the county of Kent, which faces France across the Strait of Dover.

This was the beginning of the **Ordnance Survey**, which still makes Britain's official maps. Its maps became the model for detailed topographic maps around the world, including the ones orienteers use today. Look how much it shows: every road and lane, rivers and streams, woods, churches and villages. Hills are shown by **hachures**, short strokes drawn down the slope, thicker and darker where the slope is steeper. Contour lines would later replace them.

Look closely

- Find the hachures. How can you tell a steep slope from a gentle one?
- Find a river and follow it to the sea. Which way does it flow?
- Find the coast that faces France. Why would an army want this coast mapped first?
- Find a feature an orienteer could use as a handrail.

Talk about it

1. What can a contour line tell you that a hachure cannot? (Hint: think about height in meters or feet.)
2. Why do you think a government would pay for an accurate map of its own country?

3. If you were orienteering on this map, what would make it harder to use than a modern orienteering map?

Safety first. Orienteer with a buddy or a parent nearby, and agree on the boundaries of the area (a road, fence or stream you must not cross) and a time to return. Carry a whistle: three long blasts means “I need help.” Wear long pants and check for ticks afterward. Stay out of water, off private property and away from roads.

PROJECT: BUILD AN ORIENTEERING COURSE IN THE YARD OR PARK

This is the unit project. You will draw an accurate map of your yard or a park, place 6 to 8 controls on real features, and set a course that your family can run with map and compass. A good course is fair (every control can be found from the map alone), safe and fun.

You will need

- Graph paper, ruler, protractor, pencils and colored pencils (including red or purple)
- Baseplate compass and your pace count from Lesson 7.1
- A long tape measure (optional, for checking)
- 6 to 8 control markers: cut-up white plastic jugs or cardboard squares colored half orange and half white, folded into a triangle or hung on string
- A different crayon or marker, or a small stamp, at each control for punching
- A stopwatch or phone timer

Steps

1. Walk your area and choose its boundaries. Sketch the main features: house, sheds, trees, fences, paths, flower beds, the swing set.
2. Choose a scale. For a yard, 1 cm = 2 m works well (1:200); for a park, 1 cm = 10 m (1:1,000). Draw the north arrow first, pointing to magnetic north from your compass.
3. Measure the features into place by pacing and compass bearings from a starting corner, and draw them on graph paper using the orienteering colors: black for buildings and paths, green for thick bushes, yellow for open lawn, blue for water, brown for slopes.
4. Choose 6 to 8 controls on clear features. Make the early ones easy and the later ones harder. Do not put two controls within a few meters of each other.
5. Draw the course on the map: a triangle for the start, numbered circles centered on the controls, a double circle for the finish, and straight red lines joining them in order.
6. Make a control description sheet: for each control, write its number, a two-letter code, and exactly what it is (for example: “3, KB, southeast corner of the shed”).
7. Measure each leg on your map and write its bearing and distance in a table. Add up the total length of the course.
8. Hang the controls, each with its code and a crayon for punching. Give a family member the map and a punch card, time them, and then switch.

Tips

- Test your own course before anyone else runs it. If you have trouble finding a control from the map alone, move it or fix the map.
- Add a few “no-go” areas (the garden, the street) printed with crisscross purple or red lines.
- For a harder second course, place a control behind a building so runners must choose a route around it.

Check your work

- My map has a north arrow, a scale and a key, and the features are in the right places.
- My course has a start triangle, numbered control circles, and a finish double circle, with a description sheet.
- I measured every leg’s bearing and distance, and someone else ran my course successfully.

MAP NOTEBOOK

1. Draw an orienteering map key with a small sample of each color (white, yellow, green, blue, brown, black) and what it means.
2. Copy the practice course from the figure and draw two different routes around the pond on the last leg. Which is shorter? Which is safer?
3. Draw the course symbols (start triangle, control circle, finish double circle) and an orange-and-white control flag.

From history. Orienteering became an international sport when the International Orienteering Federation was founded in 1961, and the first World Orienteering Championships were held in Finland in 1966. Today there are also orienteering races on skis, on mountain bikes, and a version called Trail-O, in which precise map reading, not speed, wins, so people in wheelchairs can compete on equal terms.

WORKED EXAMPLES

Example 1. An orienteering map has a scale of 1:10,000. On the map, the leg from control 4 to control 5 measures 4.5 cm. How long is the leg on the ground in meters and in feet?

1. 1:10,000 means 1 cm on the map is 10,000 cm on the ground, which is 100 meters.
2. $4.5 \text{ cm} \times 100 \text{ m per cm} = 450 \text{ m}$.
3. In feet: $450 \times 3.28 \approx 1,476$ feet, a little more than a quarter mile (0.28 mi).

Answer: 450 meters, about 1,480 feet (0.28 mile).

Example 2. On the practice course, leg 2 runs from control 1 (the boulder) to control 2 (the hilltop). Use the figure: give the bearing, the distance, the climb, and how many double paces it takes with a pace count of 64 per 100 m.

(Use the map or drawing “Leg 2 climbs three contour lines.” shown earlier in this lesson.)

1. Control 2 is straight east of control 1, so the bearing is 90° .
2. Using the scale bar, the leg is 2.4 scale bars long: $2.4 \times 100 \text{ m} = 240 \text{ m}$.
3. The leg crosses three contour lines going uphill. With a 5 m contour interval, the climb is $3 \times 5 = 15 \text{ m}$, about 49 feet.
4. Paces: $240 \times 0.64 \approx 154$ double paces.

Answer: Bearing 90° , 240 m (about 790 ft), a 15 m (about 50 ft) climb, about 154 double paces.

Example 3. A control sits at a footbridge over a long stream that runs east-west, 300 m away. You know your compass work is usually accurate to about 5° . Using the 1-in-60 rule, how far off could you be when you reach the stream? Why should you aim off?

1. The 1-in-60 rule: each 1° of error puts you about 1 unit off for every 60 units traveled. $300 \text{ m} \div 60 = 5 \text{ m}$ per degree.
2. A 5° error: $5 \times 5 = 25 \text{ m}$ to one side, and you would not know which side.
3. If you aim off on purpose, say 10° to the left (50 m), you know for certain you will reach the stream to the left of the bridge. Then you simply turn right and follow the stream as a handrail.

Answer: You could miss by about 25 m (about 80 ft) either way. Aiming off removes the guesswork: you know which way to turn when you hit the stream.

PRACTICE

1. **EASY** On an orienteering map, what do white, yellow, green, blue and brown each mean?
2. **EASY** What do a triangle, a numbered circle and a double circle mean on an orienteering course?
3. **EASY** Who was Ernst Killander, and what did he do in 1919?
4. **MEDIUM** A map has a scale of 1:15,000. A leg measures 3 cm on the map. How long is it on the ground in meters and feet?
5. **MEDIUM** Use the figure. Give the bearing and distance of leg 1, from the start to control 1.
(Use the map or drawing “Practice course.” shown earlier in this lesson.)
6. **MEDIUM** Use the figure. Leg 3 runs from the hilltop (control 2) to the pond (control 3), 120 m east and 160 m south. How long is it, what is its bearing, and what is its back bearing?

(Use the map or drawing “Practice course.” shown earlier in this lesson.)

7. **MEDIUM** Use the figure. What is the total straight-line length of the course from start to finish, in meters and miles (1 mile $\approx$ 1,609 m)?

(Use the map or drawing “Practice course.” shown earlier in this lesson.)

8. **HARD** Use the figure. Describe a good route for the last leg, from control 3 to the finish, and name the catching feature you would use.

(Use the map or drawing “Practice course.” shown earlier in this lesson.)

9. **HARD** A family walks at 12 minutes per kilometer and spends about 1 minute finding each of the 3 controls. About how long will the practice course take them?

10. **CHALLENGE** Orienteering maps are printed with magnetic north lines instead of true north lines. Explain in two or three sentences why this helps a runner.

COMMON MISTAKES

- Reading the map without setting it. If the map is not turned to match the ground, left and right get reversed and you run the wrong way.
- Running straight at every control. The straight line often crosses thick green, water or steep slopes; a longer route on a trail is often faster.
- Forgetting where you are. Keep your thumb on the map at your position and move it as you go, so one glance tells you where you are.

Make it a game · Indoor Micro-O. One player draws a quick map of a room or the whole house and marks 5 control circles on it, then hides a small card with a letter at each real spot. The others race, one at a time, to collect the letters in order using only the map. The letters spell a word. Fastest correct time wins; then the winner draws the next map.

Scripture. “And thine ears shall hear a word behind thee, saying, This is the way, walk ye in it, when ye turn to the right hand, and when ye turn to the left.” (Isaiah 30:21, KJV)

An orienteer must choose a way at every junction. God promises to guide His people, not only at the start of the journey but at every turn to the right hand or the left.

Practice answers

1. White: open forest you can run through. Yellow: open land. Green: thick vegetation that slows you down. Blue: water. Brown: landforms, mainly contour lines.
2. Triangle: the start. Numbered circle: a control, centered on the feature, visited in order. Double circle: the finish.
3. A Swedish army major and youth sports leader who organized a large public orienteering race in the forest near Stockholm in 1919 to interest young runners. He is called the father of orienteering.
4. 1 cm = 150 m, so 3 cm = 450 m, about 1,480 feet.
5. Due north, 0° , for 200 m (about 660 feet).
6. Distance: $\sqrt{(120^2 + 160^2)} = \sqrt{40,000} = 200$ m. The bearing is southeast, $180^\circ - 37^\circ \approx 143^\circ$. The back bearing is $143^\circ + 180^\circ = 323^\circ$.

7. $200 + 240 + 200 + 240 = 880$ m, about 0.55 mile.
8. The straight line west crosses the pond, so go around it, along the north or south shore, then head west. The north-south trail is the catching feature: when you cross it, the finish is only about 30 m farther west.
9. $880 \text{ m} = 0.88 \text{ km}$. Walking: $0.88 \times 12 \approx 10.6$ minutes. Plus 3 minutes for controls: about 13.6, or roughly 14 minutes.
10. The compass needle points to magnetic north, so if the map's north lines also point to magnetic north, a bearing taken off the map can be followed directly. The runner does not need to add or subtract declination in the middle of a race, which saves time and avoids mistakes.

7.3 GPS: HOW SATELLITES TELL A PHONE WHERE IT IS ★ ⚙

OBJECTIVES

- Tell how the tracking of Sputnik in 1957 led to satellite navigation, and how the Navy's Transit system and the Air Force's Navstar GPS were built.
- Explain trilateration: how distances from known points, drawn as circles (or spheres), pin down a single location, and why a receiver needs four satellites.
- Compute distance from a radio signal's travel time, the error caused by a clock mistake, and a position found from three distance circles.

Warm-up. Stand in a room and have a family member say, "I am exactly three big steps from the couch." Where could they be? (Anywhere on a circle around the couch.) Now they add, "and four big steps from the door." Where now? (One of only two spots.) Finally: "and two steps from the lamp." Can you point to the one spot? You have just done what your phone does a thousand times a day.

Watch. *How does GPS work?* (NASA Space Place, 2:44). <https://www.youtube.com/watch?v=RSA3feQ9gKk>

Before How it works: how GPS works, from NASA Space Place.

Backup video. *Why The US Military Made GPS Free-To-Use* (Real Engineering, 7:42). <https://www.youtube.com/watch?v=ozAPGnr-934>

With the history note: why the U.S. military made GPS free for everyone. Note: Real Engineering includes a short sponsor message; skip it.

KEY TERMS

GPS

The Global Positioning System, a group of U.S. satellites whose timed radio signals let a receiver anywhere on Earth find its position, height and the exact time.

satellite

An object that orbits a planet. GPS satellites circle Earth about 20,200 km (12,550 miles) up, each going around twice a day.

trilateration

Finding a position from its distances to several known points, where the circles (or spheres) of those distances cross.

atomic clock

An extremely precise clock that keeps time by the vibrations of atoms. GPS satellites carry them so their signals are timed to billionths of a second.

receiver

A device, such as a phone or car navigation unit, that listens to satellite signals. It only listens; it sends nothing to the satellites.

constellation

In satellite navigation, the whole group of satellites arranged in orbits so that several are always above any place on Earth.

CORE IDEAS

The story. On October 4, 1957, the Soviet Union launched **Sputnik 1**, the first man-made satellite, a polished metal ball that beeped a radio signal as it circled Earth every 96 minutes. Across America, people went outside to look for it. At the Johns Hopkins Applied Physics Laboratory in Maryland, two young physicists, **William Guier** and **George Weiffenbach**, did something more useful: they listened. As Sputnik approached, its beeps arrived at a slightly higher pitch, and as it moved away, a lower pitch, the same **Doppler effect** you hear when a siren passes. By carefully measuring that change in pitch, they could work out the satellite's entire orbit from a single pass overhead.

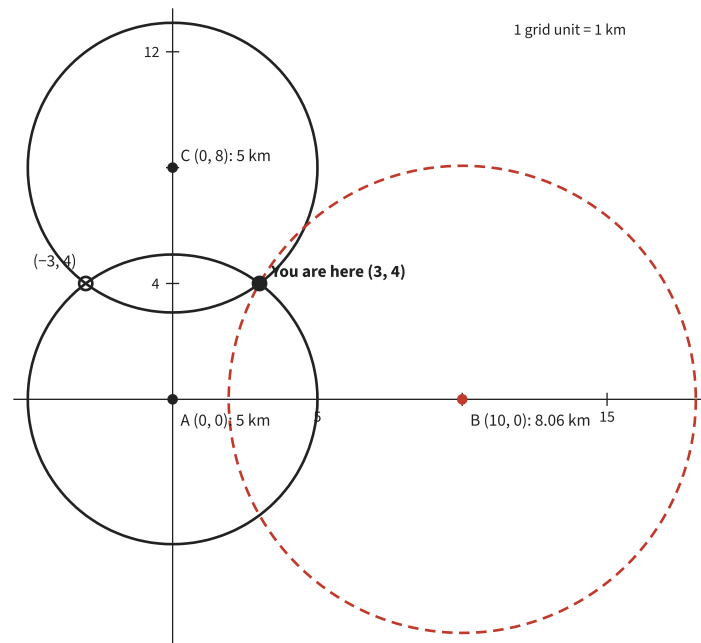
How they figured it out. In the spring of 1958 their boss, Frank McClure, asked a brilliant question: if you can find a satellite's path from a known spot on the ground, can you turn the problem around and find your spot on the ground from a known satellite? You could. That idea became **Transit**, the first satellite navigation system, built for Navy submarines and working by the mid-1960s. Transit could take many minutes to give a fix, though. On Labor Day weekend in 1973, Air Force Colonel **Bradford Parkinson** and a small team met at the Pentagon and sketched a better system based on precisely timed signals from many satellites. The first **Navstar GPS** satellite was launched on February 22, 1978, and the full constellation was declared complete in 1995. After a Korean airliner strayed off course into Soviet airspace and was shot down in 1983, President Reagan announced that GPS would be opened for civilian use. In May 2000 the deliberate blurring of civilian signals was switched off, and accuracy improved from about 100 meters to about 10.

How it works. Today at least 24 GPS satellites (usually about 31) circle Earth in six orbital planes about 20,200 km (12,550 miles) high, so that wherever you stand, several are above the horizon. Each one carries **atomic clocks** and constantly broadcasts two things: *where I am* and *what time it is by my clock*. Radio waves travel at the speed of light, about 300,000 km (186,000 miles) per second. Your **receiver** notes when each signal arrives, and the delay tells it the distance: $distance = speed \times time$. A signal that took 0.068 seconds traveled about 20,400 km.

The big idea. One distance alone tells you only that you are somewhere on a huge sphere around that satellite. A second distance narrows it to a circle where two spheres meet. A third narrows it to two points, and one of them is usually far out in space, so it can be thrown away. This is **trilateration** (not triangulation, which uses angles). On a flat map it works with circles, as in the figure: three distance circles cross at only one point. Why, then, does a receiver need a **fourth** satellite? Because your phone has a cheap quartz clock, not an atomic one. An error of just one millionth of a second would make every distance wrong by 300 meters. With four satellites, the receiver has four measurements for four unknowns (east-west, north-south, height and its own clock error) and solves for all of them. Your

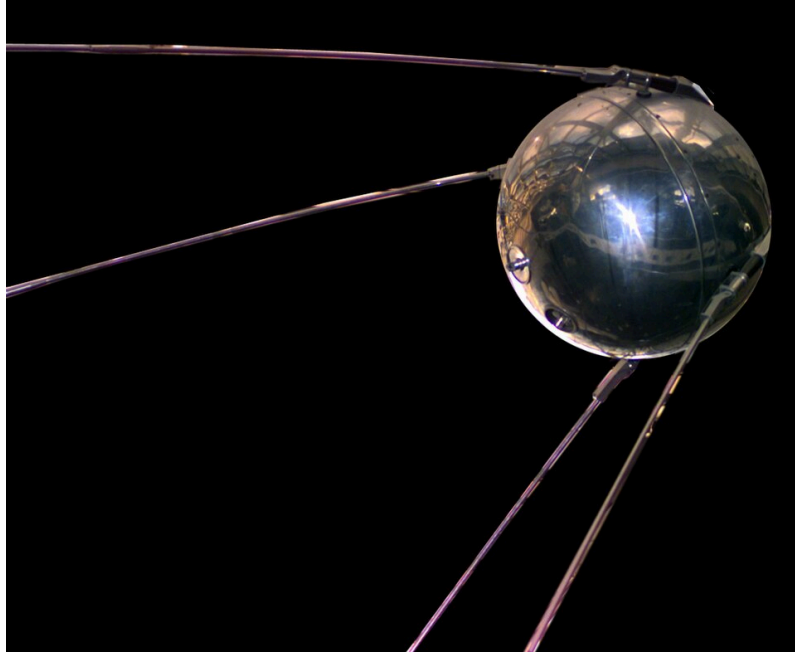
phone also uses cell towers and Wi-Fi to get a first fix quickly, and it listens to other countries' systems too: Russia's GLONASS, Europe's Galileo and China's BeiDou.

Technology overcoming geography. For thousands of years the hardest question in geography was simply, "Where am I?" Sailors measured stars with sextants and still ran aground; the longitude problem defeated navies for centuries. GPS answers it anywhere on Earth, day or night, in any weather, within a few meters, for free. Ships, aircraft, farm tractors, surveyors, ambulances and container cranes all depend on it, and its atomic-clock time signals keep cell networks, power grids and bank transfers in step. Yet it is also a reminder of our limits: the signals are weak, they cannot pass through solid rock or deep water, and they can be blocked or jammed. That is why the compass and map of Lessons 7.1 and 7.2 are still worth knowing.



Trilateration on a flat grid. Two circles leave two possible spots; the third circle picks the right one.

PICTURE STUDY



Sputnik 1 (photograph of a replica), Soviet space program (satellite); photograph from NASA, Satellite launched October 4, 1957 · Photograph · NASA (NSSDC) public-domain photograph of a replica at the Smithsonian's National Air and Space Museum

This polished ball is Sputnik 1, the first object people ever placed in orbit. It was only about 58 cm (23 inches) across and weighed about 84 kg (184 pounds). Inside were batteries, a radio transmitter and a fan to keep it cool. Its four antennas sent out a steady “beep, beep, beep” that radio listeners all over the world could pick up. The batteries ran down after about three weeks, and in January 1958 the satellite fell back into the atmosphere and burned up, so photographs like this show copies built to the same design.

Sputnik shocked Americans, who had not expected the Soviet Union to reach space first. It started the space race and led to the founding of NASA in 1958. But it also had a quieter result: two physicists listening to its beeps in Maryland realized that a satellite’s radio signal could be used to find places on the ground. Every GPS fix on your phone goes back to that discovery.

Look closely

- Count the antennas. Why might a satellite need long antennas to send a signal hundreds of kilometers down to Earth?
- Look at the shiny surface. Sunlight in space is intense. Why might the builders have polished it?
- Compare its size with something in your house. How does it compare with a phone?
- Look for anything that moves or steers. Does Sputnik have rockets, wings or solar panels?

Talk about it

1. Why would people around the world want to listen to Sputnik's beeps, even though they carried no message?
2. How did Guier and Weiffenbach turn a "beep" into a map of Sputnik's orbit?
3. Sputnik was launched as part of a contest between rival nations. What good things came from that contest?

PROJECT: STRING TRILATERATION: FIND THE MYSTERY CITY

You will do with string and pins exactly what a GPS receiver does with radio signals. First you will find a mystery city on a real map from its distances to three known cities. Then you will play "human GPS" outdoors, with family members as the satellites.

You will need

- A printed road map of the central United States (or your own state) with a scale bar
- Three pushpins, a corkboard or thick cardboard, and thin string (or a drawing compass)
- Ruler, pencil and map notebook
- For the outdoor game: three long pieces of string or rope, each about 10 m (33 ft), and a tape measure

Steps

1. Tape the map to the corkboard. Using the scale bar, work out how many centimeters (or inches) on your map equal 100 km.
2. The mystery city is about 265 km (165 mi) from Omaha, about 385 km (240 mi) from St. Louis, and about 480 km (300 mi) from Oklahoma City. Convert each distance to map length.
3. Push a pin into Omaha. Tie a loop of string to it, measure the string to the first map length, and with a pencil held at the end of the string, draw a circle around Omaha.
4. Do the same for St. Louis. The two circles cross at two points. Mark both.
5. Draw the third circle around Oklahoma City. Which of the two points does it pass through? That is the mystery city. Name it and check the answer with your parent.
6. Now have a parent choose a secret town on your own state map and measure its distances to three cities. Find it the same way.
7. Outdoors: three family members stand at three marked spots in the yard (the "satellites"), each holding a string. You secretly stand somewhere and they each measure the distance to you with their strings. Then go inside, draw the yard to scale, and use a drawing compass to find where you stood.
8. Finally, have one "satellite" stretch their string 1 m too long on purpose. Draw the circles again. What happens to the crossing point? Write one sentence explaining why GPS needs perfect clocks.

Tips

- Keep the string tight and the pencil straight up, or the circle will wander.

- On a real map, the distance circles will not meet in a perfect point, because the map is flat and the distances are rounded. Look for the place where all three come closest.
- Remember that real GPS works in three dimensions, with spheres instead of circles.

Check your work

- I found the mystery city using three distance circles.
- I can explain why two circles are not enough on a flat map.
- I can explain what happens to the answer when one distance is wrong.

MAP NOTEBOOK

1. Draw Earth with six or more GPS satellites around it and a person with a phone. Draw lines from four satellites to the phone and label the distance formula: distance = speed of light $\times$ travel time.
2. Make a timeline: Sputnik (1957), Transit idea (1958), Navstar planning (1973), first GPS satellite (1978), opened to civilians (1983), full constellation (1995), clearer civilian signals (2000).
3. Copy the trilateration grid and add a fourth circle of your own that also passes through (3, 4). Write its center and radius.

From history. GPS has to allow for Albert Einstein's theories of relativity. Because the satellites move fast and sit higher in Earth's gravity than we do, their atomic clocks run faster than clocks on the ground by about 38 microseconds a day. If engineers had not corrected for this, positions would drift by roughly 10 km (6 miles) every day. The clocks are deliberately set to tick slightly slow before launch so that, in orbit, they keep time with the ground.

WORKED EXAMPLES

Example 1. A GPS signal takes 0.068 seconds to travel from a satellite to your phone. Radio waves travel at about 300,000 km per second. How far away is the satellite in kilometers and miles?

1. Distance = speed $\times$ time.
2. $300,000 \text{ km/s} \times 0.068 \text{ s} = 20,400 \text{ km}$.
3. In miles: $20,400 \div 1.609 \approx 12,700 \text{ miles}$.

Answer: About 20,400 km, or about 12,700 miles.

Example 2. On a grid where each square is 1 km, a receiver is 5 km from tower A at (0, 0), 5 km from tower C at (0, 8), and about 8.06 km from tower B at (10, 0). Where is the receiver?

(Use the map or drawing “The third circle chooses between the two crossing points.” shown earlier in this lesson.)

1. Circles A and C both have radius 5 and centers 8 km apart. They cross halfway between, at $y = 4$. Then $x^2 + 4^2 = 5^2$, so $x^2 = 9$ and $x = 3$ or -3 . The two candidate points are (3, 4) and (−3, 4).
2. Check the distance from B (10, 0) to (3, 4): $\sqrt{7^2 + 4^2} = \sqrt{65} \approx 8.06$ km. It matches.
3. Check B to (−3, 4): $\sqrt{13^2 + 4^2} = \sqrt{185} \approx 13.6$ km. It does not match, so throw it out.

Answer: The receiver is at (3, 4).

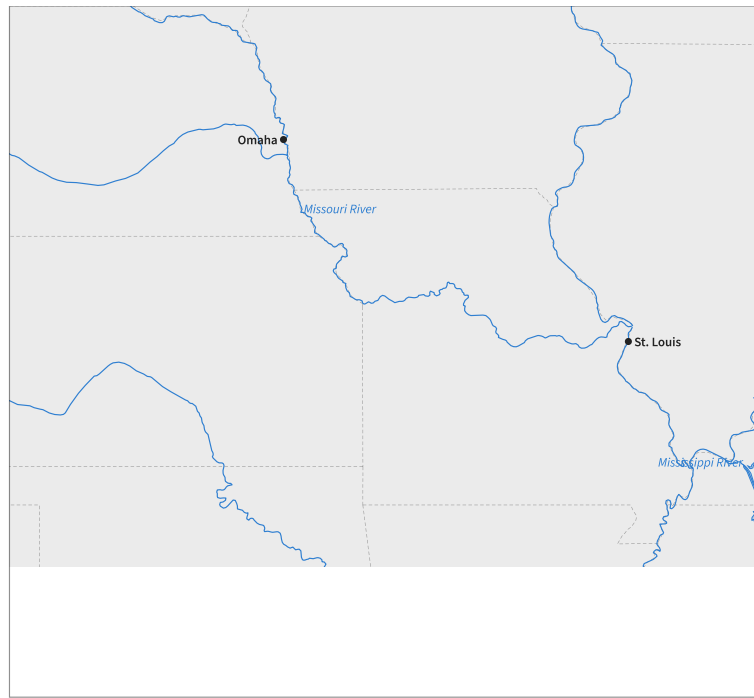
Example 3. A phone’s clock is off by just 1 microsecond (one millionth of a second, 0.000001 s). If it did not correct for this, how far off would each distance be? What if it were off by 1 millisecond (0.001 s)?

1. Distance error = speed of light $\times$ time error.
2. $300,000 \text{ km/s} \times 0.000001 \text{ s} = 0.3 \text{ km} = 300 \text{ m}$, about 1,000 feet.
3. $300,000 \text{ km/s} \times 0.001 \text{ s} = 300 \text{ km}$, about 186 miles.

Answer: A 1-microsecond error gives about 300 m (1,000 ft); a 1-millisecond error gives about 300 km (186 mi). This is why the receiver uses a fourth satellite to solve for its own clock error.

PRACTICE

1. **EASY** About how high do GPS satellites orbit, and at least how many are needed for the full system?
2. **EASY** True or false: your phone sends a signal up to the GPS satellites so they can tell it where it is. Explain.
3. **EASY** What did William Guier and George Weiffenbach discover by listening to Sputnik in 1957?
4. **MEDIUM** A signal takes 0.075 s to arrive. How far did it travel, in km and miles?
5. **MEDIUM** A satellite is 21,000 km away. How long does its signal take to reach you, in seconds and milliseconds?
6. **MEDIUM** A receiver’s clock is off by 2 microseconds (0.000002 s). How large is the distance error, in meters and feet?
7. **MEDIUM** Use the map. A mystery city is about 265 km (165 mi) from Omaha, about 385 km (240 mi) from St. Louis, and about 480 km (300 mi) from Oklahoma City. Which city is it?



Find the mystery city by trilateration.

8. **HARD** On a grid in kilometers, tower P is at (0, 0) and tower Q is at (6, 0). You are 5 km from each. Where could you be? A third tower R at (0, 8) says you are 5 km from it. Where are you?
9. **HARD** A GPS satellite's orbit has a radius of about 26,560 km (measured from Earth's center), and it goes around about once every 12 hours. How fast does it travel, in km/h and mph?
10. **CHALLENGE** Explain in two or three sentences why a GPS receiver needs signals from four satellites, not three, to find its position on Earth.

COMMON MISTAKES

- Thinking GPS satellites “watch” or track your phone. They only broadcast; your phone listens and calculates its own position.
- Confusing trilateration (finding a position from distances) with triangulation (finding a position from angles).
- Forgetting how fast light is. Tiny time errors make huge distance errors, so GPS timing must be accurate to billionths of a second.

Make it a game • Human GPS. Three players are “satellites” standing at fixed spots in a room or yard. A fourth player, the “receiver,” closes their eyes while a fifth player hides a coin. The satellites each call out how many big steps they are from the coin. The receiver, eyes now open, must walk to the coin using only the three distances. Rotate roles. For a hard round, one satellite secretly adds one step (a bad clock): can the receiver tell something is wrong?

Scripture. “If I take the wings of the morning, and dwell in the uttermost parts of the sea; Even there shall thy hand lead me, and thy right hand shall hold me.” (Psalm 139:9–10, KJV)

A GPS receiver can tell you where you are anywhere on Earth, but David knew something greater: there is no place on land or sea, however far, where God does not know us and lead us.

Practice answers

1. About 20,200 km (12,550 miles) up; the system needs at least 24 (about 31 are usually in service).
2. False. The satellites only broadcast their position and time. The phone only listens and does all the calculating itself.
3. By measuring the Doppler shift (the change in pitch) of Sputnik’s radio beeps, they could work out its whole orbit. That led to the idea of reversing the problem to find a position on the ground from a known satellite, which became the Transit system.
4. $300,000 \times 0.075 = 22,500$ km, about 14,000 miles.
5. $21,000 \div 300,000 = 0.07$ s, which is 70 milliseconds.
6. $300,000,000 \text{ m/s} \times 0.000002 \text{ s} = 600$ m, about 1,970 feet.
7. Kansas City (on the Missouri River at the Kansas–Missouri line). It is the one point that lies on all three distance circles.
8. Equal distances from P and Q put you on the line $x = 3$. Then $3^2 + y^2 = 25$, so $y = 4$ or -4 : (3, 4) or (3, -4). From R (0, 8): (3, 4) is $\sqrt{9 + 16} = 5$ km away, but (3, -4) is $\sqrt{9 + 144} \approx 12.4$ km. You are at (3, 4).
9. Circumference $= 2 \times 3.14 \times 26,560 \approx 166,800$ km. Speed $\approx 166,800 \div 12 \approx 13,900$ km/h, about 8,600 mph (nearly 4 km every second).
10. Three distances would be enough if the receiver’s clock were perfect, but a phone has an ordinary clock, and even a millionth-of-a-second error makes every distance wrong by 300 m. The receiver has four unknowns (east–west, north–south, height and its own clock error), so it needs four measurements to solve for all of them.

7.4 GIS: MAPS IN LAYERS

OBJECTIVES

- Tell how Dr. John Snow mapped the Broad Street cholera outbreak in London in 1854 and what his map showed.
- Explain what a geographic information system (GIS) is: layers of points, lines, polygons and rasters tied to the same place, each with its own data.
- Use a free online GIS map of your county, and compute rates, buffer areas and cell counts like a GIS analyst.

Warm-up. Take three sheets of tracing paper or clear plastic sheet protectors. On the first, draw the outline of your yard or street. On the second, laid on top, draw only the trees. On the third, draw only where water puddles after rain. Now lift and lower the sheets. What do you notice when you see the trees and the puddles together that you could not see on either sheet alone?

Watch. *John Snow and the 1854 Broad Street cholera outbreak* (Harvard Online, 8:02).
<https://www.youtube.com/watch?v=lNjrAXGRda4>

With the story: John Snow's cholera map and the Broad Street pump, told on the spot in London.

Backup video. *GIS Level 1 Video 6: Data layers* (MITLibraries, 1:30).
https://www.youtube.com/watch?v=Jy_P1oR3PJI

With the big idea: how a GIS stacks map layers. Note: A short clip from a university library's GIS course.

KEY TERMS

GIS (geographic information system)

A computer system that stores maps as layers of data tied to real places, so they can be stacked, searched, measured and compared.

layer

One kind of information about a place, such as roads, rivers, schools or elevation, that can be turned on or off over the others.

vector data

Map features stored as points (a well, a school), lines (a road, a river) or polygons (a park, a county).

raster data

Map information stored as a grid of square cells, each with one value, like an air photo or an elevation map.

attribute

A piece of data attached to a map feature, such as a road's name and speed limit or a house's address and year built.

buffer

A zone drawn at a set distance around a feature, such as everything within 500 meters of a river.

CORE IDEAS

The story. At the end of August 1854, cholera struck Soho, a crowded neighborhood in London. People who were well at breakfast were dead by nightfall. In about ten days, more than five hundred people living within about 250 yards of one street corner died. Most doctors of the day believed cholera spread through a poisonous “bad air,” or miasma, rising from filth. A London physician named **Dr. John Snow** did not agree. Years earlier he had argued that cholera spread through water fouled with sewage. He lived nearby, and he went straight to the registry office to get the names and addresses of the dead. Almost all of them had lived near one public water pump, on **Broad Street**. On September 7 he met with the parish leaders, and the next day, September 8, they had the handle taken off the pump.

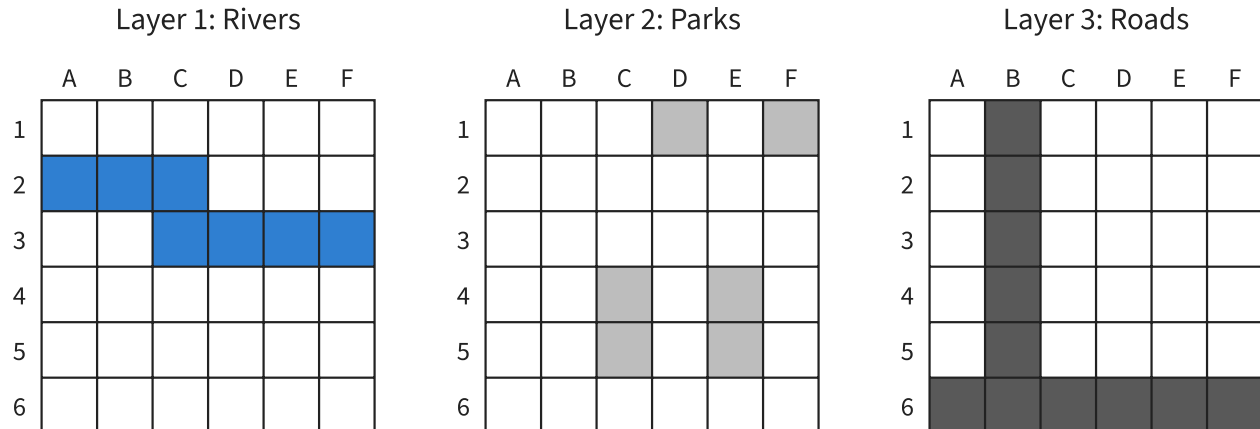
How he figured it out. Snow did not stop at a list. He went door to door and looked for the exceptions, because exceptions test a theory. A **workhouse** on Poland Street, almost surrounded by houses where people died, had 535 inmates, but only 5 died of cholera; it had its own well. A **brewery** on Broad Street had more than 70 workmen, and none died; they drank the beer they made and never touched the pump. Yet a widow in Hampstead, miles away, died of cholera: she liked the taste of the Broad Street water so much that a bottle of it was brought to her by cart every day. A local clergyman, Rev. Henry Whitehead, set out to disprove Snow and ended up confirming him; he even traced the probable start of the outbreak to a sick baby whose diapers had been washed into a cesspool a few feet from the well. Then Snow drew his famous **map**: a street map of Soho with the pumps marked and a small black bar for every death, stacked at each house. The bars cluster thickly around the Broad Street pump and thin out toward the other pumps.

The big idea. Snow's map works because it lays one kind of information *on top of* another: deaths on top of pumps on top of streets. That is the idea behind a **geographic information system**, or **GIS**. A GIS stores each kind of information as a separate **layer** lined up to real latitude and longitude. Some layers are **vector data**: *points* (wells, schools, fire hydrants), *lines* (roads, rivers, power lines) and *polygons* (parks, flood zones, counties). Others are **raster data**, grids of cells like an air photo or an elevation map. Every feature can carry **attributes**: a road's name and speed limit, a house's address and year built. Then you can ask questions no paper map can answer quickly: Which houses lie within 500 meters of the river (a **buffer**)? Which school is closest to each home? Which farms lie in the flood zone *and* on good soil (an **overlay**)?

Technology overcoming geography. In the early 1960s, an English-born geographer working in Canada, **Roger Tomlinson**, faced an impossible job: Canada wanted an inventory of its land (soils, forests, farms, wildlife and recreation) across about a million square miles, and drawing and comparing the maps by hand would have taken an army of mapmakers

decades. Tomlinson proposed putting the maps into a computer, and the result, the **Canada Geographic Information System**, is remembered as the first true GIS. Today GIS tells a dispatcher which ambulance is nearest, helps farmers spread fertilizer only where the soil needs it, shows engineers where a new road would cross wetlands, and lets a county keep track of every property line within its borders.

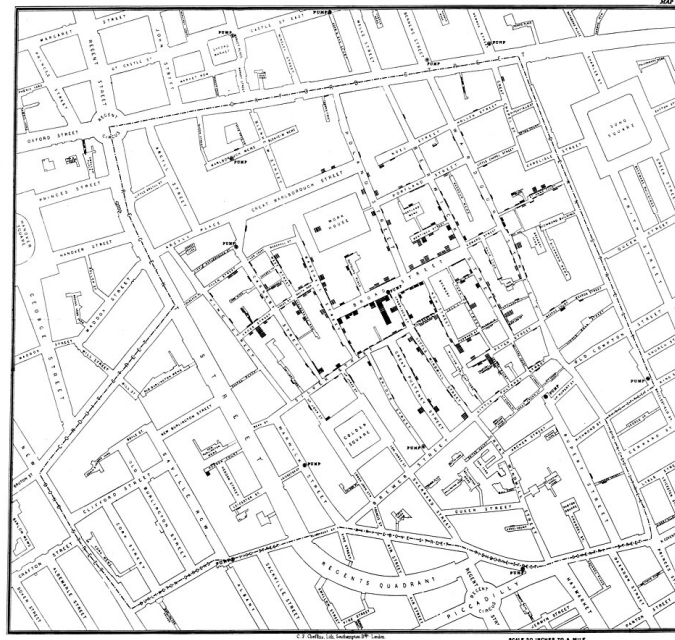
On the map. Nearly every county in the United States now has a free public GIS map online, often called a parcel viewer or county GIS map. Open your county's map with a parent (search for your county's name and "GIS map"). Turn the layers on and off: roads, property parcels, school districts, zoning, flood zones, aerial photos, elevation contours. Click on a parcel to read its attributes. Use the measuring tool to find the distance from your house to the nearest fire station, or the area of a park. You can also explore the U.S. Geological Survey's free National Map viewer, which has elevation, rivers, land cover and old topographic maps for the whole country. You are doing, in a few clicks, what took John Snow weeks of walking.



Columns A to F, rows 1 to 6. Overlay the layers to find the treasure square.

A GIS stacks layers of different kinds of data over the same place on Earth.

PICTURE STUDY



*Map of cholera deaths around Broad Street, Soho, Dr. John Snow (lithograph by Charles F. Cheffins), 1854 (published 1855) · Lithograph printed in Snow's book · Printed in Snow's *On the Mode of Communication of Cholera* (2nd edition, London, 1855); copies are held in many libraries*

This is probably the most famous map in the history of medicine. John Snow (1813–1858) was a careful London doctor who had already become known for giving ether and chloroform to patients during surgery. He drew this map of Soho for the second edition of his book on cholera, published in 1855. Each short black bar stands for one death, and the bars are stacked at the address where the person lived. The water pumps of the neighborhood are marked, with the Broad Street pump near the center.

Snow knew the map alone was not proof; a crowd of deaths near a pump could have other causes. It was his detective work on the exceptions (the workhouse, the brewery, the widow in Hampstead) and his larger study of London's water companies that made the case. But the map makes the pattern clear at a glance, and that is why geographers call it the first famous example of map-layer analysis. Broad Street is now called Broadwick Street, and a copy of the pump, without its handle, stands there today.

Look closely

- Find the Broad Street pump. Where are the black bars thickest?
- Find another pump on the map. How many bars are near it compared with Broad Street?
- Look for streets near the Broad Street pump with few or no bars. What might explain them?
- Find the scale or count the blocks. About how far does the thick cluster of bars reach from the pump?

Talk about it

1. What layers did Snow combine on this map? Name at least three.
2. Why was it important that Snow studied the people who did *not* get sick?
3. If Snow had a GIS today, what other layers might he add to make his case stronger?

PROJECT: MY LAYERED COUNTY MAP

You will make a layered map of your own county in two ways: by hand, with tracing-paper overlays, and on a computer, with a free online GIS. Comparing the two will show you why GIS changed mapmaking. This map is also the unit map assignment and a first step toward your city study in Unit 8.

You will need

- A printed outline map of your county (print one from your county or state website, or trace one from a road atlas)
- Five sheets of tracing paper or clear plastic sheets cut to the same size, and tape
- Fine-tip markers in several colors, including blue
- A computer or tablet with internet access, used with a parent
- Map notebook

Steps

1. With a parent, find your county's online GIS map (search your county name and "GIS map") or open the USGS National Map viewer. Spend ten minutes turning layers on and off and list every layer you find.
2. Base layer: tape the county outline map down. Add a title, a north arrow, a scale bar and your county seat. Mark three registration crosses in the corners so every overlay lines up.
3. Layer 1, water (lines and polygons): on the first tracing sheet, copy the crosses, then trace rivers, creeks and lakes in blue.
4. Layer 2, transportation (lines): trace the main highways, railroads and any airport or port.
5. Layer 3, towns (points and polygons): mark each town and city with a dot sized by population, and shade the built-up areas.
6. Layer 4, the land (raster or contour): using the elevation or terrain layer online, shade the high ground and low ground, or draw a few contour lines.
7. Layer 5, your choice: schools, parks, farms, flood zones, historic sites or churches. Write a key for it.
8. Stack the layers and write three things you can see only when layers are combined. (For example: "The towns all sit where the railroad crosses the river.")
9. Finally, use the online map's measuring tool to find the area of your county and the straight-line distance from your home to the county seat. Record them.

Tips

- Line up the registration crosses every time, or your layers will not match.
- Keep each layer to one kind of information. A crowded layer is hard to read.
- Many county GIS maps also show old aerial photos. Compare one from decades ago with today's; you will use this skill in Lesson 8.3.

Check your work

- My map has a base layer with title, north arrow, scale and county seat, plus at least four overlays with keys.
- I used a free online GIS map of my county and listed its layers.
- I wrote three discoveries that came from combining layers.

MAP NOTEBOOK

1. Draw a simple version of Snow's map: a few streets, three pumps, and bars for deaths clustered around one pump. Label the workhouse and the brewery.
2. Make a three-column chart of map features in your town sorted into points, lines and polygons (at least four in each column).
3. Draw a river with a 500-meter buffer shaded along both banks. Mark two houses inside the buffer and one outside it.

From history. John Snow was also one of the first doctors in England to make a careful science of anesthesia, and in 1853 he gave chloroform to Queen Victoria during the birth of her son Prince Leopold. He died in 1858, before most doctors accepted his water theory of cholera. That same summer, the "Great Stink" of sewage in the Thames was so bad that Parliament finally approved Joseph Bazalgette's great system of sewers, which carried London's waste away from the river and, together with clean water supplies, helped end cholera epidemics in the city.

WORKED EXAMPLES

Example 1. In his larger study of 1854, Snow compared London houses supplied by two water companies. The Southwark and Vauxhall Company, which drew water from the Thames downstream of the city's sewers, supplied 40,046 houses, which had 1,263 cholera deaths. The Lambeth Company, which had moved its intake upstream, supplied 26,107 houses, which had 98 deaths. Find the deaths per 10,000 houses for each, and compare.

1. Southwark and Vauxhall: $1,263 \div 40,046 \times 10,000 \approx 315$ deaths per 10,000 houses.
2. Lambeth: $98 \div 26,107 \times 10,000 \approx 37.5$ deaths per 10,000 houses.
3. Compare: $315 \div 37.5 \approx 8.4$.

Answer: About 315 versus about 37 deaths per 10,000 houses: the houses on dirty water had a death rate more than 8 times higher.

Example 2. A county wants to know how much land lies within 500 m of a river for a flood study. A straight stretch of the river is 12 km long. Ignoring the rounded ends, what is the area of a 500 m buffer on both banks, in square kilometers and square miles ($1 \text{ km}^2 \approx 0.386 \text{ sq mi}$)?

(Use the map or drawing “A buffer is drawn around a feature in one layer, then laid over the others.” shown earlier in this lesson.)

1. A buffer of 500 m on each side makes a strip $1,000 \text{ m} = 1 \text{ km}$ wide.
2. Area = length $\times$ width = $12 \text{ km} \times 1 \text{ km} = 12 \text{ km}^2$.
3. $12 \times 0.386 \approx 4.6$ square miles.

Answer: About 12 km^2 , or about 4.6 square miles.

Example 3. Elevation data from the U.S. Geological Survey is often stored as a raster of square cells 30 m on a side. How many cells cover 1 square kilometer? How many cover a county of $1,000 \text{ km}^2$ (about 386 sq mi)?

1. Area of one cell: $30 \text{ m} \times 30 \text{ m} = 900 \text{ m}^2$.
2. $1 \text{ km}^2 = 1,000 \text{ m} \times 1,000 \text{ m} = 1,000,000 \text{ m}^2$. Cells: $1,000,000 \div 900 \approx 1,111$.
3. For $1,000 \text{ km}^2$: $1,111 \times 1,000 \approx 1,111,000$ cells.

Answer: About 1,111 cells per square kilometer, and about 1.1 million cells for the county. A computer handles that easily; a person with a pencil could not.

PRACTICE

1. **EASY** What is a GIS? Answer in one sentence.
2. **EASY** Sort these into points, lines or polygons: a fire hydrant, a railroad, a state park, a church, a creek, a school district.
3. **EASY** What did John Snow put on his 1854 map, and what pattern did it show?
4. **MEDIUM** The Poland Street workhouse had 535 inmates, and 5 died of cholera. What percentage is that? Why did Snow think so few died there?
5. **MEDIUM** A raster has cells 10 m on a side. How many cells cover 1 km^2 ?
6. **MEDIUM** A highway runs straight for 3 miles. Ignoring the ends, what is the area of a 1-mile buffer on both sides, in square miles and square kilometers ($1 \text{ sq mi} \approx 2.59 \text{ km}^2$)?
7. **MEDIUM** Use the figure. Which kind of layer would you use for (a) the elevation of every spot in your county, (b) the routes of school buses, (c) the boundaries of farms?
(Use the map or drawing “The four kinds of layers.” shown earlier in this lesson.)
8. **HARD** A county wants a site for a new fire station that is (1) within 1 km of a main road, (2) outside the flood zone, and (3) on land the county already owns. Which layers would you need, and what GIS steps would you take?

9. **HARD** Snow found about 315 cholera deaths per 10,000 houses supplied by the Southwark and Vauxhall Company and about 37 per 10,000 for the Lambeth Company. In a street of 400 houses on each supply, about how many deaths would you expect from each?
10. **CHALLENGE** A map shows that two things cluster in the same place. Explain in two or three sentences why that alone does not prove one causes the other, and what Snow did besides drawing his map.

COMMON MISTAKES

- Thinking a GIS is just a pretty map. Its power is in the data behind each feature, which can be searched, measured and combined.
- Mixing up raster and vector. Rasters are grids of cells (photos, elevation); vectors are points, lines and polygons.
- Believing a cluster on a map proves a cause. A map shows a pattern; careful reasoning and testing explain it.

Make it a game · Layer Detective. A parent secretly chooses a spot on your county GIS map (or a printed map) and gives clues one layer at a time: “It is within a mile of a river.” “It is in a school district that starts with W.” “It is on high ground.” “It is next to a highway.” After each clue, players guess. The fewer clues you need, the more points you score. Then switch and give the clues yourself.

Scripture. “And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;” (Acts 17:26, KJV)

God has set each of us in a particular place, with its own rivers, roads and neighbors. Knowing that place well, as Snow knew Soho, lets us love and serve the people who live there.

Practice answers

1. A geographic information system is a computer system that stores maps as layers of data tied to real places, so they can be stacked, searched, measured and compared.
2. Points: fire hydrant, church. Lines: railroad, creek. Polygons: state park, school district.
3. He drew the streets of Soho, marked the public water pumps, and placed a black bar for each cholera death at the house where it occurred. The deaths clustered thickly around the Broad Street pump.
4. $5 \div 535 \times 100 \approx 0.9\%$, fewer than 1 in 100. The workhouse had its own well, so the inmates did not drink from the Broad Street pump.
5. Each cell is 100 m². $1,000,000 \div 100 = 10,000$ cells.
6. The strip is 2 miles wide: $3 \times 2 = 6$ square miles, about 15.5 km².
7. (a) Raster, a grid of cells each holding an elevation. (b) Lines. (c) Polygons.
8. Layers: main roads (lines), flood zones (polygons) and property parcels with an owner attribute (polygons). Steps: draw a 1 km buffer around the main roads; remove any land

inside the flood zone; select parcels whose owner is the county; overlay all three and keep only the areas that meet every condition.

9. 400 is 0.04 of 10,000. Southwark and Vauxhall: $315 \times 0.04 \approx 12.6$, about 13 deaths. Lambeth: $37 \times 0.04 \approx 1.5$, about 1 or 2 deaths.
10. Two things can sit together on a map by coincidence or because of a third cause (for example, crowding or poverty). Snow tested his idea by studying the exceptions: the workhouse and brewery with their own water had almost no deaths, while a widow far away who drank Broad Street water died. He also compared thousands of houses on two water companies. Those tests, not the map alone, made his case.

UNIT 7 REVIEW

Answer each question. Show your work for calculations and use complete sentences for explanations. Give distances in both metric and U.S. units where asked. The review is worth 60 points.

1. (6 pts) Give the back bearing of (a) 115° and (b) 290° .
2. (6 pts) You measure a bearing of 200° on a map. The declination is 8° west. What bearing do you set on your compass? What if the declination were 8° east?
3. (6 pts) List the steps for following a bearing of 75° with a baseplate compass.
4. (6 pts) Your pace count is 62 double paces per 100 meters. How many paces is a leg of 400 meters? About how many feet is that ($1 \text{ m} \approx 3.28 \text{ ft}$)?
5. (6 pts) An orienteering map has a scale of 1:15,000. A leg measures 6 cm on the map. How long is it on the ground in meters and miles ($1 \text{ mile} \approx 1,609 \text{ m}$)?
6. (6 pts) A leg crosses four contour lines going uphill. The contour interval is 5 m. How much do you climb, in meters and feet? On an orienteering map, what do green and yellow mean?
7. (6 pts) Explain “aiming off” and why it works when a control is on a long stream or fence.
8. (6 pts) A GPS signal takes 0.07 seconds to reach your phone. Radio waves travel about 300,000 km per second. How far away is the satellite, in km and miles?
9. (6 pts) Explain trilateration on a flat map using three distance circles, and explain why a real GPS receiver needs a fourth satellite.
10. (6 pts) What layers did John Snow combine on his 1854 map of Soho, and what pattern did it show? Name two other pieces of evidence he gathered. Then name one point layer, one line layer and one polygon layer you might find on your county’s GIS map.

UNIT PROJECT: MY ORIENTEERING COURSE AND LAYERED COUNTY MAP

Present the two big maps of this unit together. First, the orienteering course you built for your yard or park: a clean final copy of the map with north arrow, scale, key and course overprint, the control description sheet, a table of every leg’s bearing and distance, and the times of at least two family members who ran it. Second, your layered county map: the base map and at least four tracing-paper overlays, with a short list of the layers you explored on your county’s online GIS map.

Finish with a one-page write-up explaining how a compass, GPS and GIS each answer the question “Where am I?” in a different way, and which three discoveries you made only by stacking your county’s layers together.

- **Map accuracy:** Both maps have a north arrow, scale and key; features are placed correctly and the orienteering legs’ bearings and distances are measured correctly.
- **Course design:** The orienteering course is safe and fair, uses the standard symbols, has a complete description sheet, and was run successfully by someone else.

- **Layers and analysis:** The county map has at least four well-aligned layers with keys, and the write-up names three real patterns found by combining them.
- **Explanation and care:** The write-up correctly explains bearings, trilateration and GIS layers in clear sentences, and the work is neat and complete.

Answer key

1. (a) $115^\circ + 180^\circ = 295^\circ$. (b) $290^\circ - 180^\circ = 110^\circ$.
2. West declination: add, $200^\circ + 8^\circ = 208^\circ$. East declination: subtract, $200^\circ - 8^\circ = 192^\circ$.
3. Turn the housing until 75° is at the index line. Hold the compass flat at your waist with the direction-of-travel arrow pointing straight ahead. Turn your whole body until the red end of the needle sits inside the orienting arrow ("red in the shed"). Pick a landmark in the direction of the travel arrow, walk to it, and repeat.
4. $400 \times 0.62 = 248$ double paces. $400 \text{ m} \times 3.28 \approx 1,312$ feet.
5. $1 \text{ cm} = 150 \text{ m}$, so $6 \text{ cm} = 900 \text{ m}$, about 0.56 mile.
6. $4 \times 5 = 20 \text{ m}$, about 66 feet. Green is thick vegetation that slows you down; yellow is open land.
7. Aiming off means steering deliberately a few degrees to one side of the control. When you reach the stream or fence, you know for certain which side of the control you are on, so you know which way to turn and follow the line feature to it. If you aimed straight and missed slightly, you would not know which way to turn.
8. $300,000 \times 0.07 = 21,000 \text{ km}$, about 13,000 miles.
9. Each distance puts you somewhere on a circle around a known point. Two circles usually cross at two points; the third circle passes through only one of them, which is your position. A real receiver works in three dimensions and has an imperfect clock; a clock error of one millionth of a second makes each distance 300 m wrong, so it uses a fourth satellite to solve for its clock error along with its three position coordinates.
10. Streets, water pumps and cholera deaths (a bar for each death at its house). The deaths clustered around the Broad Street pump. Other evidence: the Poland Street workhouse with its own well had only 5 deaths among 535 inmates; the brewery workers who drank beer did not die; a widow in Hampstead who had Broad Street water brought to her died; houses on the dirty Southwark and Vauxhall water had over 8 times the death rate of Lambeth houses. County GIS examples: points, schools or fire hydrants; lines, roads or rivers; polygons, parcels, parks or flood zones.

CAPSTONE: THE GEOGRAPHY OF MY CITY

All year you have asked why cities stand where they do: at the ford and the confluence, on the fall line and the harbor, beside the great rivers of the ancient world, on the straits and canals of the sea. Now you turn the same questions on the place you know best: your own city or the town nearest your home. Scripture tells us that God “hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;” (Acts 17:26). Every city is a set of human choices made within the land God made, and in this unit you will learn to read those choices on the ground and on the map.

You will stand with Pierre Laclède on the bluff where he founded St. Louis in 1763–1764 and learn to tell **site** from **situation**. You will follow Stephen H. Long to the railroad stake in the Georgia woods that became Atlanta, a city with no river or harbor that grew on rails, highways and air routes. You will lay Peter Gordon’s 1734 view of Savannah beside a modern map and count Oglethorpe’s squares, and you will learn to use Sanborn fire insurance maps and old topographic maps to see how your own city has changed. Finally you will meet Daniel Burnham and the Chicago eighth graders who studied the *Plan of Chicago* in school, and then present your own city with a poster, a map and a talk.

The whole unit builds one project, the **city study**: a salt-dough relief model of your city’s original site, a pin-and-string connections map, a then-and-now overlay of an old map on a new one, and a finished capstone map, poster and five-minute talk. The unit can stretch across a month or more; take the time to visit your city’s oldest streets, its riverfront or depot, and its library or historical society.

BEFORE YOU BEGIN

- Can explain the founding types of Unit 1 (ford, confluence, fall line, hill and harbor)
- Can read latitude and longitude and convert degrees of latitude to miles and kilometers (about 69 miles or 111 km per degree)
- Can use a map scale written as a word scale, a scale bar or a representative fraction
- Has used layered maps and a free online map or GIS viewer (Unit 7)

MASTERY CHECKLIST

- I can explain the difference between site and situation and use both to explain why my city was founded where it was.
- I can name and map the water, rail, road and air links that connect my city to the world and decode Interstate highway numbers.
- I can compare an old map with a new one at the same scale and explain what has lasted and what has changed.
- I can use map scales (1:24,000, 1:62,500, 1 inch = 50 feet) to measure distances and areas in miles, feet and kilometers.

- I can make a finished map with title, orientation, date, author, legend, scale and sources.
- I can present my city's geography to an audience in a clear, well-timed talk.

OPTIONAL BOOKS AND RESOURCES

- **Panoramic Maps, Library of Congress** (<https://www.loc.gov/collections/panoramic-maps/>): Free. Bird's-eye views of American and Canadian cities and towns, mostly from the 1850s to the 1920s. Search for your city or county name for the unit's picture study and Lesson 8.3.
- **Sanborn Maps, Library of Congress** (<https://www.loc.gov/collections/sanborn-maps/>): Free. Detailed fire insurance maps of thousands of American towns, showing every building's outline and material. Browse by state and city for Lesson 8.3.
- **TopoView, U.S. Geological Survey** (<https://ngmdb.usgs.gov/topoview/>): Free. Current and historic USGS topographic maps of the whole United States, back to the 1880s, which you can view and download. Use it for the relief model (8.1), the overlay (8.3) and the capstone map (8.4).

8.1 SITE AND SITUATION OF MY CITY ★

OBJECTIVES

- Explain the difference between a city's site and its situation and use both ideas to explain why Pierre Laclède founded St. Louis where he did in 1763–1764.
- Find the latitude, longitude, elevation and nearby waterways of my own city and decide which founding type (ford, confluence, fall line, harbor, hill, crossroads, railroad town or another) fits it best.
- Build a relief model of my city's original site and write a short site-and-situation statement for my city study.

Warm-up. Spread a thin layer of sand, rice or cornmeal in a baking dish and prop up one end on a book. Pour a spoonful of water at the high end and watch where it runs and pools. Now set a bottle cap “town” where you would build: on the wet low ground, on a dry rise beside the water, or far from the water? Give one reason. Then name one thing your town needs that is not in the dish at all, such as a road, a neighbor or a market. Your first answer was about **site**; your second was about **situation**.

Watch. *What's inside of the Gateway Arch? (St. Louis, Missouri)* (Jared Owen, 15:35).

<https://www.youtube.com/watch?v=cBG2S8FW5KM>

With the story: inside the Gateway Arch at St. Louis.

Note: Jared Owen's animation runs about 15 minutes.

Backup video. *History of Saint Louis: French king and American city* (The History Guy: History Deserves to Be Remembered, 10:18). <https://www.youtube.com/watch?v=L20yUvOLRQ8>

With the history note: the founding of St. Louis where the Missouri meets the Mississippi.

KEY TERMS

site

The physical ground a city stands on: its landforms, water, soil, elevation and building materials.

situation

Where a city lies in relation to other places: the rivers and roads that reach it, its neighbors, markets and the resources around it.

confluence

The place where two rivers meet and flow on as one.

floodplain

Low, flat land beside a river that is covered with water when the river floods.

bluff

A high, steep bank or cliff rising above a river or a plain.

gateway city

A city at the entrance to a large region, through which people and goods pass in and out.

CORE IDEAS

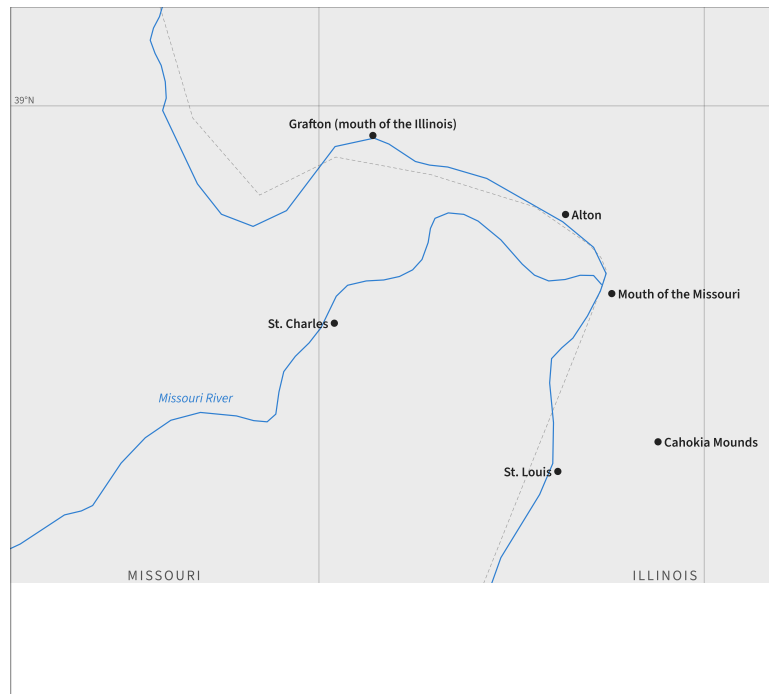
The story. In December 1763 a French fur trader named Pierre Laclède walked along the west bank of the Mississippi River looking for a place to build a trading post. He was a partner in a New Orleans company that had been given the right to trade with the Osage and other Indian nations up the Missouri River, and he had spent about three months pushing boats upstream from New Orleans to reach this country. He passed over the low, swampy ground on the east bank. He looked at the mouth of the Missouri. Then he chose a stretch of high ground on the west bank a little below the place where the two great rivers meet, and he cut marks on trees to show where the town should stand. In February 1764 his stepson, Auguste Chouteau, a boy of about fourteen, brought some thirty workmen to clear the ground and build. Laclède named the post for Louis IX, the patron saint of the French king, Louis XV. Chouteau later remembered that Laclède was sure the place would one day become one of the finest cities in America.

How they figured it out. Laclède was reading the land the way you have learned to read a map. First he looked at the ground itself. The town site sat on a limestone terrace and bluff high enough to stay dry when the river rose, while across the water the broad bottomland, later called the American Bottom, went under in floods. The bank gave a good landing for boats, the woods gave timber, and the limestone gave building stone. Then he looked at where the place lay in relation to everything else. About 15 miles (24 km) upriver the Missouri came in from the far northwest, bringing the fur trade of the plains to his door. Less than 40 miles (64 km) upriver the Illinois River led toward the Great Lakes. Downriver lay New Orleans and the sea, where furs could be sold and trade goods bought. Even the politics were part of the picture: after France lost the war of 1754–1763, French families from villages on the east bank, now British, moved across the river to the new town. (Laclède did not yet know that France had secretly given Louisiana west of the Mississippi to Spain in 1762, so his French town soon flew a Spanish flag.)

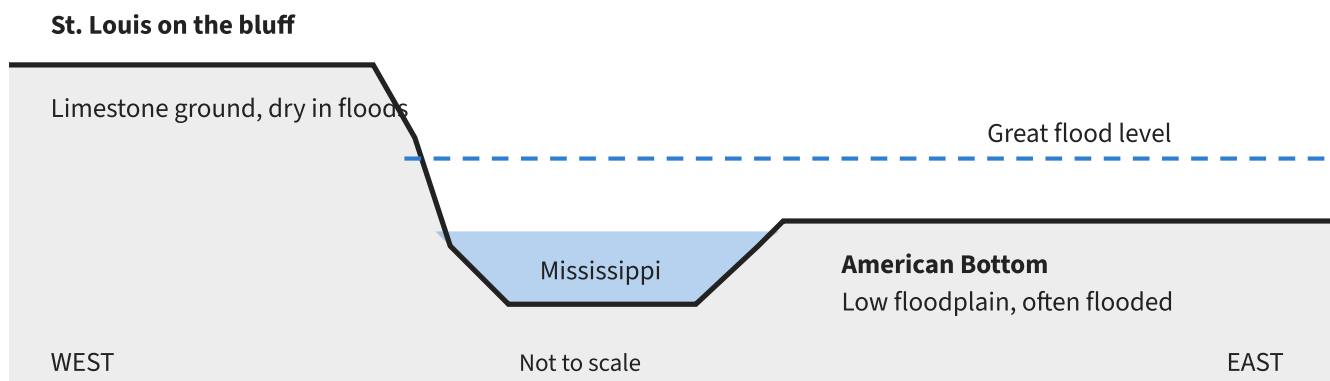
The big idea. Geographers ask two questions about every city. The first is about its **site**: what is the ground like? Is it high or low, wet or dry, flat or steep, rich in water and stone? The second is about its **situation**: where is it compared with other places? What rivers, roads, neighbors and resources are within reach? Site decides whether a town is easy to build and safe to live in. Situation decides whether it will grow. A fine site with a poor situation usually stays a village, while an ordinary site with a great situation can become a metropolis, because people will drain the marsh, fill the shore and build the levee to fix the site. Situation can also change when technology changes. In 1870 St. Louis was a little larger than Chicago; by 1880 Chicago had about 500,000 people and St. Louis about 350,000, because the railroads had made Chicago's situation even stronger. In Unit 1 you met the classic founding types: the ford, the confluence, the fall line, the hill and the harbor. Add a few more for America: the railroad town, the crossroads, the mining camp, the county seat and the planned capital.

On the map. The Mississippi and its branches drain parts of 31 states, about two-fifths of the lower 48, and St. Louis sits near the middle of that great basin at about 38.6°N, 90.2°W (see the map). That is why it became a **gateway city**. In May 1804 Lewis and Clark set out from their camp across from the mouth of the Missouri, and in September 1806 they returned to St. Louis. Fur traders, steamboats, wagon trains and emigrants all passed through. In March 1804 St. Louis was the scene of the ceremony that handed Upper Louisiana to the United States. Today the stainless-steel Gateway Arch, 630 feet (192 m) high and finished in 1965, stands on the very riverfront where Laclède marked his trees.

Your city. Now turn the same two questions on your own city. Find its oldest part: the old landing, fort, mill, depot, courthouse square or church. Ask what the ground was like there before anyone built: a riverbank, a bluff, a spring, a harbor, a crossing, a pass, a flat spot beside a railroad survey line? Then ask what lay within reach: a river to the sea, a trail, a mine, farmland, a state capital, a rail line. Every city is a choice someone made within the land God made, and Scripture says He “hath determined the times before appointed, and the bounds of their habitation” (Acts 17:26). Your city study begins with this question: why here?

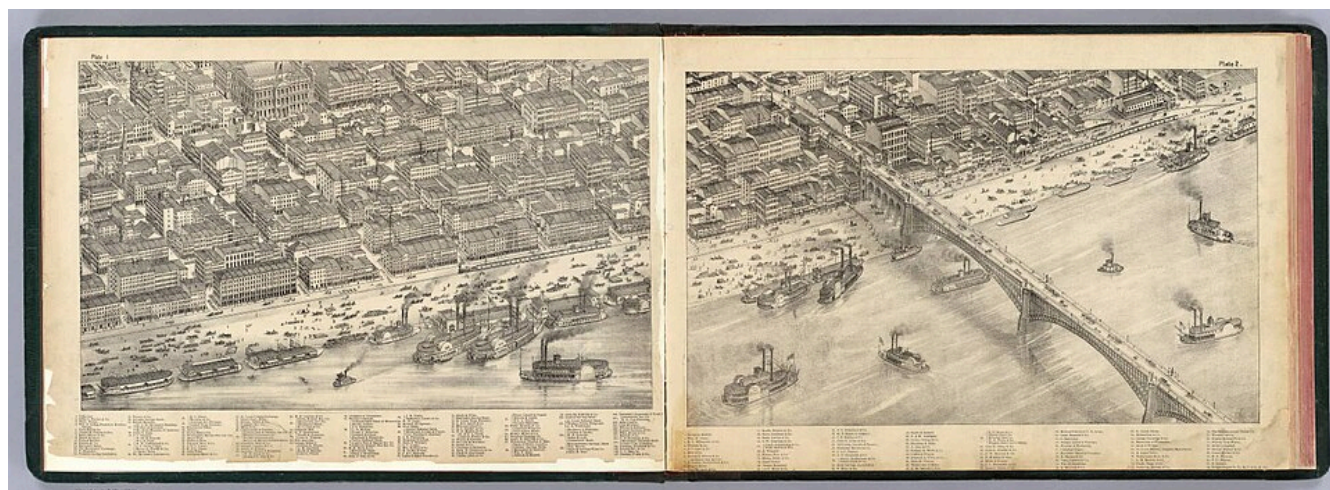


St. Louis stands on high ground on the west bank, a little below the meeting of the Missouri and the Mississippi.



Site in cross-section: why Laclède chose the west-bank bluff and not the east-bank bottomland.

PICTURE STUDY



Pictorial St. Louis, the Great Metropolis of the Mississippi Valley, Camille N. Dry (artist), published by Richard J. Compton, drawn 1874–1875, published 1875–1876 · Lithograph, a bird's-eye view printed on 110 plates · Library of Congress, Geography and Map Division, Washington, D.C. (this image of plates 1–2 is from the David Rumsey Map Collection copy)

In the 1870s the publisher Richard Compton and the artist Camille Dry set out to draw every street and every building in St. Louis, as if seen from a balloon floating high above the Mississippi and looking west. The finished view filled 110 separate plates. Put together, they make one of the most detailed pictures of an American city ever drawn, made just after the Eads Bridge opened in 1874.

Bird's-eye views like this one were popular in America from the 1850s to the 1920s. Traveling artists walked the streets, sketched every block and then drew the town in perspective from an imaginary point in the sky. The Library of Congress panoramic maps collection holds well over a thousand of them, and your own city or a town near you may well be among them. In this unit you will look for yours.

Look closely

- Find the Mississippi and the riverfront levee where steamboats tied up. Why would the busiest streets be close to it?
- Look for the Eads Bridge. What did a bridge do to St. Louis's situation that ferryboats could not?
- Notice how the ground rises away from the river. Can you see why Laclède thought this bank was safer than the low east bank?
- Find church steeples, factory chimneys and open squares. What do they tell you about how people lived and worked in 1875?

Talk about it

1. Which parts of this view show the city's site, and which show its situation?
2. If an artist drew a bird's-eye view of your city today, what would be in the foreground, and why?
3. What could a historian learn from this view that a modern photograph could not show?

PROJECT: MY CITY'S SITE IN SALT DOUGH

This is the first part of your city study, the big project of Unit 8. You will find where your city began, build a relief model of that ground, and write a site-and-situation statement that explains why the city was founded there. If you live in the country or a small town, study the nearest town or the city where your family shops, works or worships.

You will need

- A printed topographic map of your city's oldest part (free from USGS TopoView; a historic map from the 1880s-1950s is best because it shows the ground before modern building)
- A piece of stiff cardboard about 12 by 12 inches (30 by 30 cm)
- Salt dough: 2 cups flour, 1 cup salt and about 3/4 cup water, kneaded smooth
- Pencil, carbon paper or tracing paper, a ruler and toothpicks
- Blue paint or blue yarn for water; green and brown paint for land
- Index cards and a city-study folder or notebook

Steps

1. Research the founding. Using your city's or county's official website, a local historical society or the library, find: the year the town was founded, who founded it, and the very spot where it began (a landing, fort, mill, depot, crossroads or courthouse square). Write these on an index card.
2. Find your city's latitude, longitude and elevation (a USGS map, a GPS app or an atlas will do). Write them on the card in degrees to one decimal place.
3. Print or trace the topographic map of the original settlement area. Mark the founding spot with a star.

4. Trace the shoreline, rivers and three or four contour lines onto the cardboard. Label each contour with its elevation.
5. Build up the land with salt dough, adding a thicker layer for each higher contour line. Press river valleys and harbors down below the surrounding land.
6. When the dough is dry (a day in the air or a few hours in a low oven with an adult's help), paint the water blue and the land green and brown. Push a toothpick flag into the founding spot.
7. On a second card, write three facts about your city's **site** and three facts about its **situation**. Then name its founding type and explain your choice in two sentences.
8. Visit the Library of Congress panoramic maps collection online and search for your city or county. If you find a bird's-eye view, save it for Lesson 8.3.

Tips

- Many cities began at the water, even if the water hardly matters today. Look for old names like Landing, Ferry, Mill, Ford, Falls, Springs, Junction or Port.
- If your city has more than one founding story, write them all down and note which sources say what. Good historians compare sources.
- Keep the vertical scale bigger than the horizontal scale so low hills show, and write "vertical scale exaggerated" on the model.

Check your work

- I can name when, by whom and at what exact spot my city began.
- My model shows the water, the high and low ground and the founding spot.
- I can give three site facts and three situation facts for my city and name its founding type.

MAP NOTEBOOK

1. Draw the St. Louis cross-section from memory: the west-bank bluff, the river and the east-bank floodplain. Label site advantages in green and dangers in red.
2. Make a two-column chart titled "My City" with the headings Site and Situation. Add at least four facts in each column as you research.
3. Sketch a small locator map of your state with your city marked by a star, the nearest large river in blue, and an arrow pointing toward the sea or the nearest port.

From history. Across the river from St. Louis lie the Cahokia Mounds, the remains of the largest town north of Mexico before Columbus, built by the people of the Mississippian culture and at its height around AD 1100. Its greatest earthwork, Monks Mound, rises about 100 feet (30 m). The same good situation near the meeting of great rivers drew people here long before Laclède. St. Louis itself once had dozens of smaller mounds and was nicknamed the "Mound City," but nearly all of them were leveled as the city grew; the largest, the Big Mound, was dug away in 1869 for fill.

WORKED EXAMPLES

Example 1. St. Louis lies at about 38.63°N , 90.20°W . New Orleans lies at about 29.95°N , 90.07°W . Find the straight-line distance between them. One degree of latitude is about 69 miles (111 km).

1. Compare the longitudes: 90.20°W and 90.07°W are almost the same, so New Orleans is almost due south of St. Louis. We can use the difference in latitude alone.
2. Difference in latitude: $38.63^{\circ} - 29.95^{\circ} = 8.68^{\circ}$.
3. Miles: $8.68 \times 69 = 598.9$, about 600 miles.
4. Kilometers: $8.68 \times 111 = 963.5$, about 960 km.
5. The river route is far longer, over 1,000 miles, because the Mississippi winds back and forth in great bends across its floodplain.

Answer: About 600 miles (about 960 km) in a straight line, nearly due south.

Example 2. In the Great Flood of 1993 the Mississippi at St. Louis crested at 49.58 feet on the river gauge on August 1. Flood stage at St. Louis is 30 feet. How far above flood stage was the river, in feet and meters? The downtown floodwall was built to hold back a stage of about 52 feet. How much room was left?

1. Above flood stage: $49.58 - 30 = 19.58$ feet, about 19.6 feet.
2. Convert to meters: $19.58 \times 0.3048 = 5.97$, about 6.0 meters.
3. Room left at the floodwall: $52 - 49.58 = 2.42$ feet, about 2.4 feet (0.74 m).

Answer: About 19.6 feet (6.0 m) above flood stage, with only about 2.4 feet (0.7 m) to spare below the top of the floodwall's design height.

Example 3. Sort these six facts about early St. Louis into site and situation: (a) high limestone ground above the floodplain; (b) about 15 miles below the mouth of the Missouri; (c) timber and building stone close at hand; (d) on the water route between the Great Lakes country (by the Illinois River) and New Orleans; (e) a good boat landing along the riverbank; (f) Osage villages up the Missouri ready to trade furs.

1. Ask of each fact: is it about the ground itself, or about where the place lies compared with other places?
2. (a), (c) and (e) describe the ground, materials and riverbank right at the town: site.
3. (b), (d) and (f) describe what lies within reach of the town: situation.

Answer: Site: (a), (c), (e). Situation: (b), (d), (f).

PRACTICE

1. **EASY** In your own words, define site and situation. Give one example of each from St. Louis.
2. **EASY** Who chose the site of St. Louis, and when? Who led the workers who began building, and when?
3. **EASY** The Gateway Arch is 630 feet tall. How tall is it in meters? (1 foot = 0.3048 m)
4. **EASY** Look at the map of St. Louis and the rivers. Which river joins the Mississippi closest to St. Louis, and which joins farther upstream?
(Use the map or drawing "Use the map to find the two confluences." shown earlier in this lesson.)
5. **MEDIUM** The mouth of the Missouri is at about 38.81°N; St. Louis is at about 38.63°N. How far north of St. Louis is the confluence in a straight line, in miles and kilometers? Why is the distance by water a little longer?
6. **MEDIUM** Memphis, Tennessee, lies at about 35.15°N, 90.05°W, almost due south of St. Louis (38.63°N, 90.20°W). Find the straight-line distance between them in miles and kilometers.
7. **MEDIUM** Sort these facts about Memphis (founded 1819) into site and situation: (a) built on the Fourth Chickasaw Bluff, above the floods; (b) a landing at the foot of the bluff where steamboats tied up; (c) the cotton lands of the Mississippi Delta lay to the south; (d) railroads later linked it to the Atlantic coast and the West.
8. **HARD** In 1870 St. Louis had about 311,000 people and Chicago about 299,000. In 1880 St. Louis had about 350,000 and Chicago about 503,000. Find each city's growth in people and in percent over those ten years.
9. **HARD** Name the founding type of each town: (a) boats from the coast could go no farther upstream because of rapids, so a mill town grew there; (b) two rivers meet at a point of land; (c) a railroad company ended its line and built a depot in the woods; (d) a trail crossed a river at a shallow place.
10. **CHALLENGE** Write a short paragraph (4–5 sentences): Can a city with an ordinary site outgrow a city with an excellent one? Use St. Louis and Chicago as your example.

COMMON MISTAKES

- Mixing up site and situation. A quick test: if you could see it standing on the spot, it is probably site; if you need a map of the region to see it, it is situation.
- Thinking the reason a city was founded is the same as the reason it is big today. Many river towns now live by highways, airports or universities, but their oldest streets still sit by the water.
- Giving only one founding story without checking. Local legends can be wrong; compare the city's records, a county history and a historic map.

Make it a game • Site or Situation?. One player reads a fact about any city you have studied this year (for example, "Venice is built on mud banks in a lagoon" or "Pittsburgh is where three rivers meet"). The other has five seconds to call "Site!" or "Situation!" and give a one-sentence reason. Some facts can be argued both ways; a good argument earns

the point. Switch readers after five facts and play to ten points. For a bonus round, use only facts about your own city.

Scripture. “And he led them forth by the right way, that they might go to a city of habitation.” (Psalm 107:7, KJV)

The psalm remembers wanderers whom the Lord brought to a place where they could settle and live. Every city began when people found a place to dwell; as you study your own city, give thanks for the land, water and roads God provided there.

Practice answers

1. Site is the physical ground a city stands on; situation is where it lies compared with other places. Site example: a high bluff above floods. Situation example: just below the mouth of the Missouri River.
2. Pierre Laclède chose the site in December 1763. His stepson Auguste Chouteau, about fourteen years old, led the workers in February 1764.
3. $630 \times 0.3048 = 192.0$, about 192 meters.
4. The Missouri joins closest, just north of the city; the Illinois joins farther upstream, at Grafton.
5. $38.81 - 38.63 = 0.18^\circ$. $0.18 \times 69 = 12.4$ miles; $0.18 \times 111 = 20$ km. By water it is about 15 miles because the river curves and the confluence also lies a little east.
6. $38.63 - 35.15 = 3.48^\circ$. $3.48 \times 69 = 240$ miles; $3.48 \times 111 = 386$ km.
7. Site: (a) and (b). Situation: (c) and (d).
8. St. Louis grew $350,000 - 311,000 = 39,000$, which is $39,000 \div 311,000 \approx 12.5\%$. Chicago grew $503,000 - 299,000 = 204,000$, which is $204,000 \div 299,000 \approx 68\%$.
9. (a) fall-line town; (b) confluence town; (c) railroad town; (d) ford town.
10. Sample: Yes, because situation usually decides growth. St. Louis had a fine, dry site and a superb river situation, and in 1870 it was slightly larger than Chicago. Chicago's site was low and marshy, but it sat where the Great Lakes came closest to the Mississippi system, and when railroads became the main way to move goods, more lines met in Chicago than anywhere else. By 1880 Chicago had about 500,000 people to St. Louis's 350,000. People fixed Chicago's poor site by raising streets and draining land, but no one could easily change St. Louis's situation.

8.2 ROADS, RAILS AND RIVERS

OBJECTIVES

- Tell how Atlanta grew from a surveyor's stake in the woods in 1837 into a hub of railroads, interstate highways and air routes, with no navigable river or harbor at all.
- Decode U.S. Interstate highway numbers and compare the time-distance of the same trip by wagon, train, car and airplane.
- Make a connections map of every river, rail line, highway, port and air route that links my city to the world, and judge which link matters most today.

Warm-up. Put a dot in the middle of a sheet of paper for your home. In two minutes, draw a line for every way something reaches your house: the road the mail truck uses, the water pipe, the power line, the internet cable, the road to the grocery store, the airport your relatives fly into. Circle the lines that did not exist a hundred years ago. Which line would your family miss most if it were cut for a week?

Watch. *How Are Highways Designed?* (Practical Engineering, 12:21).

<https://www.youtube.com/watch?v=9XIjqdk69O4>

With the big idea: how engineers design highways, curves and interchanges.

Note: Practical Engineering includes a short sponsor message; skip it.

Backup video. *Why Are Texas Interchanges So Tall?* (Practical Engineering, 13:17).

<https://www.youtube.com/watch?v=-16RFxr44fY>

As review: why the big Texas interchanges are stacked so high. Note: Practical Engineering includes a short sponsor message; skip it.

KEY TERMS

transportation hub

A place where many routes meet, so people and goods change from one line or vehicle to another.

network

A set of routes (links) joining places (nodes), such as a railroad system or the Interstate highways.

node

A point in a network where routes meet: a station, port, airport or highway interchange.

hinterland

The region around a city that sends it goods and buys from it.

break-in-bulk point

A place where cargo must be unloaded from one kind of transport and loaded onto another, such as a river landing, port or rail yard.

time-distance

How long a trip takes, rather than how many miles long it is. New technology shrinks time-distance even when the miles stay the same.

CORE IDEAS

The story. In 1836 the state of Georgia voted to build its own railroad, the Western & Atlantic, northwest through the hills to the Tennessee River at Chattanooga. Its chief engineer was Stephen H. Long, the army officer who had led an exploring expedition to the Rocky Mountains in 1820. In 1837 Long chose the spot where the line would end in the south: a ridge in thick forest, several miles east of the Chattahoochee River, where other railroads coming from the Atlantic coast could meet it. A marker was set to show the zero point of the line, and the little camp of workers there was called simply **Terminus**, the end of the line. Long is said to have thought the place would never hold more than a tavern, a blacksmith shop and a store. In 1843 it was renamed Marthasville, in 1845 it became Atlanta, and in 1847 it was made a city.

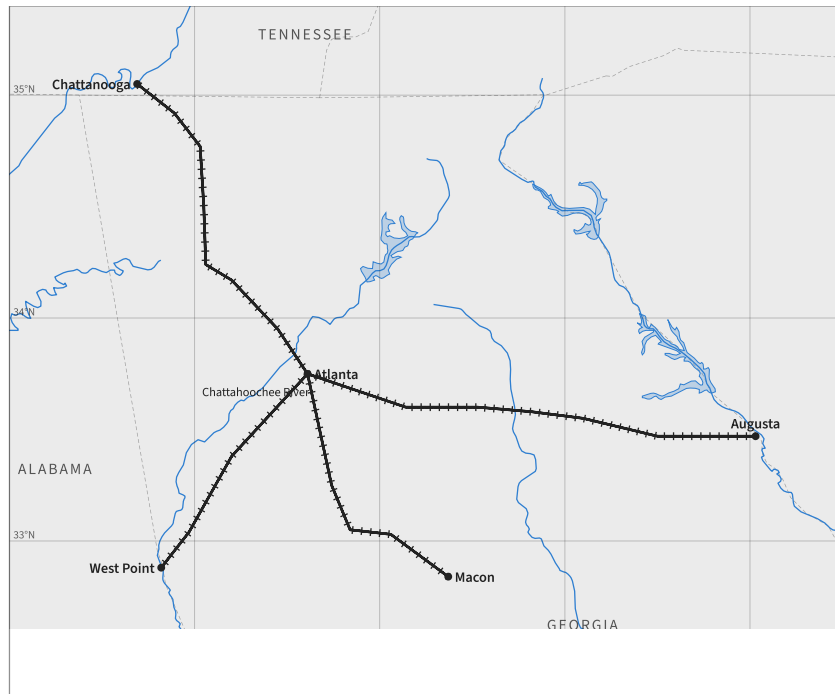
How it worked. Atlanta had no harbor and no river that boats could use. What it had was ground that suited rails. The town sits about 1,000 feet (300 m) above the sea on the Eastern Continental Divide: rain falling on one side runs to the Chattahoochee and the Gulf of Mexico, and on the other side toward the Atlantic. Railroad builders liked ridges, because a line along a ridge needs few bridges and few steep grades. The Georgia Railroad from Augusta arrived in 1845, the Macon & Western in 1846, and the Western & Atlantic was finished to Chattanooga in 1850. By the mid-1850s four railroads met at Atlanta, linking the Atlantic ports, the cotton country and the Tennessee valley. That made Atlanta a **node** in the Southern network, so important that in 1864 General William T. Sherman made it his target. His army took the city on September 2, 1864, and in November, before marching to the sea, burned its depot, rail yards and much of the town. Atlanta rebuilt so fast that it took the motto *Resurgens*, “rising again,” and in 1868 it became Georgia’s capital.

Technology overcoming geography. Each new kind of transport repeated Atlanta’s trick. In 1919 a U.S. Army truck convoy took 62 days to cross the country on muddy roads; one young officer on that trip was Dwight D. Eisenhower. As president he signed the Federal-Aid Highway Act of 1956, which planned about 41,000 miles of Interstate highways. Three of them, I-75, I-85 and I-20, meet in downtown Atlanta, and I-285, the Perimeter, circles the city for about 64 miles (103 km). In 1925 the city leased an old racetrack south of town for an airfield; it grew into Hartsfield-Jackson Atlanta International Airport, which in most years since the late 1990s has handled more passengers than any other airport in the world, over 100 million in a normal year. The same situation, in the middle of the Southeast, now served by rails, roads and wings.

The big idea. Cities live by their connections. A geographer pictures them as a **network** of links and nodes. The bigger a node, the more routes meet there and the larger its **hinterland**, the region that sends it goods and buys from it. Where cargo must change from one kind of transport to another, a **break-in-bulk point** grows warehouses, jobs and towns: the river landing, the port, the rail yard and today the truck terminal and the air-cargo hub. And technology shrinks **time-distance**. Atlanta to Chattanooga was more than a week by

wagon, about seven hours by an 1850s train, about two hours by car on I-75 and well under an hour by plane. The miles did not change; the time did. Yet geography still matters. Interstates often follow old rail lines, and old rail lines often follow old trails, because all of them seek the same gentle valleys, ridges and passes.

On the map. Study the map of Atlanta's first four railroads. Each points toward something: Chattanooga and the Tennessee River, Augusta and the Savannah River, Macon and the cotton lands, West Point and Alabama. Now look at your own city in five layers: *water* (river, lake, canal or seaport), *rail* (freight lines and any passenger trains), *road* (U.S. and Interstate highways), *air* (the nearest airport and where its flights go), and *wires* (power lines, pipelines and internet cables). Ask which layer came first, which carries the most today, and which one your city could least do without.



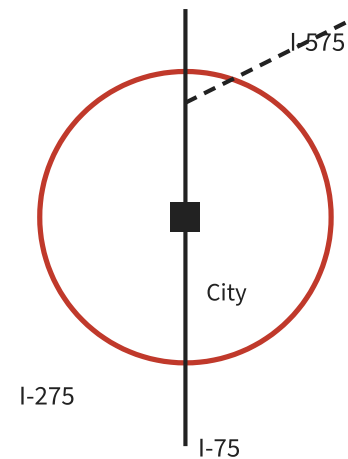
By the mid-1850s four railroads met at Atlanta. Routes are drawn approximately through the main towns they served.

Two-digit routes

	I-5	I-55	I-95
	I-90		
	I-40		
	I-10		

Odd: north-south, numbers grow west to east
Even: east-west, numbers grow south to north

Three-digit routes



Even first digit: loop
Odd first digit: spur

How to read an Interstate number.

PICTURE STUDY



Atlanta, Georgia. Ruins of Depot, Blown Up on Sherman's Departure, George N. Barnard, November 1864 · Photograph from a glass-plate negative · Library of Congress, Prints and Photographs Division, Washington, D.C.

George N. Barnard was the official photographer of the Union army's engineers in Sherman's campaign of 1864. He carried a heavy camera, glass plates and a darkroom wagon through Georgia. In November 1864, as Sherman's army prepared to leave Atlanta for the march to the sea, soldiers destroyed the railroad buildings so the Confederacy could not use them again. Barnard photographed what was left.

This is a picture of a city's connections. Atlanta mattered in the war for one reason: its railroads. When the army left, the rails, depots and machine shops were what it wrecked. After the war, rebuilding the railroads was the first step in rebuilding Atlanta.

Look closely

- Find the railroad tracks. Why would rails matter more to an army than almost any other building in the city?
- Look at the rubble. What was the depot made of, and why would a railroad want a building that strong?
- Look for buildings still standing beyond the ruins. What does that tell you about what the army chose to destroy?
- Notice how much detail the glass plate shows. Why would an engineer want a photograph like this?

Talk about it

1. Why was destroying the depot and rail yards a way of cutting Atlanta off from the world?
2. How long do you think it took to rebuild the railroads, compared with rebuilding houses?
3. What single connection, if it were cut, would hurt your own city the most?

Safety first. Do your traffic count with an adult from a safe public place well back from the road, such as a sidewalk, parking lot edge or park bench. Never stand on, cross or walk along railroad tracks; they are private property and trains cannot stop quickly. Watch trains only from a station platform or a public area behind the crossing gates.

PROJECT: STRINGS TO THE WORLD: MY CITY'S CONNECTIONS MAP

This is the second part of your city study. You will make a pin-and-string map that shows every major way your city is connected to the world, then count real traffic to see which link carries the most.

You will need

- A large printed map of your state or region (a state highway map from your state's department of transportation works well)
- A corkboard or a piece of foam board, and pushpins
- Yarn or string in five colors: blue (water), black (rail), red (highways), green (air routes), yellow (pipelines or power lines, if you find them)
- Index cards, a clipboard, a pencil and a watch or phone timer

Steps

1. Pin your map to the board and put a large pin at your city.

2. Water: find the nearest navigable river, lake port, canal or seaport. Run blue yarn from your city to it, and from there toward the sea.
3. Rail: find the freight railroads that serve your city (your state's rail map will show them) and any passenger trains. Run black yarn along each line to the next large city in each direction.
4. Roads: list every Interstate and U.S. highway that passes through or near your city. Decode each Interstate number (north-south or east-west, loop or spur) and run red yarn along it.
5. Air: from your nearest airport's website, list ten nonstop destinations. Run green yarn from the airport toward each one, off the edge of the map if needed, with a card naming the city.
6. Count: with an adult, spend ten minutes at a safe spot near a highway or busy road. Tally cars, pickups, delivery vans and big trucks. If you can safely watch a rail line from a public place, count train cars as well.
7. On a card, write which layer came first in your city's history, which carries the most people today, which carries the most goods, and which your city could least do without. Give a reason for each answer.

Tips

- A highway map's legend separates Interstates, U.S. routes and state routes. Use only the first two to keep the map clear.
- Look up your city's nearest port even if it is far away. Almost everything in your house came through a port at some point.
- Photograph the finished board for your poster in Lesson 8.4.

Check your work

- My map shows the water, rail, road and air links of my city in different colors.
- I decoded every Interstate number near my city.
- I counted real traffic and used the count to argue which link matters most.

MAP NOTEBOOK

1. Draw the Atlanta railroad star from memory: Atlanta in the middle and the four first lines pointing toward Chattanooga, Augusta, Macon and West Point.
2. Draw your city as a node: a circle in the middle with every highway, rail line, river and air route coming out of it as spokes. Label each spoke with where it leads.
3. Make a time-distance strip for a trip from your city to the nearest big city: how long by walking, by horse and wagon, by train, by car and by plane.

From history. The Western & Atlantic was the scene of the Great Locomotive Chase. On April 12, 1862, a party of Union volunteers led by James J. Andrews seized the locomotive *General* at Big Shanty (today Kennesaw), north of Atlanta, and raced toward Chattanooga, trying to cut telegraph wires and damage the line behind them. The train's

conductor, William A. Fuller, chased them on foot, by handcar and finally aboard the locomotive *Texas*, running it in reverse. The *General* ran low on fuel near Ringgold and the raiders scattered. Several of them were among the first soldiers ever awarded the Medal of Honor. The *General* is preserved today in a museum in Kennesaw, Georgia.

WORKED EXAMPLES

Example 1. Atlanta lies at about 33.75°N , 84.39°W , and Chattanooga at about 35.05°N , 85.31°W . Find the straight-line distance between them. The Western & Atlantic Railroad between them was about 138 miles long. How many times longer than the straight line was the railroad?

1. North-south difference: $35.05^{\circ} - 33.75^{\circ} = 1.30^{\circ}$. $1.30 \times 69 = 89.7$ miles.
2. East-west difference: $85.31^{\circ} - 84.39^{\circ} = 0.92^{\circ}$. At this latitude (about 34.4°) a degree of longitude is about $69 \times \cos 34.4^{\circ} \approx 69 \times 0.825 \approx 56.9$ miles, so $0.92 \times 56.9 \approx 52.4$ miles.
3. Straight-line distance: $\sqrt{(89.7^2 + 52.4^2)} = \sqrt{(8,046 + 2,746)} = \sqrt{10,792} \approx 104$ miles. In kilometers: $104 \times 1.609 \approx 167$ km.
4. Ratio: $138 \div 104 \approx 1.33$. The railroad was about one-third longer than the straight line, because it wound through valleys to avoid steep hills.

Answer: About 104 miles (167 km) in a straight line; the railroad was about 1.3 times as long.

Example 2. Decode these Interstates near Atlanta: I-20, I-75, I-285 and I-575.

(Use the map or drawing “Use the rules in the diagram to decode each number.” shown earlier in this lesson.)

1. Two-digit numbers: odd numbers run north-south; even numbers run east-west.
2. I-20 is even, so it runs east-west. Low even numbers are in the south, so it is a southern east-west route.
3. I-75 is odd, so it runs north-south. Numbers grow from west (I-5) to east (I-95), so I-75 is in the eastern half of the country.
4. Three-digit numbers are branches of the route named by the last two digits. I-285 belongs to I-85; its first digit, 2, is even, so it is a loop around the city.
5. I-575 belongs to I-75; its first digit, 5, is odd, so it is a spur leading off the main route.

Answer: I-20: east-west (southern). I-75: north-south (eastern). I-285: a loop around Atlanta tied to I-85. I-575: a spur branching off I-75.

Example 3. Compare the time-distance from Atlanta to Chattanooga: (a) by wagon on a road about 120 miles long at 15 miles a day; (b) by an 1850s train on the 138-mile railroad at an average of 20 mph; (c) by car on I-75, about 118 miles, at an average of 60 mph.

1. (a) Wagon: $120 \div 15 = 8$ days.
2. (b) Train: $138 \div 20 = 6.9$ hours, about 7 hours.
3. (c) Car: $118 \div 60 \approx 1.97$ hours, about 2 hours.
4. Compare: 8 days is 192 hours, so the train was about $192 \div 7 \approx 27$ times faster than the wagon, and the car is about 3 to 4 times faster than the train.

Answer: About 8 days by wagon, about 7 hours by train and about 2 hours by car.

PRACTICE

1. **EASY** Which way does an odd-numbered two-digit Interstate run? An even-numbered one?
2. **EASY** What was Atlanta's first name, and why was it given?
3. **EASY** Which is farther east, I-75 or I-95? Which is farther north, I-10 or I-90?
4. **EASY** I-495 circles Washington, D.C., and I-695 circles Baltimore. What does the first digit of each number tell you?
5. **MEDIUM** I-285 is about 64 miles around. How many kilometers is that? How long would one full lap take at an average of 50 mph?
6. **MEDIUM** Four railroads met at Atlanta, from Chattanooga, Augusta, Macon and West Point. How many different pairs of these four cities could be connected by changing trains at Atlanta? How many pairs if a fifth line were added?
7. **MEDIUM** Why did General Sherman make Atlanta his target in 1864, and why did his army destroy the depot and rail yards when it left?
8. **HARD** A truck leaves Atlanta for Chicago, about 715 miles (1,150 km) by Interstate, and averages 55 mph. How long is the driving time? A truck driver may drive no more than 11 hours before a required rest. Can the trip be done without a rest stop?
9. **HARD** Atlanta's airport lies at about 33.64°N , 84.43°W and Chicago O'Hare at about 41.98°N , 87.90°W . Estimate the straight-line distance (use 69 miles per degree of latitude and about 54.5 miles per degree of longitude at this middle latitude). How long would the flight take at 450 mph?
10. **CHALLENGE** Write a paragraph (4–6 sentences): Atlanta has no navigable river and no harbor, yet it became one of the great cities of the South. Explain how, using the words site, situation, node and technology.

COMMON MISTAKES

- Thinking a city needs water to be connected. Railroads, highways and airports can make a hub where no boat can go, though nearly every city still depends on a seaport

somewhere for its goods.

- Measuring connection only in miles. A town 50 miles from an Interstate exit can be “farther” in time than a city 300 miles away by nonstop flight. Think in time-distance too.
- Reading three-digit Interstate numbers backward. The *last two* digits name the parent route; the *first* digit tells you loop (even) or spur (odd).

Make it a game • Hub Hop. Write ten city names on cards and lay them in a circle on the floor, with your own city in the middle. Run string or yarn from the middle to five of them as “routes.” A player draws two cards and must travel from one city to the other along the strings, saying the mode at each step (“river barge to the port, train to the hub, plane to the coast”). A trip that passes through the middle hub scores a point; a trip with no route scores nothing. Add one new route after each round and notice how fast the middle hub’s score grows.

Scripture. “Every valley shall be exalted, and every mountain and hill shall be made low: and the crooked shall be made straight, and the rough places plain:” (Isaiah 40:4, KJV)

Isaiah describes a highway made ready for the coming of the Lord, a picture fulfilled in John the Baptist (Luke 3:4–6). Road and railroad builders know the picture well: they fill valleys, cut through hills and straighten crooked paths. The prophet reminds us that the greatest road ever prepared was the one by which God came to His people.

Practice answers

1. Odd-numbered Interstates run north-south; even-numbered Interstates run east-west.
2. Terminus, because the spot was the end (terminus) of the Western & Atlantic Railroad, chosen by Stephen H. Long in 1837.
3. I-95 is farther east (north-south numbers grow toward the east). I-90 is farther north (east-west numbers grow toward the north).
4. Both first digits (4 and 6) are even, which marks a loop or beltway around a city.
5. $64 \times 1.609 \approx 103$ km. $64 \div 50 = 1.28$ hours, about 1 hour 17 minutes.
6. Six pairs: Chattanooga–Augusta, Chattanooga–Macon, Chattanooga–West Point, Augusta–Macon, Augusta–West Point, Macon–West Point. With a fifth line, 10 pairs. Each new line adds a connection to every line already there, which is why hubs grow stronger as they grow.
7. Atlanta was the meeting point of four railroads that carried supplies and soldiers for the Confederacy. Destroying the depot, yards and shops cut those connections so the city could not serve the Confederate army again.
8. $715 \div 55 = 13$ hours of driving. That is more than 11, so the driver must stop for the required rest and finish the trip after it.
9. North-south: $8.34^\circ \times 69 \approx 575$ miles. East-west: $3.47^\circ \times 54.5 \approx 189$ miles. Distance $\approx \sqrt{(575^2 + 189^2)} \approx \sqrt{(330,600 + 35,700)} \approx 605$ miles, about 970 km. Time: $605 \div 450 \approx 1.35$ hours, about 1 hour 20 minutes.
10. Sample: Atlanta’s site was a ridge on the Eastern Continental Divide, with gentle ground that suited railroads but no river for boats. Its situation was what mattered: it lay where lines from the Atlantic ports, the cotton country and the Tennessee valley could meet, so it became a

node in the Southern rail network. Railroads overcame the lack of a river by doing the river's job of carrying goods. When new technology came, the same central situation drew three Interstates and the world's busiest passenger airport. Atlanta shows that technology can turn an ordinary site into a great city if the situation is right.

8.3 OLD MAPS AND NEW

OBJECTIVES

- Tell how James Oglethorpe laid out Savannah in 1733 and explain why so much of his plan still shows on today's map.
- Use map scales (1:24,000, 1:62,500 and the Sanborn scale of 1 inch to 50 feet) to measure distances and areas and to match an old map to a new one.
- Find an old map of my own city (a panoramic view, a Sanborn map or a historic topographic map) and make a tracing-paper overlay that shows what has stayed and what has changed.

Warm-up. Find two photographs of the same place or the same person taken many years apart: a grandparent's house, your church, your own baby picture and a recent one. Lay them side by side. In three minutes, list three things that changed and three things that stayed the same. Which kind of thing tends to stay: the shape of the land, the street, the building, or the paint color?

Watch. *Savannah's mysterious historic plan* (City Beautiful, 6:49).

<https://www.youtube.com/watch?v=MbyuNHCDdNM>

With the story: Oglethorpe's plan for Savannah and its squares.

Note: City Beautiful is a channel about city planning. This video sticks to the history of the Savannah plan.

Backup video. *Sanborn Fire Insurance Maps Collection - Collection Connection Ep.5* (Tulane University Libraries, 2:09). <https://www.youtube.com/watch?v=f7lI9KT5BCs>

With How it works: what Sanborn fire insurance maps show and how to read them.

KEY TERMS

Sanborn map

A large-scale map made for fire insurance companies that shows each building's outline, size, building material and use. The Sanborn company mapped American towns from 1867 well into the twentieth century.

representative fraction

A map scale written as a ratio, such as 1:24,000, meaning one unit on the map stands for 24,000 of the same unit on the ground.

overlay

A transparent copy of one map laid on top of another so the two can be compared.

tie point

A feature that appears on both an old and a new map, such as a street corner, church or river bend, used to line the two maps up.

ward

In Oglethorpe's Savannah, a neighborhood unit built around a public square, with house lots to the north and south and trust lots to the east and west.

georeferencing

Matching points on an old map to their true locations so that a computer can stretch the old map to lie exactly over a modern one.

CORE IDEAS

The story. On February 12, 1733, James Oglethorpe and the first colonists of Georgia, who had crossed from England on the ship *Anne*, climbed a sandy bluff above the Savannah River. Oglethorpe had already met Tomochichi, the mico, or chief, of the Yamacraw, whose village stood nearby. With Mary Musgrove, a trader of Creek and English parents, translating, the two men agreed that the English could settle on the bluff, and they became lasting friends. Oglethorpe chose the bluff for its site: high and dry, with a good landing below and the river leading out to the Atlantic, yet far enough upstream to be safe from surprise attack from the sea. Then, with the help of Colonel William Bull of South Carolina, he laid out the town on the ground with stakes and chains. A year later one of the colonists, Peter Gordon, drew the young town from the river, and his view was engraved and printed in London.

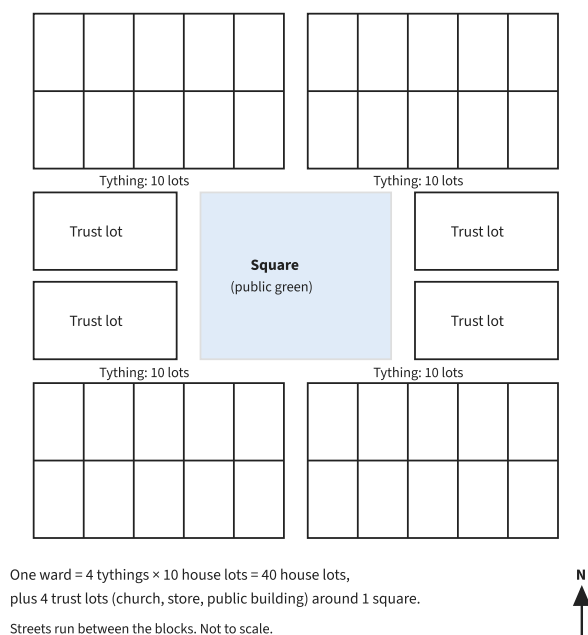
How it worked. Oglethorpe's plan was built of repeating units called **wards**. Each ward had an open public square in the middle. To the north and south lay four blocks called tythings, each with ten house lots, so a ward held forty families. To the east and west of the square lay four larger **trust lots** kept for churches, stores and public buildings. Each family also received a garden lot just outside town and a farm lot farther out. When the town needed to grow, the colonists did not stretch the old streets; they simply laid out another ward, square and all. Savannah began with four wards in 1733 and had 24 squares by the 1850s. Twenty-two of them remain today, shaded by live oaks, and cars still slow down to bend around them. Put Gordon's 1734 view beside a modern street map of downtown Savannah and you can count the same squares.

The big idea. When you compare an old map with a new one, some things change quickly and some hardly change at all. Buildings come and go within a century. Rail yards, factories, docks and highways appear and disappear. Shorelines are filled in and marshes drained. But the lay of the land, the course of the larger rivers, the pattern of the oldest streets and the lines between property lots often last for centuries, because every owner and every new building fits into them. That is why a modern map is a kind of layered record, like the GIS layers of Unit 7, with the oldest decisions lying underneath. To read your city's history, look for the old layers that still show through.

How they figured it out. Three kinds of old maps can help you with your own city. *Bird's-eye views* (1850s–1920s), like Pictorial St. Louis in Lesson 8.1, show buildings in perspective but are not drawn to a true scale. *Topographic maps* from the U.S. Geological Survey, made since the 1880s, show hills, rivers, roads and buildings to scale; older ones were often printed at 1:62,500, about one inch to the mile, and newer ones at 1:24,000, one inch to 2,000 feet. *Sanborn maps* were begun by a surveyor named Daniel Alfred Sanborn in 1867 for fire insurance companies, which needed to know how likely each building was to burn.

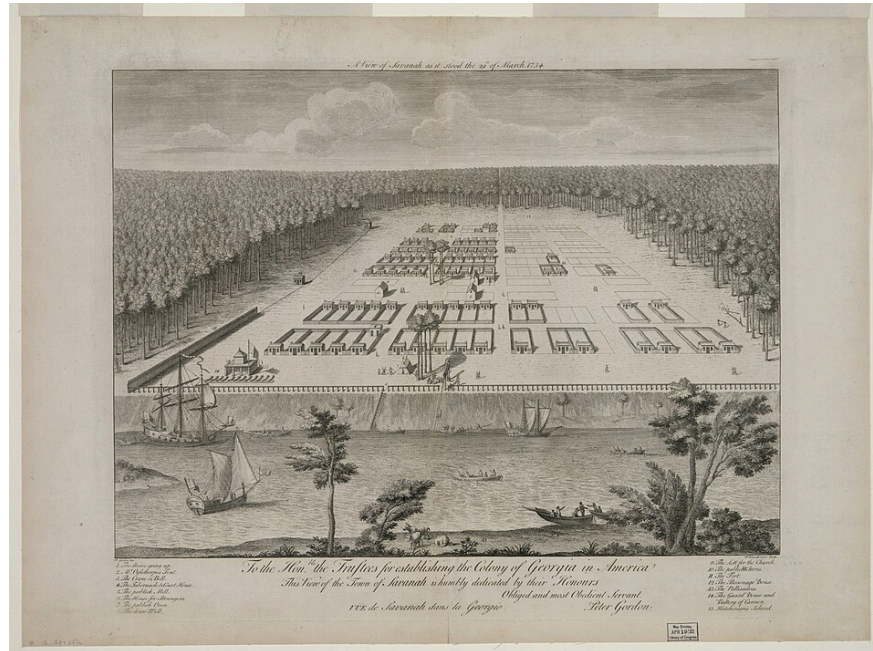
Most were drawn at 1 inch to 50 feet and colored by material: pink or red for brick, yellow for wood frame and blue for stone. When a town changed, the company sent paste-on slips to cover the old drawing. The Library of Congress holds about 700,000 Sanborn sheets covering roughly 12,000 American cities and towns, and many are free to view online.

On the map. To compare two maps fairly, first bring them to the same scale. If an old map is at 1:62,500 and a new one at 1:24,000, enlarge the old one by $62,500 \div 24,000 \approx 2.6$ times, or 260 percent, on a copier. Then pick at least three **tie points** that appear on both, such as the courthouse, a bridge and an old street corner. Lay tracing paper over the old map, trace it, and slide the tracing over the new map until the tie points match. Where the maps disagree, you have found a change. Computers do the same job by **georeferencing**, which is how websites can fade an 1890 map over a satellite photo.



One ward of Oglethorpe's Savannah: 4 tythings of 10 house lots, 4 trust lots and a public square.

PICTURE STUDY



A View of Savannah as It Stood the 29th of March, 1734, Peter Gordon (drawing), engraved by Pierre Fourdrinier, 1734 (engraving published in London, about 1734–1735) · Engraving · Library of Congress, Geography and Map Division, Washington, D.C. (one of several surviving prints)

Peter Gordon was one of the colonists who came to Georgia with Oglethorpe in 1733. A year after the landing he drew the new town as it looked from across the river, and the drawing was engraved in London by Pierre Fourdrinier and printed for the people in England who supported the colony. The engraving has a lettered key naming the town's buildings and features.

It is one of the best early pictures of any American town plan. The forest still crowds right up to the edge of the clearing, but the streets, wards and squares Oglethorpe staked out are already there, and you can still walk them today.

Look closely

- Find the bluff above the river. How would people and goods get from the boats up into the town?
- Find the open squares among the blocks of houses. How many can you count?
- Look at the forest around the edges. How much of the land had been cleared in the first year?
- Look at the key. What kinds of buildings did the colonists think were important enough to name?

Talk about it

1. What in this 1734 view would you still recognize on a map of Savannah today?

2. Why do you think Oglethorpe left open squares in the middle of every ward instead of filling the land with houses?
3. If someone drew your neighborhood in its first year, what would the picture show?

PROJECT: THEN AND NOW: A TRACING-PAPER OVERLAY OF MY CITY

This is the third part of your city study. You will find an old map of your city's oldest part, bring it to the same scale as a modern map, and make an overlay that shows in color what has stayed, what has vanished and what is new.

You will need

- An old map of your city: a Sanborn sheet or bird's-eye view (Library of Congress), or a historic topographic map (USGS TopoView)
- A modern map of the same area at a known scale (a current USGS topographic map, a city map or a printed online map with a scale bar)
- Tracing paper or baking parchment, masking tape, a ruler and fine-tipped pens in green, red and blue
- A copier or printer that can enlarge and reduce

Steps

1. Choose a small area around your city's founding spot, about ten to twenty blocks.
2. Find the scale of each map (a representative fraction or a scale bar). Work out how much to enlarge or reduce the old map so both have the same scale, and make that copy.
3. Choose at least three tie points that appear on both maps, such as a church, the courthouse, a bridge or a street corner. Circle them on both.
4. Tape tracing paper over the old map. Trace the streets, the shoreline or riverbank, the railroad and the major buildings, and mark the tie points.
5. Lay the tracing over the modern map and slide it until the tie points match. Tape it down.
6. Color the tracing: **green** for features found on both maps, **red** for features on the old map that are gone today, and on the modern map below, circle in **blue** the important new features.
7. Measure one street or block on both maps using their scales. Do the lengths agree? If not, suggest a reason.
8. Write a paragraph: What has lasted longest in my city's oldest part, and what changed the most? What date is the old map, and how do I know?

Tips

- Bird's-eye views are not drawn to a true scale, so use them for clues about buildings and uses, not for measuring.
- Rivers can move and shores can be filled. Use street corners and stone buildings as tie points before river bends.

- Save a photo of your overlay for the poster in Lesson 8.4.

Check your work

- I matched the scales of my two maps and showed my work.
- My overlay lines up on at least three tie points.
- I can name three things that lasted and three things that changed, and explain why.

MAP NOTEBOOK

1. Draw one Savannah ward from memory: the square, the four tythings with ten lots each and the four trust lots. Add a north arrow.
2. Copy the Sanborn color key into your notebook: pink or red for brick, yellow for wood frame, blue for stone. Then draw a pretend block of five buildings using it.
3. Make a then-and-now table for your city with three rows (land and water, streets, buildings) and two columns (old map, today).

From history. In 1734 Oglethorpe took Tomochichi, his wife, his nephew and several Yamacraw men to England. They met King George II and the Archbishop of Canterbury, and Tomochichi asked that his people's children be taught. When the old chief died in 1739, Oglethorpe honored his friend with a public funeral in Savannah and helped carry his body to the grave in one of the town's squares, today called Wright Square. A large granite boulder now marks the spot.

WORKED EXAMPLES

Example 1. On a 1:24,000 topographic map, a street measures 3.5 inches. How long is it on the ground, in feet, miles and kilometers?

1. On the ground the street is 24,000 times as long: $3.5 \times 24,000 = 84,000$ inches.
2. Feet: $84,000 \div 12 = 7,000$ feet.
3. Miles: $7,000 \div 5,280 \approx 1.33$ miles.
4. Kilometers: 3.5 inches = $3.5 \times 2.54 = 8.89$ cm on the map; $8.89 \times 24,000 = 213,360$ cm = 2.13 km.

Answer: 7,000 feet, about 1.33 miles (2.13 km).

Example 2. A Sanborn map at a scale of 1 inch = 50 feet shows a pink building 1.6 inches long and 0.5 inch wide. What are its ground dimensions and its floor area (one story) in square feet and square meters? What was it built of?

1. Length: $1.6 \times 50 = 80$ feet. Width: $0.5 \times 50 = 25$ feet.
2. Area: $80 \times 25 = 2,000$ square feet.
3. Metric: $80 \text{ ft} \times 0.3048 = 24.4 \text{ m}$; $25 \text{ ft} \times 0.3048 = 7.6 \text{ m}$; $24.4 \times 7.6 \approx 186$ square meters.
4. Pink on a Sanborn map means brick.

Answer: 80 by 25 feet (24.4 by 7.6 m), 2,000 square feet (about 186 m²), built of brick.

Example 3. An old 15-minute topographic map is at 1:62,500; a new one is at 1:24,000. A road is 2 inches long on the old map. How long is it on the ground, how long should it be on the new map, and by what percent must you enlarge the old map to match the new one?

1. Ground length: $2 \times 62,500 = 125,000$ inches = 10,417 feet ≈ 1.97 miles (3.18 km).
2. On the new map: $125,000 \div 24,000 \approx 5.21$ inches.
3. Enlargement: $62,500 \div 24,000 \approx 2.60$, so enlarge the old map to about 260 percent.
4. Check: $2 \text{ inches} \times 2.60 = 5.2 \text{ inches}$, which matches.

Answer: About 1.97 miles (3.18 km) on the ground; about 5.2 inches on the new map; enlarge the old map about 260 percent.

PRACTICE

1. **EASY** Name the parts of one ward in Oglethorpe's Savannah. How many house lots did one ward hold?
(Use the map or drawing "Use the plan to count the lots." shown earlier in this lesson.)
2. **EASY** When did Oglethorpe's colonists land at Savannah, and which Yamacraw leader agreed to their settling there?
3. **EASY** On a Sanborn map, what do pink (or red), yellow and blue buildings mean? Why did insurance companies care?
4. **MEDIUM** On a 1:24,000 map, how many feet does 1 inch stand for? How many meters does 1 cm stand for?
5. **MEDIUM** On a 1:62,500 map, how many feet does 1 inch stand for, and why do people call it "an inch to the mile"? How many meters does 1 cm stand for?
6. **MEDIUM** Savannah had 24 squares by the 1850s, and 22 remain. What percent survive?
7. **MEDIUM** On a Sanborn map at 1 inch = 50 feet, a lot measures 0.8 inch by 2.4 inches. Find its size in feet and its area in square feet, acres (1 acre = 43,560 sq ft) and square meters.

8. **HARD** Write the Sanborn scale of 1 inch = 50 feet as a representative fraction. To lay a Sanborn sheet over a modern map printed at 1:12,000, to what percent must you reduce the Sanborn copy?
9. **HARD** On an 1890 map at 1 inch = 200 feet, the riverbank lies 0.75 inch beyond Front Street. On today's map at the same scale, the bank lies 2.0 inches beyond Front Street. How far has the shore been built out by filling, in feet and meters?
10. **CHALLENGE** Explain in a short paragraph why the street plan of a city usually lasts much longer than its buildings. Use Savannah and one example from your own city.

COMMON MISTAKES

- Measuring distances on a bird's-eye view. Those views are drawn in perspective, so the scale changes across the picture; use them for clues, and use Sanborn or topographic maps for measuring.
- Comparing two maps at different scales and calling the difference a "change." First bring the maps to the same scale, then compare.
- Using a river bend as the only tie point. Rivers wander and shores are filled; street corners and stone buildings are steadier.

Make it a game · Spot the Change. Print an old map and a modern map of the same few blocks at the same scale. Set a timer for three minutes. Each player hunts for differences and writes them down: a vanished railroad, a new highway, a filled shoreline, a renamed street, a building gone. Score 1 point for each change found, and 2 points for each change you can explain (why it happened). Then hunt for things that did *not* change, 1 point each. Highest total wins.

Scripture. "Remove not the ancient landmark, which thy fathers have set." (Proverbs 22:28, KJV)

In Bible times a landmark was a boundary stone marking a family's land, and moving it was a kind of theft. Old maps help us see the boundaries and choices of the people who came before us, and to treat what they built and owned with honesty and respect.

Practice answers

1. A public square in the middle, four tythings (two north and two south) of ten house lots each, and four trust lots (two east and two west). One ward held $4 \times 10 = 40$ house lots.
2. February 12, 1733. Tomochichi, the mico of the Yamacraw, with Mary Musgrove as interpreter.
3. Pink or red is brick, yellow is wood frame, blue is stone. Wood buildings burn more easily than brick or stone, so insurers charged different rates depending on the material.
4. 1 inch = 24,000 inches = 2,000 feet. 1 cm = 24,000 cm = 240 meters.
5. $62,500 \div 12 \approx 5,208$ feet, which is 0.99 mile, nearly a full mile (5,280 feet). 1 cm = 62,500 cm = 625 meters.
6. $22 \div 24 \approx 0.917$, about 92 percent.
7. 40 by 120 feet; 4,800 square feet; $4,800 \div 43,560 \approx 0.11$ acre; $12.2 \text{ m} \times 36.6 \text{ m} \approx 446 \text{ m}^2$.

8. 50 feet = 600 inches, so the scale is 1:600. Reduce to $600 \div 12,000 = 0.05$, or 5 percent.
9. $2.0 - 0.75 = 1.25$ inches; $1.25 \times 200 = 250$ feet, about 76 meters.
10. Sample: Streets and property lines are shared decisions: every lot, deed, pipe and building is fitted to them, so changing them means changing everything at once. A building can be torn down and replaced by one owner, but a street belongs to the whole town. In Savannah, buildings from 1734 are long gone, yet Oglethorpe's wards and 22 of the 24 squares remain because every later building was built to fit them. In my city, the main street still follows the old road to the landing, though none of its first buildings survive.

8.4 PRESENTING MY CITY

OBJECTIVES

- Tell how Daniel Burnham's Plan of Chicago (1909) was explained to a whole city through maps, paintings, talks and a schoolbook written for eighth graders.
- Make a finished capstone map with all seven essential parts (title, orientation, date, author, legend, scale and sources) and a correct scale bar in miles and kilometers.
- Design a poster and give a five-minute talk to my family that explains my city's site, situation, connections and change over time.

Warm-up. Hold up a map of your town or neighborhood in front of a family member for sixty seconds without saying a word. Ask what they learned. Then take sixty more seconds, point to the map and tell them three things about it. Ask again. Which minute taught more? A map tells where; a speaker tells why.

Watch. *Principles of Cartographic Symbolization* #maps #GIS #visualization #cartography #data science (GIScience, 11:39). <https://www.youtube.com/watch?v=bsjvd3BmlBs>

Before the project: how mapmakers choose symbols, colors and sizes, so your city map reads clearly.

Note: A university lecture; watch the first part for the main ideas.

KEY TERMS

capstone

A final project that brings together everything learned in a course, as the top stone finishes a wall.

thematic map

A map that shows one topic, such as routes, growth over time or flood zones, on top of a simple base map.

legend

The box, also called a key, that explains a map's symbols, lines and colors.

scale bar

A line drawn on a map and divided into ground distances, so a reader can measure with a ruler or a strip of paper.

TODALSS

A checklist of the parts every finished map needs: Title, Orientation, Date, Author, Legend, Scale and Sources.

audience

The people who will read your poster or hear your talk. A good presenter chooses words and pictures for them.

CORE IDEAS

The story. On July 4, 1909, the Commercial Club of Chicago published a large and beautiful book called *Plan of Chicago*, by the architects Daniel H. Burnham and Edward H. Bennett. Burnham was already famous. He had been chief of construction for the World's Columbian Exposition of 1893, had served on the commission that replanned Washington, D.C., in 1901–1902, and in 1905 had drawn plans for Manila in the Philippines. For Chicago he and Bennett studied the city's whole geography: the long, flat shore of Lake Michigan, the Chicago River cutting through downtown, the level prairie stretching west, and the dozens of railroad lines that crowded into the center. Their plan proposed lakefront parks open to everyone, wide boulevards, a double-level street along the river, new bridges, grouped railroad stations and a great civic center. To show it, the painter Jules Guérin made large color paintings of the city as it might look, seen as if from the sky at dusk.

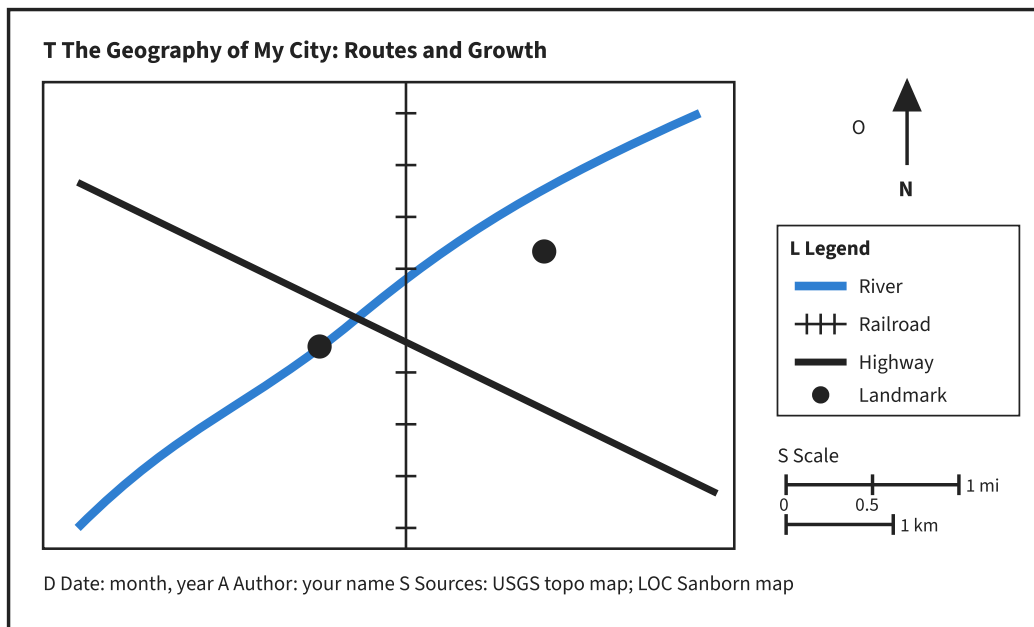
How it worked. A plan nobody understands is never built, so Chicago's leaders set out to explain this one to every citizen. The city created the Chicago Plan Commission in 1909, with the businessman Charles H. Wacker as its chairman. Its managing director, Walter D. Moody, wrote a shorter book, *Wacker's Manual of the Plan of Chicago* (1911), and from 1912 Chicago's eighth graders studied it in school, learning the geography of their own city and how the plan would improve it. The commission also gave illustrated lectures and handed out pamphlets across the city. Not every idea was built; the great domed civic center never rose. But much was: the Michigan Avenue Bridge (1920), the double-decked Wacker Drive along the river (1926), the Municipal Pier (now Navy Pier, 1916) and miles of lakefront parks. Students your age helped a city understand itself.

The big idea. Presenting geography takes three tools working together. The **map** shows where. The **poster** shows what and why at a glance, with pictures, a timeline and a few clear facts. The **talk** tells the story and answers questions. Your capstone brings together every question you asked in this unit. *Why here?* (site and situation, Lesson 8.1). *How is it connected?* (roads, rails, rivers and air, Lesson 8.2). *What has changed?* (old maps and new, Lesson 8.3). And a fourth question for the end: *What should my city become?* Burnham's plan asked exactly that.

On the map. Your capstone map is a **thematic map** of your city. Start with a light base: the rivers, lake or shore, and the main hills. Add the layers of your study: the founding spot, the routes of water, rail, road and air, the edge of the old town from your historic map compared with the city limits today, and a few landmarks. Use one color for each layer, and the same colors on your poster. Then check the map against **TODALSS**: a *title* that says what the map shows, an *orientation* arrow pointing north, the *date* you made it, you as the *author*, a *legend* for every symbol, a *scale* bar in miles and kilometers, and your *sources* (for example, "USGS topographic map, 1952; Library of Congress Sanborn map, 1895"). Leave white space. A crowded map hides its message.

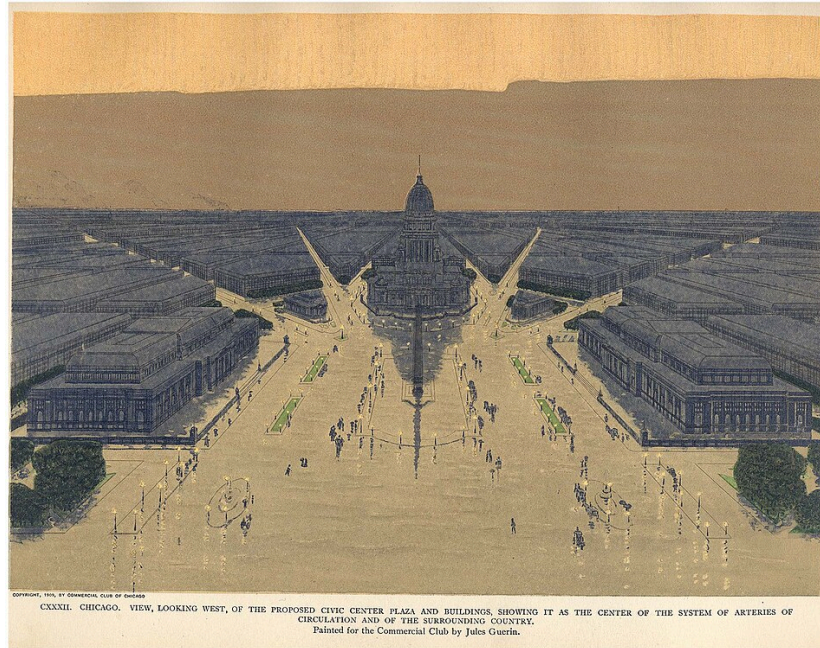
Your talk. Plan five minutes. Open with a real moment, as every lesson in this course has: the day your city's founder arrived, the first train, the great flood. Then give your city's site, its situation and connections, and what changed between the old map and the new. Point to

the map as you speak. Close with what you hope for your city, and perhaps a prayer for it. Practice twice with a timer, speak slowly to the back of the room, and invite questions. When the people of Judah were carried away to Babylon, the Lord told them to seek the good of the city where they lived (Jeremiah 29:7). Knowing your city well is a good place to begin.



The seven parts of a finished map (TODALSS): Title, Orientation, Date, Author, Legend, Scale and Sources.

PICTURE STUDY



Chicago. View, Looking West, of the Proposed Civic Center Plaza and Buildings, Jules Guérin, for the *Plan of Chicago* by Daniel H. Burnham and Edward H. Bennett, about 1908 (published 1909) · Watercolor and graphite on paper · Original drawing in the Art Institute of Chicago (Plan of Chicago drawings, on permanent loan from the City of Chicago); this image is reproduced from the printed Plan of Chicago, 1909

Jules Guérin was an American painter famous for his soft, glowing colors. For the *Plan of Chicago* he painted the city not as it was but as Burnham and Bennett hoped it might become. In this view a great domed civic center stands where the main avenues meet, and broad streets spread out toward the flat prairie, which seems to go on forever.

The painting is a kind of map. It shows the real geography of Chicago, flat and open, on a lake, crossed by a river and roads, but it is drawn to persuade. Guérin wanted Chicagoans to see the plan and want it. Your poster has the same job: to help your audience see your city clearly and care about it.

Look closely

- Find the domed building. Why did the planners put it where the avenues meet?
- Follow the avenues out toward the horizon. What do they tell you about how the planners saw Chicago's situation?
- Look at the colors and the light. How do they make you feel about the future city?
- Look for the flat land. How does the painting show that Chicago stands on a prairie?

Talk about it

1. How is this painting like a map, and how is it different from one?
2. This civic center was never built. Why might a beautiful plan still be left unbuilt?

3. If you painted your own city as you hope it will look in fifty years, what would you change, and what would you keep?

PROJECT: THE CITY STUDY: POSTER, CAPSTONE MAP AND TALK

This is the final part of your city study. You will gather the work of Lessons 8.1–8.3 into a poster, draw a finished capstone map, and present your city in a five-minute talk to your family, grandparents or co-op class.

You will need

- Poster board, about 22 by 28 inches (56 by 71 cm) or a trifold board
- Heavy drawing paper or a large sheet for the capstone map, colored pencils, fine pens and a ruler
- Your relief model (8.1), photo of your connections map (8.2), overlay (8.3) and your index cards
- Printed pictures: an old view or map of your city, a modern photo and one picture of each kind of connection
- Glue stick, index cards for talk notes and a timer

Steps

1. Draw the capstone map. Choose the area (the whole city, or the old town and its surroundings) and work out a scale that fits your paper (see the worked examples). Draw the base layer lightly in pencil: rivers, shore, main hills.
2. Add your layers in color: the founding spot (a star), the oldest streets, the routes of water, rail, road and air, the edge of the old town and today's city limits, and five landmarks.
3. Finish the map with all of TODALSS: title, north arrow, date, your name, a legend, a scale bar in miles and kilometers, and a list of sources. Ink the lines and erase the pencil.
4. Plan the poster with four panels: **Why here?** (site and situation), **How connected?** (routes), **Then and now** (old map and new) and **A timeline** of six to eight dates in your city's history. Put the capstone map in the center or beside the poster.
5. Write the talk on five index cards: a hook from a real moment, site, situation and connections, then and now, and a closing. Time it for about five minutes.
6. Practice twice with a timer, once in front of a mirror and once for a sibling or parent.
7. Give the talk. Point to the map as you speak, show your relief model, and invite three questions. Afterward, write down the hardest question and how you would answer it next time.

Tips

- Use the same color for each layer on the map, the poster and the connections board, so your audience learns your code once.

- A poster should be read from across the room: big titles, short labels, one main picture per panel.
- If you are nervous, keep your eyes on the map and talk to it. Pointing gives your hands something to do.

Check your work

- My capstone map has all seven TODALSS parts and a correct scale bar in miles and kilometers.
- My poster answers why here, how connected and what changed, with a timeline.
- I gave a talk of about five minutes and answered questions.

MAP NOTEBOOK

1. Write TODALSS down the margin of a page and, beside each letter, write what that part will say on your capstone map.
2. Sketch a thumbnail plan of your poster (a small drawing about 3 by 4 inches) showing where each panel, picture and title will go.
3. Write the first two sentences of your talk: the real moment that opens your city's story.

From history. Jules Guérin, who painted the views for the *Plan of Chicago*, went on to paint the two great murals high on the walls inside the Lincoln Memorial in Washington, D.C., which was dedicated in 1922. The memorial itself stands at the west end of the National Mall, on ground laid out by the 1901–1902 commission on which Daniel Burnham served. One planner and one painter helped shape how two American cities still look.

WORKED EXAMPLES

Example 1. Your city is about 9 miles (14.5 km) across, and the map space on your paper is 18 inches wide. What scale should you use? Write it as a word scale and as a representative fraction.

1. Divide ground distance by map distance: $9 \text{ miles} \div 18 \text{ inches} = 0.5 \text{ mile per inch}$.
Word scale: 1 inch = 0.5 mile.
2. Change the ground distance to inches: $1 \text{ mile} = 5,280 \times 12 = 63,360 \text{ inches}$, so $0.5 \text{ mile} = 31,680 \text{ inches}$.
3. Representative fraction: 1 inch on the map = 31,680 inches on the ground, so 1:31,680.
4. Check in metric: $18 \text{ inches} = 45.7 \text{ cm}$; $14.5 \text{ km} \div 45.7 \text{ cm} \approx 0.317 \text{ km per cm}$, or $1 \text{ cm} = 31,700 \text{ cm}$, which matches.

Answer: 1 inch = 0.5 mile, or 1:31,680.

Example 2. Draw the scale bar for a map at 1 inch = 0.5 mile (1:31,680). How long should the bar be for 1 mile, and for 1 kilometer (1 km = 0.621 mile)?

(Use the map or drawing “The sample scale bar uses the same proportions: 1 km is about 0.62 of the 1-mile” shown earlier in this lesson.)

1. 1 mile $\div$ 0.5 mile per inch = 2 inches (5.08 cm).
2. 1 km = 0.621 mile; $0.621 \div 0.5 = 1.24$ inches.
3. In centimeters: 1 km = 100,000 cm; $100,000 \div 31,680 \approx 3.16$ cm. Check: $1.24 \times 2.54 \approx 3.16$ cm.
4. Draw a 2-inch bar marked 0, 0.5 and 1 mile, and under it a 3.16 cm bar marked 0 and 1 km.

Answer: The 1-mile bar is 2 inches (5.08 cm) long; the 1-kilometer bar is about 1.24 inches (3.16 cm) long.

Example 3. You want to speak for 5 minutes. Most people speak clearly at about 130 words a minute. How many words should your talk be? Divide it into a hook ($\frac{1}{2}$ minute), site (1 minute), situation and connections ($1\frac{1}{2}$ minutes), then and now ($1\frac{1}{2}$ minutes) and closing ($\frac{1}{2}$ minute).

1. Total words: $5 \times 130 = 650$ words.
2. Hook: $0.5 \times 130 = 65$ words. Site: $1 \times 130 = 130$ words.
3. Situation and connections: $1.5 \times 130 = 195$ words. Then and now: $1.5 \times 130 = 195$ words.
4. Closing: $0.5 \times 130 = 65$ words.
5. Check: $65 + 130 + 195 + 195 + 65 = 650$ words.

Answer: About 650 words: 65, 130, 195, 195 and 65 words for the five parts.

PRACTICE

1. **EASY** What does each letter of TODALSS stand for?
2. **EASY** Who wrote the *Plan of Chicago*, and when was it published? Who studied *Wacker’s Manual* in school?
3. **EASY** A reader cannot tell which way is north on your map, and another cannot tell what the dotted red line means. Which two parts are missing?
4. **MEDIUM** On a map at 1 inch = 0.25 mile, two landmarks are 6 inches apart. How far apart are they in miles and kilometers?
5. **MEDIUM** Write the scale 1 inch = 1 mile as a representative fraction.
6. **MEDIUM** On a 1:50,000 map, two bridges are 4 cm apart. How far apart are they in kilometers and miles?

7. **MEDIUM** Your city is 14 km across and your map space is 35 cm wide. What is the scale in kilometers per centimeter and as a representative fraction?
8. **HARD** You must speak for 4 minutes and you speak at 140 words a minute. Your draft is 800 words. How many words must you cut? How long would the 800-word draft take?
9. **HARD** A map printed at 1:48,000 is enlarged on a copier to 200 percent. What is its new scale? Why is a scale bar better than a written fraction on a map that might be copied?
10. **CHALLENGE** Write the five-part outline for your own talk, with one sentence for each part: hook, site, situation and connections, then and now, and closing.

COMMON MISTAKES

- Crowding the map. Put every fact on the poster or in the talk, and keep only the layers that answer your four questions on the map.
- Drawing a scale bar by guessing. Work out the scale from your paper size and the city's width, then measure the bar with a ruler.
- Reading the talk word for word from a page. Use short notes on cards, look up at your audience and point to the map.

Make it a game · Thirty-Second Tour Guide. Write ten places in your city on slips of paper: the founding spot, a bridge, the depot, a highway interchange, the airport, a church, a park and so on. A player draws a slip and has thirty seconds to give a “tour” of it, pointing to it on the capstone map and telling one fact about its site, situation or history. Listeners award 1 point for finding it on the map, 1 for a correct fact and 1 for a fact nobody else knew. Play until all ten slips are used.

Scripture. “And seek the peace of the city whither I have caused you to be carried away captives, and pray unto the LORD for it: for in the peace thereof shall ye have peace.” (Jeremiah 29:7, KJV)

God told the exiles in Babylon to work and pray for the good of the city where they lived. Studying your city is one way to love your neighbors: you learn its land, its roads and its story, and you can pray for it by name.

Practice answers

1. Title, Orientation (north arrow), Date, Author, Legend, Scale, Sources.
2. Daniel H. Burnham and Edward H. Bennett; published July 4, 1909, by the Commercial Club of Chicago. Chicago's eighth graders studied *Wacker's Manual* from 1912.
3. Orientation (a north arrow) and the legend.
4. $6 \times 0.25 = 1.5$ miles; $1.5 \times 1.609 \approx 2.4$ km.
5. 1 mile = $5,280 \times 12 = 63,360$ inches, so 1:63,360.
6. $4 \times 50,000 = 200,000$ cm = 2 km; $2 \times 0.621 \approx 1.24$ miles.
7. $14 \div 35 = 0.4$ km per cm. 0.4 km = 40,000 cm, so 1:40,000.
8. $4 \times 140 = 560$ words, so cut $800 - 560 = 240$ words. $800 \div 140 \approx 5.71$ minutes, about 5 minutes 43 seconds.

9. Everything on the map is twice as big, so 1 inch now covers half the ground: 1:24,000. A scale bar is enlarged or reduced along with the map, so it stays correct; a written fraction does not change and becomes wrong.
10. Answers will vary. A strong outline opens with a real dated moment (for example, "In 1837 a surveyor drove a stake in the woods..."), names at least one site fact and one situation fact, names the main connections, gives one clear change from the old map to the new, and closes with a hope or thanksgiving for the city.

UNIT 8 REVIEW

Answer each question. Show your work for calculations, give both U.S. customary and metric units where asked, and use complete sentences for explanations. The review is worth 60 points.

1. (5 pts) Define site and situation. Give one example of each from your own city.
2. (5 pts) Why did Pierre Laclède choose the west bank of the Mississippi a little below the mouth of the Missouri for St. Louis? Give two site reasons and two situation reasons.
3. (6 pts) Minneapolis lies at about 44.98°N and St. Louis at about 38.63°N . Counting only the north-south distance, how far is Minneapolis north of St. Louis, in miles and kilometers?
4. (5 pts) Decode these Interstate numbers: I-80, I-35, I-465 and I-395.
5. (6 pts) Your city is 240 miles (386 km) from your state capital. How long would the trip take by ox wagon at 15 miles a day, by an 1880s train averaging 25 mph, and by car averaging 60 mph?
6. (5 pts) Explain how Atlanta became a great city without a navigable river or harbor. Use the words node and time-distance.
7. (6 pts) On a 1:24,000 topographic map, a road measures 4.5 inches. How long is it on the ground, in feet, miles and kilometers?
8. (5 pts) On a Sanborn map at 1 inch = 50 feet, a yellow building measures 1.2 inches by 0.9 inch. What are its dimensions and floor area, and what was it built of?
9. (5 pts) Describe one ward of Oglethorpe's Savannah, and explain why so much of the 1733 plan still shows on a map of Savannah today.
10. (6 pts) Your city is 6 miles across and your map space is 24 inches wide. Find the scale as a word scale and a representative fraction. How long should the scale bar be for 1 mile and for 1 kilometer (1 km = 0.621 mile)?
11. (6 pts) A classmate's map has a title, a legend and a north arrow, but nothing else. Name the missing TODALSS parts and explain why a reader needs each one. Then tell one way the Chicago Plan Commission helped citizens understand the *Plan of Chicago*.

UNIT PROJECT: THE CITY STUDY: THE GEOGRAPHY OF MY CITY

Present the complete geography of your city or nearest town. Include your salt-dough relief model of the original site with its site-and-situation cards (8.1), your pin-and-string connections map with your traffic count (8.2), your then-and-now tracing overlay with its paragraph (8.3), and your finished capstone map with all seven TODALSS parts. Mount your findings on a four-panel poster (Why here? How connected? Then and now, and a timeline) and give a five-minute talk to your family or class, then answer their questions.

- **Accuracy:** Dates, founders, places, routes and measurements are correct, sources are listed, and every map uses a correct scale in miles and kilometers.
- **Geographic reasoning:** The study clearly explains the city's site and situation, how its connections shaped its growth, and what has lasted and changed, using the unit's

terms.

- **Maps and craftsmanship:** The relief model, connections map, overlay and capstone map are neat, use consistent colors, and include title, orientation, date, author, legend, scale and sources.
- **Presentation:** The talk lasts about five minutes, opens with a real moment from the city's history, points to the map, speaks clearly to the audience and answers questions thoughtfully.

Answer key

1. Site is the physical ground a city stands on (landforms, water, soil, elevation); situation is where it lies compared with other places (rivers, roads, neighbors, resources within reach). Examples will vary, for example: site, a dry bluff beside the river; situation, on the main railroad between two larger cities.
2. Site: high limestone ground above floods (unlike the low east bank); a good landing, timber and building stone. Situation: just below the mouth of the Missouri, which brought the fur trade of the plains; on the river route to New Orleans and the sea, and near the Illinois River route toward the Great Lakes. (Any two of each.)
3. $44.98 - 38.63 = 6.35^\circ$. $6.35 \times 69 \approx 438$ miles; $6.35 \times 111 \approx 705$ km.
4. I-80: even, so east-west (a northern route, since even numbers grow toward the north). I-35: odd, so north-south (in the middle of the country). I-465: a branch of I-65 with an even first digit, so a loop around a city (Indianapolis). I-395: a branch of I-95 with an odd first digit, so a spur.
5. Wagon: $240 \div 15 = 16$ days. Train: $240 \div 25 = 9.6$ hours (about 9 hours 36 minutes). Car: $240 \div 60 = 4$ hours.
6. Atlanta began in 1837 as the end point (Terminus) of the Western & Atlantic Railroad, and by the mid-1850s four railroads met there, making it a node in the Southern network. Railroads did the work rivers did elsewhere and shrank the time-distance to the ports and the Tennessee valley. Later three Interstates and the world's busiest passenger airport came to the same central situation.
7. $4.5 \times 24,000 = 108,000$ inches = 9,000 feet; $9,000 \div 5,280 \approx 1.70$ miles. Metric: 4.5 in = 11.43 cm; $11.43 \times 24,000 = 274,320$ cm ≈ 2.74 km.
8. $1.2 \times 50 = 60$ feet and $0.9 \times 50 = 45$ feet; area $60 \times 45 = 2,700$ square feet (about 18.3×13.7 m ≈ 251 m²). Yellow means wood frame.
9. A ward had a public square in the middle, four tythings of ten house lots each (40 house lots) to the north and south, and four trust lots for public buildings to the east and west. The plan survives because streets and lot lines are shared by every owner and later building; buildings were replaced, but they were built to fit the wards, and 22 of the 24 squares remain.
10. $6 \div 24 = 0.25$ mile per inch, so 1 inch = 0.25 mile. 0.25 mile = $0.25 \times 63,360 = 15,840$ inches, so 1:15,840. 1 mile = 4 inches (10.16 cm). 1 km = $0.621 \div 0.25 \approx 2.48$ inches (about 6.3 cm).
11. Missing: Date (to know when the map was true), Author (to know who made it and whom to ask), Scale (to measure distances) and Sources (to check where the information came from). The commission published *Wacker's Manual* (1911), which Chicago eighth graders studied from 1912, and it gave illustrated lectures and handed out pamphlets.

BONUS: MAP LAB

This bonus unit turns the map skills of the year into games. You will race an orienteering course against your family with interval starts and control cards, run a shipping company in a trade-route board game built on real ports and canals, play detective with old maps to discover when they were made, and hide a treasure that can only be found by stacking map layers and reading GPS coordinates.

Every game starts from a real moment: the first World Orienteering Championships in the forests of Finland in 1966, the merchants and underwriters of Edward Lloyd’s coffee house in London, the unmasking of Yale’s Vinland Map in 2021, and the first geocache hidden in the Oregon woods in May 2000. Each lesson is lighter than the main units, with one worked example and five practice problems, so it fits a summer week, a co-op afternoon or a family game night.

As you play, remember the series verse: God “hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation” (Acts 17:26). Maps help us see the lands He made and the ways He has given people to reach one another.

BEFORE YOU BEGIN

- Can take and follow a bearing with a baseplate compass (Lesson 7.1)
- Can use a map scale to find real distances in kilometers and miles
- Knows the world’s main straits and canals (Units 5 and 6)
- Can read latitude and longitude

MASTERY CHECKLIST

- I can plan an orienteering leg by its distance and bearing and compare route choices.
- I can compute a voyage’s time from its distance in nautical miles and its speed in knots.
- I can explain how a closed canal or strait changes the cost and time of trade.
- I can date an old map within a window of years using “not before” and “not after” clues.
- I can overlay map layers to find a place that fits several rules, and convert GPS coordinates between formats.

OPTIONAL BOOKS AND RESOURCES

- **Library of Congress Maps Collection** (<https://www.loc.gov/maps/>): Free. Thousands of old maps, viewable in high resolution and downloadable, with catalog dates to check your detective work in Lesson 9.3.
- **USGS topoView** (<https://ngmdb.usgs.gov/topoview/>): Free. Current and historical U.S. Geological Survey topographic maps of any place in the United States. Use an old and

a new sheet of your area for map detective cases, or a topographic base for an orienteering course.

- **Orienteering USA** (<https://orienteeringusa.org/>): The national orienteering federation. Use its club finder to locate a local club; many hold beginner-friendly public events with real orienteering maps.

9.1 ORIENTEERING RACE

OBJECTIVES

- Plan a leg of an orienteering course by measuring its distance with the scale bar and its bearing with a compass or protractor.
- Compare two route choices and explain why the straight line is not always the fastest way.
- Run (or walk) a timed family orienteering race with interval starts, control cards and a fair finish.

Warm-up. Stand in the middle of a room with a quick sketch map of it. Turn the paper until the door on the map points at the real door: you have “set” (oriented) the map. Now turn your body halfway around and set the map again without looking at a compass. How did you know which way to turn it?

Watch. *Route Choice // Alice Leake // Think Fast, Run Hard, Go Orienteering* (South London Orienteers / On The Red Line, 4:58). <https://www.youtube.com/watch?v=YVMQJOJRMyo>

Before the race: how orienteers choose a route between controls.

Backup video. *Orienteering - Route Choice* (Orienteering Australia, 3:52). https://www.youtube.com/watch?v=-wNfknn_-9k

Another short lesson on route choice, from Orienteering Australia.

KEY TERMS

leg

One part of an orienteering course, from one control to the next.

route choice

The path a runner picks for a leg: straight through, around an obstacle, or along a trail. Good orienteers compare distance, ground and risk.

attack point

An easy-to-find feature close to a control (a path bend, a boulder, a pond corner) from which you make a short, careful final approach.

handrail

A long feature you can follow without much map reading, such as a stream, fence, path or the edge of a field.

catching feature

A feature just past the control (a road, a lake shore) that tells you that you have gone too far.

interval start

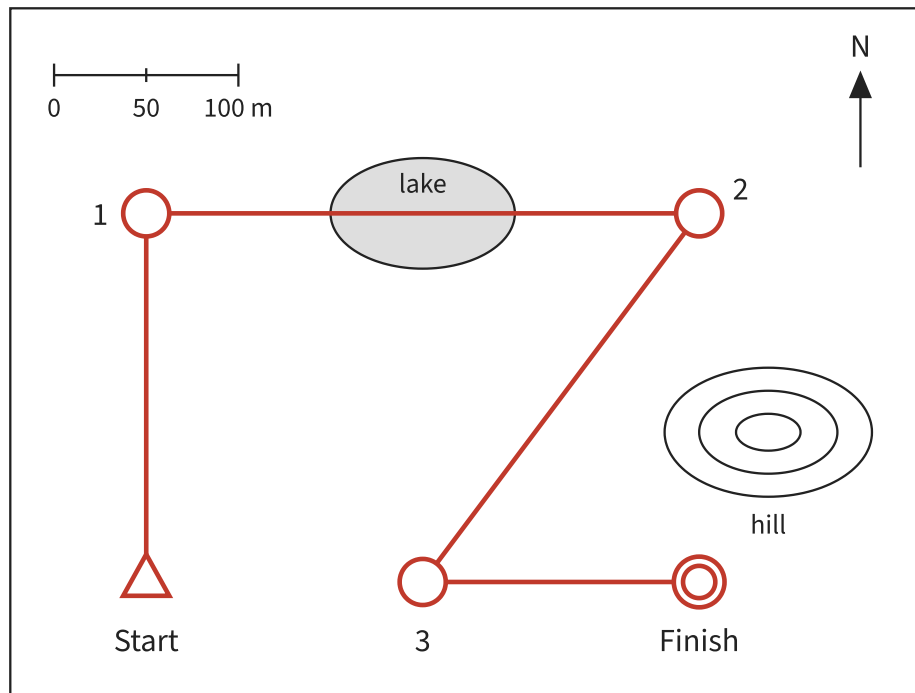
Starting runners one at a time, a minute or more apart, so that each must find the way alone.

CORE IDEAS

The story. In the autumn of 1966 the best map-and-compass runners in Europe came to the forests around Fiskars, an old ironworks village in southern Finland, for the first World Orienteering Championships. The International Orienteering Federation had been founded only five years before, in 1961. The runners did not start together in a crowd. They left one at a time, minutes apart, and each was handed a map at the start line, so no one could simply follow the leader. Åge Hadler of Norway won the men's race, and Ulla Lindkvist of Sweden won the women's. Neither won only by having the fastest legs. Each won by reading the forest well and making fewer mistakes than everyone else.

How it works. An orienteering race is really a string of small puzzles. For each leg the runner asks three questions: *Where am I going? Which way will I go? What will I see on the way?* A straight line is shortest, but it may cross a lake, a thicket or a steep hill. A longer route along a path may be faster. Clever runners pick a **handrail** to follow, run hard to an **attack point**, then slow down for the last 50 to 100 meters and walk in on a careful bearing. If they overshoot, a **catching feature** stops them. Look at the practice course in the figure: the leg from control 1 to control 2 runs straight across a lake, so every runner must choose to go around the north shore or the south shore.

The big idea. Real-life navigation is the same: a ship picks its sea lane, a truck driver picks a highway, and a hiker picks a trail by weighing distance against difficulty. In this lab you will race. But the winner is the one who plans each leg first, keeps the map turned to the ground, and counts paces honestly. "Ponder the path of thy feet," says Proverbs. That is good advice for a race and for a life.



A practice course. The scale bar shows 100 m. Start to 1 is 200 m north; 1 to 2 is 300 m east (straight across the lake); 2 to 3 is 150 m west and 200 m south; 3 to the finish is 150 m east.

PICTURE STUDY



Topographic Map of Switzerland (the Dufour Map), Guillaume-Henri Dufour and the Swiss federal survey, published 1845–1864 · Copperplate engraving, printed in 25 sheets at a scale of 1:100,000 · Swiss Federal Office of Topography (swisstopo); copies in many libraries

General Guillaume-Henri Dufour led the first complete official survey of Switzerland. His team measured the whole mountainous country from carefully surveyed base lines, and the finished sheets came out between 1845 and 1864. The Dufour Map shows steep ground with

hachures, rows of tiny lines drawn in the direction water would run downhill, and with shading as if the sun were shining from the northwest. It was admired all over Europe and won praise at the Paris world's fair of 1855.

Modern orienteering maps show the same ground with brown contour lines instead of hachures, but the goal is the same: to let a person standing in a forest or on a mountain "see" the shape of the land on paper.

Look closely

- Find the steepest slopes. How did the engravers make them look darker?
- Find a lake. Which way do you think the streams around it flow?
- Find a road or path that climbs to a pass. Does it go straight up, or does it zigzag? Why?
- Imagine you are running this map. Pick a valley you would use as a handrail.

Talk about it

1. What can contour lines tell you that hachures cannot? (Hint: think of exact heights.)
2. Why might a runner choose a longer route along a valley instead of a shorter route over a ridge?

Safety first. Race only in a yard, park or school ground where an adult has given permission and can see the course. Agree on a boundary (a road, fence or path) that no one crosses, a meeting place, and a time limit. Walk, do not run, near water, roads and steep ground. Carry a whistle; three blasts means "I need help."

PROJECT: THE FAMILY ORIENTEERING RACE

In Lesson 7.2 you built an orienteering course. Now you will turn it into a real race with interval starts, control cards, a route-choice leg and a results board. Everyone in the family can run, from the youngest (with a partner) to the grown-ups.

You will need

- Your course map from Lesson 7.2, or a new sketch map of a yard or park drawn to scale with a scale bar and north arrow
- Baseplate compass
- 6 to 8 control markers: paper or cloth flags colored orange and white, tied to stakes, trees or fence posts
- A different letter or crayon color at each control (for "punching")
- Control cards: index cards with numbered boxes
- Stopwatch or phone timer, pencil, clipboard, ruler
- Copies of the map, one per runner

Steps

1. Choose 6 to 8 control sites that are easy to describe: the northeast corner of the shed, the big oak, the gate. Mark each on the master map with a numbered circle, and draw the course in red: a triangle for the start, circles for controls, a double circle for the finish.
2. Include at least one route-choice leg where the straight line crosses something you must go around (a flower bed, a pond, a play set). Include one leg that needs a compass bearing.
3. Place a marker at each control with its letter. Write a secret “key” of letters for the judge.
4. For each leg, measure the map distance with a ruler, convert it with the scale, and measure the bearing. Write these on a leg table for the judge.
5. Start runners one at a time, 2 minutes apart. Write each start time. At each control the runner writes the letter in the matching box on the control card.
6. At the finish, stop the clock. Elapsed time = finish time minus start time. Check the card against the key: a missing or wrong control means the run does not count (in real orienteering, “mispunch”).
7. Post the results on a board. Then have each runner draw on the map the route they actually took. Compare route choices on the tricky leg: who went which way, and who was fastest?

Tips

- Set the map every time you turn. Keep your thumb on the map where you are (“thumbing”) so you never lose your place.
- Slow down near the control. Most time is lost in the last 50 meters, not on the open path.
- For a younger child, use a “streamer” course: tie ribbons between controls so the child can follow them, while still reading the map.

Check your work

- I measured the distance and bearing of every leg before the race.
- I ran the course with a fair interval start and a checked control card.
- I can explain my route choice on the tricky leg and whether it was a good one.

MAP NOTEBOOK

1. Copy the practice course from the figure into your map notebook. Beside each leg write its distance and bearing.
2. Draw two route choices for the lake leg in two colors and label which one you would take and why.
3. Draw the six common orienteering map colors as a small key: black (rock and man-made things), brown (landforms and contours), blue (water), yellow (open land), white (easy-running forest), green (thick vegetation).

From history. Orienteering maps around the world follow standards set by the International Orienteering Federation, so a runner from Finland can read a map drawn in Japan or Colorado. The colors are always the same: brown for landforms and contours, blue for water, yellow for open land, white for forest that is easy to run through, green for thick vegetation that slows you down, and black for rocks, paths and buildings. Course markings are drawn on top in a purple-red: a triangle for the start, circles for controls and a double circle for the finish.

WORKED EXAMPLES

Example 1. On the practice course, the leg from control 2 to control 3 goes 150 m west and 200 m south. Find its straight-line length (in meters and feet), its bearing, and how many paces it is for a runner who takes 65 paces (counting every second step) per 100 m.

(Use the map or drawing “Leg 2 to 3 forms a 150-200-250 right triangle.” shown earlier in this lesson.)

1. The leg is the long side of a right triangle with sides 150 m and 200 m: length = $\sqrt{(150^2 + 200^2)} = \sqrt{(22,500 + 40,000)} = \sqrt{62,500} = 250$ m. In feet: $250 \times 3.28 \approx 820$ ft.
2. The leg points south and a little west. The angle west of south is the angle whose tangent is $150 \div 200 = 0.75$, which is about 37° .
3. Bearings are measured clockwise from north. South is 180° , so south-and- 37° -west is $180^\circ + 37^\circ = 217^\circ$.
4. Paces: 250 m is 2.5 hundreds of meters, and $2.5 \times 65 = 162.5$, so about 163 paces.

Answer: About 250 m (about 820 ft), on a bearing of about 217° , which is about 163 paces.

PRACTICE

1. **EASY** Using the figure, give the bearing of the leg from the start to control 1 and of the leg from control 1 to control 2.
(Use the map or drawing “Use the north arrow.” shown earlier in this lesson.)
2. **EASY** Add the straight-line lengths of all four legs (200 m, 300 m, 250 m and 150 m). Give the total in kilometers and in miles.
3. **MEDIUM** You reach control 3 and realize you dropped your pencil at control 2. What bearing do you follow to go straight back to control 2?
4. **MEDIUM** A runner averages 8 minutes per kilometer through the forest. How long would the straight-line course of 0.9 km take? Give minutes and seconds.
5. **HARD** On the lake leg (1 to 2), Route A goes around the north shore on an open path: 360 m at 4 minutes per kilometer. Route B goes around the south shore through thick brush: 340 m at 7 minutes per kilometer. Which is faster, and by about how much? In one sentence, explain what this teaches about route choice.

COMMON MISTAKES

- Running off before setting the map. Turn the map to match the ground (or the compass needle) every time you change direction.
- Following another runner. That runner may be lost, or headed for a different control. Interval starts exist to make each person navigate.
- Racing all the way into the control. Speed up on handrails, then slow down from the attack point and walk in on a careful bearing.

Make it a game · Memory Relay. Put one copy of the course map on a table at the start. Runners may not carry it. Each runner studies the map, memorizes one leg, runs to that control, writes its letter, and comes back to tag the next runner, who memorizes the next leg. The team with all letters correct in the shortest time wins. Afterward, talk about which landmarks were easiest to remember and why.

Scripture. “Ponder the path of thy feet, and let all thy ways be established.” (Proverbs 4:26, KJV)

A good orienteer thinks before running. The same wisdom serves us in every choice: look at the map, consider the way, then go steadily.

Practice answers

1. Start to 1: due north, 0° (also written 360°). Control 1 to 2: due east, 90° .
2. $200 + 300 + 250 + 150 = 900 \text{ m} = 0.9 \text{ km}$. $0.9 \times 0.621 \approx 0.56 \text{ mi}$ (a little over half a mile).
3. The back bearing: $217^\circ - 180^\circ = 37^\circ$.
4. $0.9 \times 8 = 7.2 \text{ minutes} = 7 \text{ minutes } 12 \text{ seconds}$ ($0.2 \text{ minute} \times 60 = 12 \text{ seconds}$).
5. Route A: $0.36 \times 4 = 1.44 \text{ min}$ (about 1 min 26 s). Route B: $0.34 \times 7 = 2.38 \text{ min}$ (about 2 min 23 s). Route A is faster by about 0.94 min, nearly a minute, even though it is 20 m longer. The shortest route is not always the fastest; the ground matters as much as the distance.

9.2 PORT TYCOON

OBJECTIVES

- Build and play a trade-route board game on a world map of real ports, canals and straits.
- Compute voyage times from distance and speed in knots, and convert nautical miles to kilometers and miles.
- Weigh distance, time, tolls and risk to choose the best route, and explain why a choke point closure changes world trade.

Warm-up. Find three things in your kitchen with a “Made in” label. For each one, guess the port where it first landed in America and trace with your finger on a globe the sea route it likely took. Which one traveled the farthest?

Watch. *Transit through Expanded Panama Canal (Northbound)* (The Panama Canal, 2:22). <https://www.youtube.com/watch?v=VWGac7LzI3U>
Before the game: a container ship passes through the expanded Panama Canal.

Backup video. *Full transit through NEOPANCAN (New Panama Canal), Southbound [4K]* (SeaTube, 7:37). <https://www.youtube.com/watch?v=6pjmN2XmMss>
During the game: a full transit of the Panama Canal on a ship.

KEY TERMS

knot

A speed of one nautical mile per hour. A ship at 20 knots covers $20 \times 24 = 480$ nautical miles a day.

nautical mile

The sea mile, 1.852 km (about 1.15 statute miles). It equals one minute of latitude.

freight rate

The price a shipper pays to carry cargo from one port to another.

toll

A fee paid to use a canal, bridge or road. Ships pay tolls to pass the Suez and Panama Canals.

underwriter

A person or company that agrees to pay for a loss at sea in return for a fee; an insurer of ships and cargo.

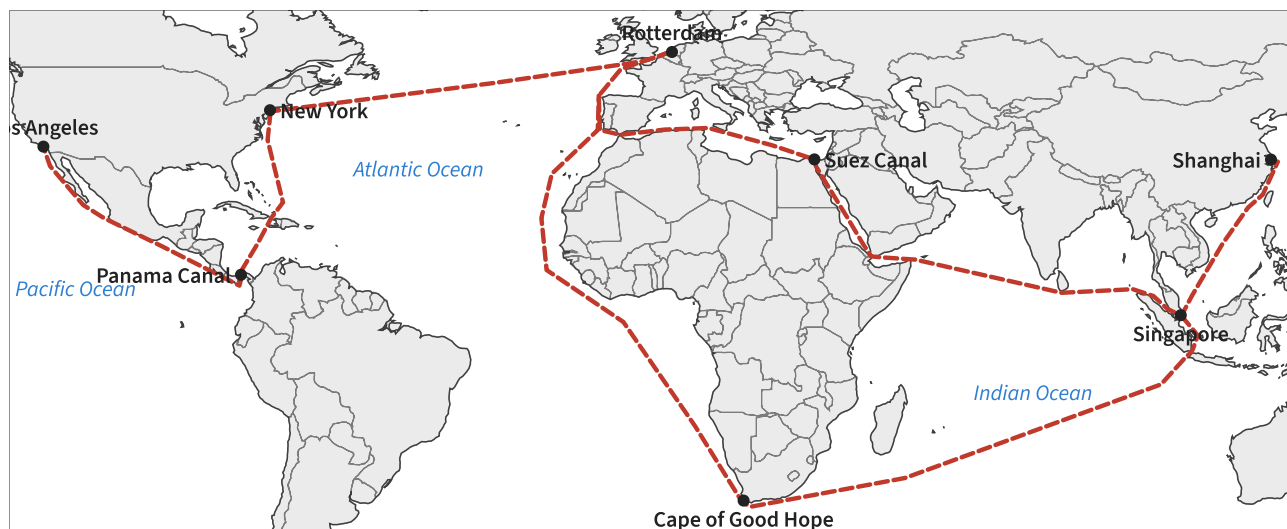
CORE IDEAS

The story. In February 1688 a London newspaper carried a small notice about stolen watches, telling readers to bring news of them to Edward Lloyd’s coffee house on Tower

Street, near the busy wharves of the Thames. Lloyd's was already the place where ship captains, merchants and sailors gathered. Lloyd made sure his customers had the freshest news of which ships had arrived, which were late and which had been lost. Men who were willing to insure a voyage met there too; a merchant would pass around a paper describing his ship and cargo, and each insurer who agreed to share the risk wrote his name *under* it. From that habit comes the word **underwriter**. After Lloyd's death, a printed sheet of shipping news, *Lloyd's List*, began appearing in 1734. Trade, it turned out, ran on three things: ships, routes and good information.

How it works. Every voyage is a problem of distance, speed, cost and risk. A modern container ship cruising at 20 knots covers about 480 nautical miles (about 890 km or 550 miles) a day. The route from Shanghai to Rotterdam through the Strait of Malacca and the Suez Canal is about 10,500 nautical miles. Going around Africa's Cape of Good Hope avoids the canal toll but adds roughly 3,500 nautical miles. When the giant ship *Ever Given* ran aground in the Suez Canal on March 23, 2021, hundreds of ships waited in line until she was freed on March 29, and some captains turned south to go the long way around Africa. One stuck ship in one narrow canal slowed trade for the whole world.

On the map. In Port Tycoon you are a shipowner. The board (see the map) links seven real places: Shanghai, Singapore, the Suez Canal, Rotterdam, New York, the Panama Canal and Los Angeles, plus the long Cape route around Africa. Each link is marked with its sea days for a ship at about 20 knots, rounded for the game. You carry cargo contracts, pay for fuel and tolls, and race to make the most profit. Along the way you will feel what every merchant at Lloyd's knew: geography decides the route, and the route decides the price.



The Port Tycoon board. Sea days at about 20 knots (rounded): Shanghai-Singapore 5; Singapore-Suez 10; Suez-Rotterdam 7; Singapore-Rotterdam by the Cape 24; Rotterdam-New York 7; New York-Panama 4; Panama-Los Angeles 6; Los Angeles-Shanghai 12 (across the Pacific, off the edge of this map).

PICTURE STUDY



The Interior of the Port of Marseille, Claude-Joseph Vernet, 1754 · Oil on canvas · Musée national de la Marine, Paris (Louvre collection)

In 1753 King Louis XV of France asked the painter Joseph Vernet to paint the great seaports of France. Vernet spent about ten years traveling from port to port and painted fifteen large views, known as *The Ports of France*. Marseille, on the Mediterranean, was one of the busiest of all, trading with Italy, Spain, North Africa and the eastern Mediterranean.

Vernet did not paint only ships and water. He filled the quays with people at work: porters, sailors, traders and buyers. His paintings are a record of how a port actually worked before steam engines and containers.

Look closely

- Find the goods on the quay. What kinds of containers did they use before the steel box?
- Find people who are buying, selling, carrying and watching. How many different jobs can you count?
- Look at how close the ships are packed. Why would a sheltered harbor be so crowded?
- Find the hills or fortifications around the harbor. How do they protect it?

Talk about it

1. Compare this harbor with a modern container port (Lesson 4.4). What has changed, and what is still the same?
2. Why would a king want paintings of his ports? What do ports mean for the wealth of a country?

PROJECT: BUILD AND PLAY PORT TYCOON

You will make a trade-route board game from a world map and play it with your family. The board uses real ports and real routes; the sea days and money are rounded so the game moves quickly.

You will need

- A large poster board or the back of a wall map
- A printed or traced outline world map (Americas, Europe, Africa and Asia)
- Markers, ruler, coins or small toy boats as ship tokens
- One six-sided die
- Index cards for Cargo Contracts and Event Cards
- Play money (or a ledger with a running balance for each player)

Steps

1. Draw the board: mark the seven places (Shanghai, Singapore, Suez Canal, Rotterdam, New York, Panama Canal, Los Angeles) as circles, plus a circle at the Cape of Good Hope. Draw the routes and write the sea days on each link: Shanghai–Singapore 5, Singapore–Suez 10, Suez–Rotterdam 7, Singapore–Cape–Rotterdam 24 in all, Rotterdam–New York 7, New York–Panama 4, Panama–Los Angeles 6, Los Angeles–Shanghai 12 (draw arrows off the right and left edges for the Pacific).
2. Write 12 Cargo Contracts. Each names a cargo, a start port, a destination, a payment and a deadline. Examples: Electronics, Shanghai to Rotterdam, pays \$60, due in 25 days. Machinery, Rotterdam to New York, pays \$30, due in 10 days. Grain, New York to Shanghai, pays \$70, due in 30 days. Toys, Shanghai to Los Angeles, pays \$35, due in 14 days.
3. Write 10 Event Cards. Examples: Suez Canal blocked (as in March 2021): no ship may pass for the next 2 turns. North Atlantic storm: lose 1 turn. Pirates reported near the Gulf of Aden: pay \$5 for extra security or roll again. Fuel prices rise: fuel costs \$2 per day this round. Good weather: move 2 extra days.
4. Rules: each player starts at any port with \$50 and draws one contract. Each turn, roll the die and move that many sea days along the routes. Pay \$1 fuel for every sea day moved. Pay a \$10 toll each time you pass through the Suez Canal or the Panama Canal. Keep a day count for each contract; a late delivery pays \$5 less.
5. When you reach a port, deliver any cargo bound there, collect payment, and draw a new contract. Draw an Event Card whenever you roll a 6.
6. Every player keeps a ledger: Turn, Route, Days, Fuel, Tolls, Payment, Balance.
7. Play for 12 turns (or one hour). The richest shipowner wins. Afterward, each player tells which route decision earned or lost the most money and why.

Tips

- Before moving, add up the sea days and costs of each possible route. The shortest route is not always the most profitable one.

- If the Suez Canal is blocked, compare waiting with going around the Cape. The answer depends on how many turns the blockage lasts and on your deadline.
- Younger players can play on a team with an older one who keeps the ledger.

Check your work

- My board shows the real ports, canals and the Cape route in the right places.
- My ledger is complete and correctly added.
- I can explain one route choice using days, fuel, tolls and deadline.

MAP NOTEBOOK

1. Draw the Suez route from Shanghai to Rotterdam and label every strait or canal it passes: the Strait of Malacca (with Singapore), Bab-el-Mandeb, the Suez Canal, the Strait of Gibraltar and the Strait of Dover.
2. Draw a small coffee-house scene of Lloyd's in 1688: a captain, a merchant and an underwriter signing under a risk.
3. Copy the Port Tycoon board as a simple network diagram: circles for ports, lines for routes, numbers for sea days.

From history. Lloyd's coffee house moved from Tower Street to Lombard Street, in the heart of the City of London, in 1691. The insurers who met there later formed their own society, and Lloyd's of London is still one of the world's best-known insurance markets. *Lloyd's List*, the shipping newspaper begun in 1734, became one of the longest-running publications in the world, reporting the movements of ships for nearly three centuries.

WORKED EXAMPLES

Example 1. A container ship sails from Shanghai to Rotterdam by the Suez Canal, about 10,500 nautical miles, at 20 knots. (a) How many days does the voyage take? (b) Give the distance in kilometers and miles. (c) If the canal is closed and the ship goes around the Cape of Good Hope, adding about 3,500 nautical miles, how many extra days does it sail?

(Use the map or drawing "Compare the Suez route with the Cape route." shown earlier in this lesson.)

1. A day at 20 knots: $20 \text{ nautical miles per hour} \times 24 \text{ hours} = 480 \text{ nautical miles per day}$.
2. (a) $10,500 \div 480 \approx 21.9$, so about 22 days.
3. (b) $10,500 \times 1.852 \approx 19,400 \text{ km}$. $10,500 \times 1.151 \approx 12,100 \text{ miles}$.
4. (c) $3,500 \div 480 \approx 7.3$, so about 7 more days at sea, plus more fuel and crew wages, but no canal toll.

Answer: (a) About 22 days. (b) About 19,400 km or 12,100 miles. (c) About 7 extra days.

PRACTICE

1. **EASY** A ship steams 480 nautical miles in a day. How far is that in kilometers and in miles?
2. **MEDIUM** On the Port Tycoon board, compare two routes from Shanghai to New York: (a) west, by Singapore, Suez and Rotterdam; (b) east, by Los Angeles and the Panama Canal. How many sea days is each?
(Use the map or drawing “Sea days: Shanghai–Singapore 5; Singapore–Suez 10; Suez–Rotterdam 7; Rotterdam–N” shown earlier in this lesson.)
3. **MEDIUM** In the game, you take a contract that pays \$70 to carry grain from New York to Shanghai, due in 30 days. You go by Panama and Los Angeles (22 days). Fuel is \$1 a day, and the Panama toll is \$10. What is your profit?
4. **HARD** Your contract: electronics, Shanghai to Rotterdam, pays \$60, due in 25 days (\$5 less if late). The Suez route is 22 days with a \$10 toll; the Cape route is $5 + 24 = 29$ days with no toll. Fuel is \$1 a day. Which route earns more?
5. **CHALLENGE** In a short paragraph, explain why a single blocked canal, like the *Ever Given* in the Suez Canal in March 2021, can raise prices in stores far from Egypt.

COMMON MISTAKES

- Mixing up nautical miles and statute miles. A nautical mile is about 1.15 ordinary miles (1.852 km).
- Thinking a knot is a distance. A knot is a *speed*: one nautical mile per hour.
- Choosing the shortest route without counting tolls, deadlines and risk. Real shipowners weigh all of them.

Make it a game • Choke Point Flash Round. One player names a voyage (for example, Singapore to Rotterdam, or New York to Los Angeles). The others race to name, in order, every strait or canal the shortest sea route passes through. One point for each correct choke point in the right order; a bonus point for anyone who can name the long way around if one of them is closed.

Scripture. “They that go down to the sea in ships, that do business in great waters; These see the works of the LORD, and his wonders in the deep.” (Psalm 107:23–24, KJV)

Merchants and sailors have always depended on God’s providence on the sea. Trade is honest work that serves neighbors far away, and the sea lanes themselves show the wonder of the world He made.

Practice answers

1. $480 \times 1.852 \approx 889$ km. $480 \times 1.151 \approx 552$ miles.
2. (a) $5 + 10 + 7 + 7 = 29$ days. (b) $12 + 6 + 4 = 22$ days. The Panama route is 7 days shorter on this board.
3. Costs: $\$22$ fuel + $\$10$ toll = $\$32$. Profit: $\$70 - \$32 = \$38$. The cargo arrives in 22 days, on time.

4. Suez: $\$60 - \$22 \text{ fuel} - \$10 \text{ toll} = \$28$, on time. Cape: $\$60 - \$29 \text{ fuel} - \$5 \text{ late penalty} = \$26$. The Suez route earns \$2 more and keeps the customer happy.
5. A good answer says that much of the trade between Asia and Europe passes through one narrow canal, a choke point. When it is blocked, ships must wait or sail thousands of extra miles around Africa. That costs extra fuel, crew wages and time; goods arrive late; ships and containers are tied up and cannot carry the next cargo. Shipping companies charge more, and those costs are passed on to the stores and buyers who depend on the goods.

9.3 OLD MAP DETECTIVE

OBJECTIVES

- Find content clues (place names, borders, canals, states), making clues (paper, ink, printing) and style clues on an old map.
- Use “not before” and “not after” clues to bracket the date of a map within a range of years.
- Explain how scientists showed in 2021 that Yale’s Vinland Map was a modern forgery.

Warm-up. Pull out an old family photograph without looking at the date on the back. List every clue you can find about when it was taken: clothes, cars, hairstyles, the color of the print, the people’s ages. Then guess the year and check with a parent. How close were you?

Watch. *Maps at the Library of Congress* (Library of Congress, 3:03).

<https://www.youtube.com/watch?v=CcxbAYZqnmM>

Before the hunt: the Library of Congress map collection and how old maps are kept and studied.

Backup video. *Mapmaking...on Horseback* (Library of Congress, 2:36).

<https://www.youtube.com/watch?v=ysdwosff9PQ>

With How it works: making a map on horseback, from the Library of Congress.

KEY TERMS

content clue

Something a map shows that can be dated: a place name, a border, a state, a canal, a railroad.

not before (terminus post quem)

The earliest date a map could have been made, set by the newest thing it shows.

not after (terminus ante quem)

The latest date a map could have been made, set by something it still shows that later changed or something it does not yet show.

copperplate engraving

A printing method in which lines are cut into a copper plate, inked and pressed onto paper; common for maps from the 1500s to the 1800s.

provenance

The known history of an object: who owned it, where and when.

forgery

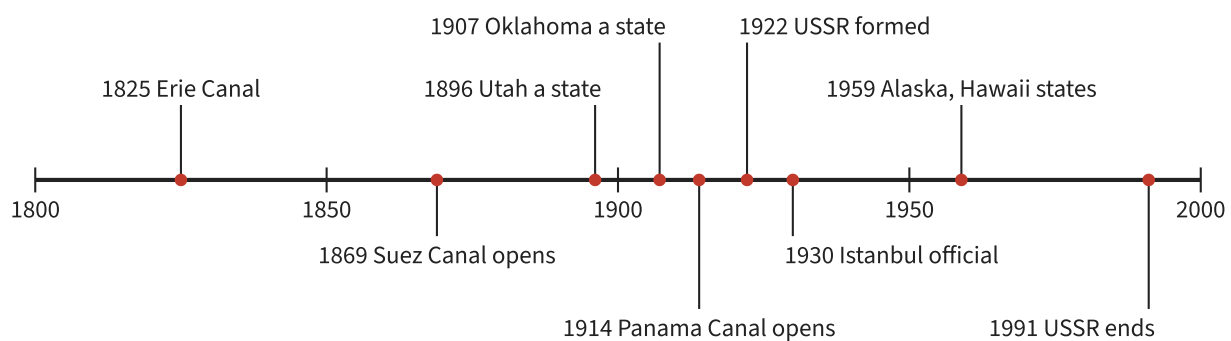
A fake made to fool people into thinking it is genuine and old.

CORE IDEAS

The story. In October 1965, just before Columbus Day, Yale University announced an astonishing treasure: a map of the world, supposedly drawn around 1440, that showed “Vinland,” the land in North America the Norse had reached around the year 1000. If it was real, it was the oldest map to show any part of America. From the start, some scholars were doubtful; the map had no clear provenance, and no one could say where it had been for five hundred years. The decisive clues were in the ink. Tests found titanium dioxide in a crystal form called anatase, a white pigment that was only manufactured from the 1920s. In September 2021, after a new round of careful scientific study, Yale announced plainly that the Vinland Map was a forgery.

How it works. A map detective looks for two kinds of dates. The newest thing a map shows sets the date it was made **not before**: a map showing the Suez Canal cannot be older than 1869. A thing the map still shows that later changed sets the date **not after**: a map that calls the city on the Bosphorus “Constantinople” was probably made before 1930, when the Turkish government made “Istanbul” the official name. Put the two together and you have a bracket, a window of years. Content clues are usually the strongest; making clues (paper, ink, printing method) and style clues (decorations, sea monsters, lettering) help confirm the answer, and, as the Vinland Map shows, can expose a fake.

On the map. Look at Abraham Ortelius’s world map of 1570 in the picture study. It shows the Strait of Magellan, so it was made after Magellan’s voyage of 1520. It shows a vast imagined southern continent but no real Australia, which fits a date before Dutch sailors first charted part of Australia’s coast in 1606. The clue timeline in the figure gives you dates for many later clues. With it, you can date dozens of old maps in the free online collection of the Library of Congress.



A map detective’s clue timeline. Each event is a “not before” clue if a map shows it, and may be a “not after” clue if a map shows the older state of things.

PICTURE STUDY



Typus Orbis Terrarum (Map of the World), from the *Theatrum Orbis Terrarum*, Abraham Ortelius, 1570 · Hand-colored copperplate engraving · Published in Antwerp; copies in many libraries, including the Library of Congress

In 1570 Abraham Ortelius, a mapmaker and dealer in Antwerp, published the *Theatrum Orbis Terrarum* (“Theater of the World”), often called the first modern atlas: a book of maps all made in the same size and style, with descriptions on the back. It sold well and was reprinted in many editions and languages.

This is its world map. It gathers the best knowledge of its day, from Portuguese, Spanish and other voyages, and it also shows what was still guessed. Later editions corrected some of its mistakes, which helps collectors tell one edition from another.

Look closely

- Find the Strait of Magellan at the tip of South America. Which voyage does it prove had already happened?
- Find the huge land across the bottom. Ortelius labeled it as a southern land “not yet known.” Is it really there?
- Find the west coast of South America. Does its shape match a modern map?
- Look for Australia. What does its absence tell you about the date?

Talk about it

1. Using only this map, give a “not before” date and a “not after” date. Which clues did you use?
2. Why would mapmakers in 1570 draw a land they had never seen?

PROJECT: MAP DETECTIVE CASE FILES

A parent (the “chief”) chooses three or four old maps from the Library of Congress online map collection and prints or shows them with the dates covered. You open a case file on each map, collect clues and narrow the date to a window of years. Then you open the catalog record to see how you did.

You will need

- 3 or 4 old maps from the Library of Congress (loc.gov/maps), printed or on screen, with dates and titles hidden
- Index cards or a notebook page for each case file
- Magnifying glass
- A modern atlas or online map
- Your clue timeline (copied from the figure and extended with new events)

Steps

1. Good starter maps: an 1800s map of the United States (count the states and territories), a world map showing or not showing the Suez and Panama Canals, a European map from before or after World War I, and a city map with or without bridges and railroads.
2. For each map, rule a case file with three columns: Clue, Not before, Not after.
3. Hunt for content clues first: names of countries and cities, state lines, territories, canals, railroads, bridges, parks, dams and lakes. Check each against the timeline or an encyclopedia.
4. Then look for making and style clues: Is it engraved (fine lines) or printed in flat color? Is the lettering old-fashioned? Are there sea monsters and decorated cartouches, or a plain modern style?
5. Write your bracket: “This map was made between ____ and ____.” Circle your strongest clue.
6. Open the catalog record and check the real date. Score yourself: within 10 years is excellent; within 25 is good.
7. Add every new clue you learned to your timeline so the next case is easier.

Tips

- A printed date is a clue too, but maps were sometimes reprinted for years without updating. Trust the content.
- A missing feature is only a clue if the mapmaker would have shown it. A small map of Ohio won’t show the Panama Canal.
- Look at the edges and the legend. Mapmakers often put scale, publisher and address there.

Check your work

- I dated each map within a window of years using at least two clues.
- I can explain the difference between a “not before” and a “not after” clue.
- I extended my clue timeline with at least three new events.

MAP NOTEBOOK

1. Copy the clue timeline into your map notebook and add three more events, such as 1863 (West Virginia becomes a state), 1869 (the transcontinental railroad), 1972 (Ceylon becomes Sri Lanka).
2. Draw the Ortelius world map in outline, and circle in red three clues that help date it.
3. Draw a “wanted poster” for the Vinland Map: what it claimed to be, and the clues that unmasked it.

From history. The Library of Congress owns the only known surviving copy of Martin Waldseemüller’s 1507 world map, the first map to use the name “America.” It was rediscovered in 1901 by the Jesuit scholar Joseph Fischer in the library of Wolfegg Castle in southern Germany, and the Library of Congress bought it in 2003 for \$10 million. Unlike the Vinland Map, its paper, printing and long history in a single castle library all agree that it is genuine.

WORKED EXAMPLES

Example 1. A map of the United States shows Utah as a state, but it labels “Oklahoma Territory” and “Indian Territory” side by side instead of a state of Oklahoma. Bracket the date of the map.

(Use the map or drawing “The bracket lies between Utah’s statehood and Oklahoma’s.” shown earlier in this lesson.)

1. Utah became a state in January 1896. A map that shows Utah as a state was made **not before** 1896.
2. Oklahoma became a state in 1907, joining Oklahoma Territory and Indian Territory. A map that still shows the two territories was made **not after** 1907.
3. Combine the two: the map was made between 1896 and 1907. (If the map also showed a finished Panama Canal, the clues would contradict each other, and you would suspect a mistake or a later reprint.)

Answer: Between 1896 and 1907.

PRACTICE

1. **EASY** A world map shows the Suez Canal and labels the island south of India “Ceylon.” The name Sri Lanka was adopted in 1972. Bracket the date.
2. **EASY** A map of Russia shows the city of “Leningrad.” The city was named Leningrad in 1924 and became Saint Petersburg again in 1991. Bracket the date.

3. **MEDIUM** A U.S. map shows 48 states and a finished Panama Canal on its inset of Central America. Using the timeline, bracket the date.
(Use the map or drawing "Use the Panama Canal and the Alaska and Hawaii events." shown earlier in this lesson.)
4. **MEDIUM** Give two clues on Ortelius's 1570 world map that fit its date, and say what each one proves.
5. **CHALLENGE** In a short paragraph, explain why the Vinland Map's ink was a stronger clue than its pictures or place names.

COMMON MISTAKES

- Trusting the printed date alone. Old maps were often reprinted for years with old plates; the content tells you what the mapmaker knew.
- Treating a missing feature as proof. It only counts if the mapmaker would have drawn it on a map of that size and subject.
- Mixing up the brackets. The newest thing shown sets "not before"; something that later changed sets "not after."

Make it a game • Clue Bracket Showdown. One player reads two clues from a mystery map, such as "It shows Hawaii as a state and calls India's largest city Bombay" (Mumbai became the official name in 1995). Others race to write the bracket (1959 to 1995). Closest correct bracket wins the round. Players then write their own clue pairs from the timeline for the next round.

Scripture. "It is the glory of God to conceal a thing: but the honour of kings is to search out a matter." (Proverbs 25:2, KJV)

God made a world full of things to discover, and He honors careful, honest searching. A good detective loves the truth more than an exciting story, which is why Yale was right to say plainly that its famous map was fake.

Practice answers

1. Not before 1869 (the Suez Canal opened) and not after 1972 (Ceylon became Sri Lanka): between 1869 and 1972.
2. Between 1924 and 1991.
3. 48 states: after Arizona and New Mexico joined in 1912 and before Alaska and Hawaii in 1959. The Panama Canal opened in 1914. So the map was made between 1914 and 1959.
4. (1) It shows the Strait of Magellan, so it is not before Magellan's voyage of 1520. (2) It shows no real Australia, only an imagined southern continent, which fits a date before the Dutch first charted part of Australia's coast in 1606. (Also acceptable: the bulging southwest coast of South America, later corrected.)
5. A forger can copy names, shapes and styles from genuine old maps, so content and style clues can be faked. But a forger working in the 1900s could not easily avoid the materials of his own time. The ink contained anatase titanium dioxide, a pigment only manufactured from the

1920s, so the ink could not have been put on the parchment around 1440. A chemical clue like this sets a firm “not before” date that pictures and names cannot hide.

9.4 GIS TREASURE HUNT

OBJECTIVES

- Overlay map layers and apply rules to find the one place that fits them all, the basic question of GIS.
- Convert GPS coordinates between decimal degrees, degrees and decimal minutes, and degrees, minutes and seconds.
- Design and run a family treasure hunt that uses layered clues and GPS coordinates.

Warm-up. Lay three sheets of tracing paper (or clear plastic sleeves) over a printed map of your neighborhood. On the first, color the water; on the second, the parks; on the third, the busy roads. Stack them. Where is a quiet green place near water and away from traffic?

Watch. *What is Geocaching?* (Geocaching, 1:16). <https://www.youtube.com/watch?v=vuFiLhhCNww>

Before the hunt: what geocaching is, from Geocaching HQ.

Backup video. *How Do GPS Coordinates Work?* (BrainStuff - HowStuffWorks, 4:14). <https://www.youtube.com/watch?v=ALN7gXF1thY>

With How it works: how GPS coordinates are written and read.

KEY TERMS

GIS (geographic information system)

A computer system that stores maps as layers of data tied to locations, so you can stack them, measure them and ask questions.

layer

One kind of information on a GIS map, such as rivers, roads, parks, buildings or elevation.

overlay

Stacking layers to find places that meet several conditions at once.

decimal degrees

A way to write latitude and longitude as one number, such as 40.6892° N.

geocache

A small container hidden for others to find using posted GPS coordinates.

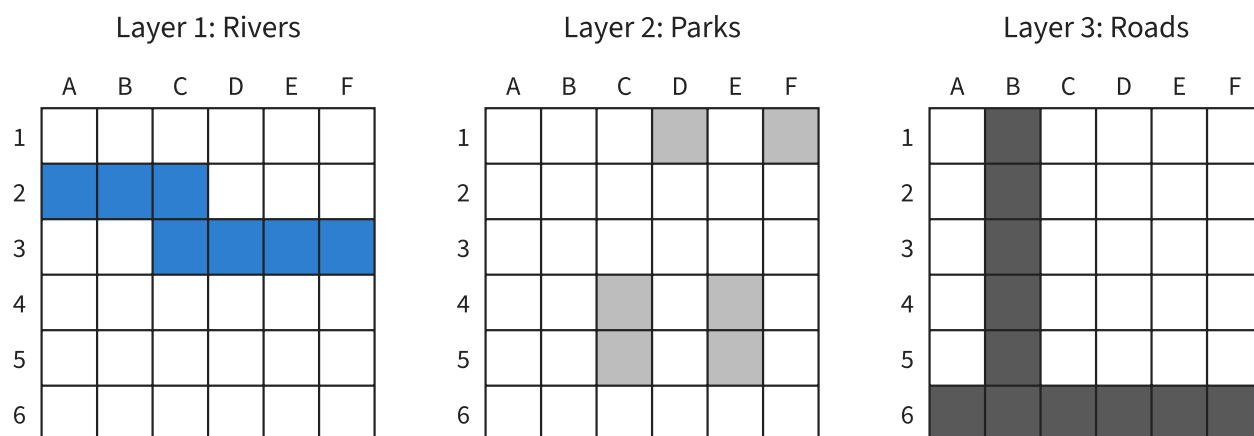
CORE IDEAS

The story. For years the U.S. military, which runs the GPS satellites, deliberately blurred the signal that ordinary people could use, a setting called Selective Availability. A civilian receiver could be off by about 100 meters (330 feet). On May 1, 2000, the White House announced that the blurring would end that night. The next day, people around the world

found that their GPS units were suddenly accurate to within roughly 10 to 20 meters. On May 3, 2000, a computer consultant named Dave Ulmer decided to test it. He hid a black bucket holding a logbook and a few small trade items in the woods near Beavercreek, Oregon, and posted its coordinates online, inviting others to find it. Within days, they did. The game of geocaching was born, and today people have hidden millions of caches around the world.

How it works. A GPS receiver tells you *where* you are. A GIS tells you *what is there* and helps you find places that meet several rules at once. In the 1960s the Canadian geographer Roger Tomlinson led the building of the Canada Geographic Information System to study the use of land across Canada; he is often called the “father of GIS.” The key idea is the overlay: put the rivers, the parks and the roads on separate layers, line them up exactly by their coordinates, and ask, “Which places are in a park, next to a river, and away from roads?” Planners use the same method to site a new school, firefighters to plan escape routes, and farmers to decide where to plant.

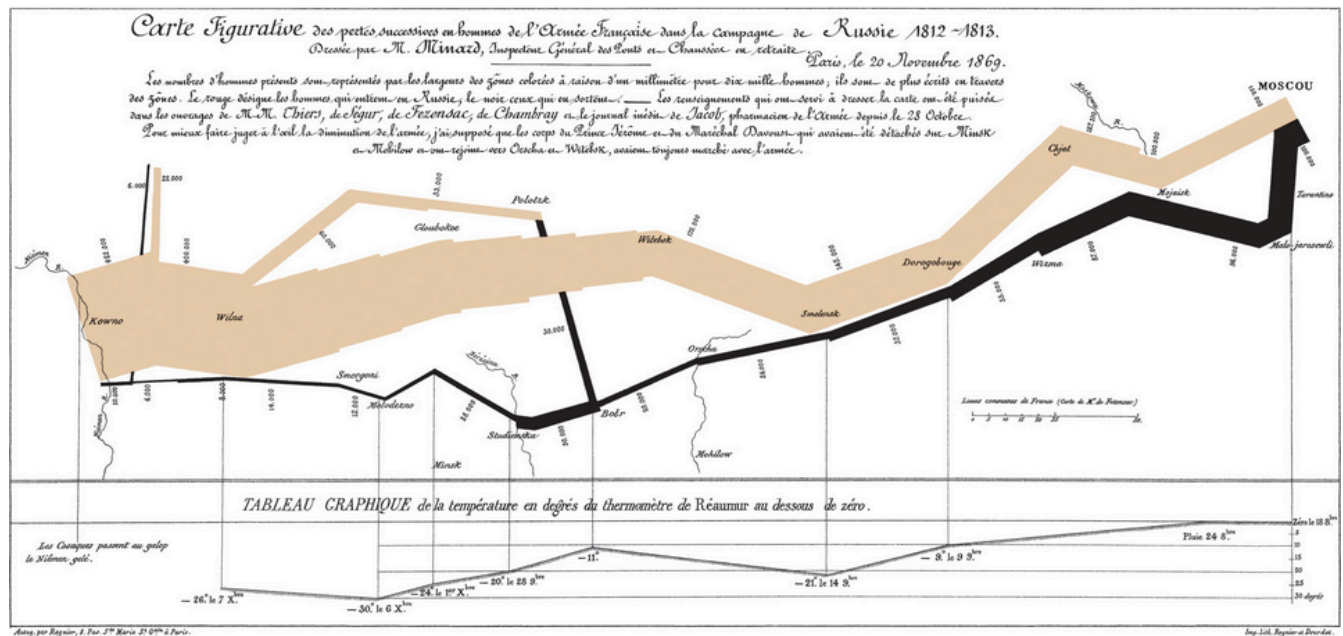
On the map. The figure shows three layers of the same 6×6 grid. Apply the rules one at a time: the treasure is in a park square; it shares a side with a river square; it does not share a side with a road square. Only one square passes all three tests. In the project you will build the same kind of puzzle for a real park, then send a partner off with layered clues and a phone GPS to find what you hid.



Columns A to F, rows 1 to 6. Overlay the layers to find the treasure square.

Three layers of the same area. Rule: the treasure is in a park square that shares a side with a river square but does not share a side with a road square.

PICTURE STUDY



Figurative Map of the Successive Losses in Men of the French Army in the Russian Campaign, 1812–1813, Charles Joseph Minard, 1869 · Lithograph, printed in color · Published in Paris; copies in libraries, including the library of the École nationale des ponts et chaussées

Charles Joseph Minard was a retired French civil engineer who loved to show numbers as pictures. In 1869 he drew Napoleon’s invasion of Russia of 1812 on a single sheet. The width of the tan band shows the size of the army as it marched toward Moscow; the black band shows the men who returned. The army that crossed the Niemen River at the start numbered about 422,000; only about 10,000 came back across it.

Below the map Minard added a graph of the bitter cold on the retreat, with dates. In one picture he stacked several layers of information: place, direction, the number of men, temperature and time. That is the heart of what a GIS does today.

Look closely

- Follow the tan band from left to right. Where does it get much thinner?
- Find the black band of the retreat. Find a place where it suddenly narrows at a river crossing.
- Look at the temperature graph at the bottom. How is it connected to the map above it?
- Count how many different kinds of information Minard put on one sheet.

Talk about it

1. Which “layers” of information does Minard combine? Which one tells the story most powerfully?
2. How is Minard’s map like John Snow’s cholera map (Lesson 7.4), and how is it different?

Safety first. Hide and hunt only in public places or on property where you have permission, with an adult. Never hide anything near roads, railroad tracks, water edges, steep drops, or in places that would damage plants. Do not share your home's coordinates online. If you join the public game of geocaching, a parent should manage the account.

PROJECT: THE FAMILY GIS TREASURE HUNT

You will hide a small “treasure” in a park or yard and give a partner two kinds of clues: a set of layer rules (like the figure) and a GPS coordinate. Your partner must use both to find it.

You will need

- A printed map or aerial image of a park, yard or school ground (from a free online map or your county's free GIS website)
- 3 sheets of tracing paper or clear plastic sheet protectors, and colored markers
- A phone or GPS unit that shows latitude and longitude (many free compass or map apps do)
- A small waterproof container with a notebook and a treat or trinket
- Ruler and pencil

Steps

1. Draw a grid on the base map (for example, 6 columns and 6 rows) and label it A to F and 1 to 6.
2. On three tracing-paper layers, color three kinds of features in the grid: for example water (pond, stream, birdbath), trees or gardens, and paths or the driveway. Line each layer up with corner marks.
3. Hide your treasure in one grid square. Write three layer rules that point to that square and to no other. Test them yourself by stacking the layers.
4. Stand at the treasure and read the coordinates on the phone. Write them in decimal degrees and convert them to degrees and decimal minutes.
5. Give your partner the base map, the three layers and the rules. Let your partner find the square first by overlay, then use the GPS reading to find the exact spot.
6. Switch roles. Then talk about which clue was more useful: the layers or the coordinates? Did the GPS put you right on the spot, or within a few meters?

Tips

- GPS on a phone is usually accurate to a few meters under open sky, but tall trees and buildings can make it worse. Layer clues help close the gap.
- Make sure your rules have exactly one answer. If two squares fit, add a rule.
- Your county probably has a free public GIS map (search your county name plus “GIS”). Try turning its layers on and off: parcels, flood zones, roads, schools.

Check your work

- My three layers line up, and my rules lead to exactly one square.
- I recorded my treasure's coordinates and converted them correctly.
- My partner found the treasure using my clues.

MAP NOTEBOOK

1. Draw the three layers of the figure as separate squares, then a fourth square with all three stacked. Color the treasure square gold.
2. Write the coordinates of your front door (keep them private) in decimal degrees and in degrees and minutes.
3. List five layers your county's GIS map has. Next to each, write one question it could help answer.

From history. GPS is a gift that Americans and the whole world use free of charge, but it was built for the military. After a Korean Air Lines passenger jet strayed off course into Soviet airspace and was shot down in 1983, President Ronald Reagan announced that GPS would be made available for civilian use once it was ready. The system reached full operation in the 1990s, and the end of Selective Availability in 2000 opened the way for car navigation, phone maps, precision farming and treasure hunts in the woods.

WORKED EXAMPLES

Example 1. The Statue of Liberty stands at about 40.6892° N, 74.0445° W. Write this (a) in degrees and decimal minutes, as geocachers do, and (b) in degrees, minutes and seconds.

1. Latitude: keep the 40° . Multiply the decimal by 60: $0.6892 \times 60 = 41.352'$. So $40^\circ 41.352'$ N.
2. For seconds, multiply the decimal minutes by 60: $0.352 \times 60 \approx 21.1''$. So $40^\circ 41' 21''$ N.
3. Longitude: keep the 74° . $0.0445 \times 60 = 2.670'$, so $74^\circ 02.670'$ W. Then $0.670 \times 60 \approx 40.2''$, so $74^\circ 02' 40''$ W.

Answer: (a) N $40^\circ 41.352'$, W $74^\circ 02.670'$. (b) $40^\circ 41' 21''$ N, $74^\circ 02' 40''$ W.

PRACTICE

1. **EASY** In the figure, the road in column B crosses the river. In which square is the bridge?
(Use the map or drawing "Compare Layer 1 and Layer 3." shown earlier in this lesson.)
2. **EASY** Apply the three rules in the figure. Which square holds the treasure? Explain how you ruled out the other park squares.
(Use the map or drawing "Park, beside the river, not beside a road." shown earlier in this lesson.)
3. **MEDIUM** Using the three GIS layers in the figure (the same grid as Problems 1 and 2), which park squares touch neither a river square nor a road square (sharing a side)?

4. **HARD** A geocache is listed at N 45° 17.460'. Write this latitude in decimal degrees. Then, since one minute of latitude is about one nautical mile (1,852 m), about how far north or south is 0.001', the last digit a geocacher reads?
5. **CHALLENGE** Before May 2000, a civilian GPS reading could be off by about 100 m; afterward, by about 10 m in good conditions. Compare the areas of the circles a searcher would have to cover ($A = \pi r^2$). In one or two sentences, explain why geocaching began right after the change.

COMMON MISTAKES

- Treating decimal minutes as seconds. 41.352' is not 41' 35"; multiply the decimal part by 60 to get seconds (21").
- Forgetting the sign or letter. West longitudes are negative in decimal form (−74.0445), and dropping the W puts you in the mountains of Central Asia instead of New York Harbor.
- Using layers that do not line up. Every layer must be registered to the same coordinates, or the overlay gives wrong answers.

Make it a game • Layer Riddles. One player secretly picks a square on a gridded map of your town or yard and gives one layer rule at a time ("It is next to water." "It is not on a road."). After each rule, the others cross out squares that no longer fit. The first to name the square correctly wins the round and becomes the next riddler. A wrong guess sits out until the next rule.

Scripture. "Again, the kingdom of heaven is like unto treasure hid in a field; the which when a man hath found, he hideth, and for joy thereof goeth and selleth all that he hath, and buyeth that field." (Matthew 13:44, KJV)

A treasure hunt is fun, but Jesus spoke of a treasure worth more than everything we own. Like the man in the field, we rejoice when we find what is truly valuable.

Practice answers

1. B2, where the road in column B meets the river square.
2. E4. Only C4 and E4 share a side with a river square (C3 and E3). C4 also shares a side with B4, a road square, so it is ruled out. D1, F1, C5 and E5 do not touch the river.
3. D1 and F1. (C4, C5 and E5 touch a road; C4 and E4 touch the river.)
4. $17.460 \div 60 = 0.291$, so 45.291° N. $0.001' \approx 1,852 \times 0.001 \approx 1.85$ m, about 6 feet.
5. 100 m radius: $\pi \times 100^2 \approx 31,400$ m² (about 7.8 acres). 10 m radius: $\pi \times 10^2 \approx 314$ m². The search area shrank about 100 times. A hidden container could now be found in minutes instead of searching an area the size of several football fields, so a GPS treasure hunt finally became a fair game.

UNIT 9 REVIEW

Answer each question. Show your work for calculations and use complete sentences for explanations. The review is worth 60 points.

1. (10 pts) On a 1:10,000 orienteering map, a leg measures 3.5 cm. (a) How long is the leg on the ground, in meters and in feet? (b) You walk the leg on a bearing of 300° . What bearing would take you straight back?
2. (10 pts) Explain what an attack point and a catching feature are, and why a good orienteer uses both on a hard leg.
3. (10 pts) A ship sails 9,000 nautical miles at 18 knots. (a) How many days does it take? (b) Give the distance in kilometers and miles.
4. (10 pts) Name, in order, four straits or canals a ship passes on the Suez route from Shanghai to Rotterdam. Then explain what a shipowner must weigh if the Suez Canal is closed.
5. (10 pts) A map of Europe shows a finished Panama Canal on its world inset and calls the Russian capital of the tsars "Petrograd." Petrograd was renamed Leningrad in 1924. Bracket the date of the map, and name which clue gives "not before" and which gives "not after."
6. (10 pts) (a) Convert 38.8977° N, 77.0365° W (near the White House) to degrees, minutes and seconds. (b) In one or two sentences, explain what a GIS overlay is and give one real use.

UNIT PROJECT: MY MAP LAB GAME BOX

Gather the four games of this unit into one box or folder that another family could play: your orienteering race map with its leg table and results, your Port Tycoon board with its contract and event cards and your ledger, your Map Detective case files and clue timeline, and your GIS treasure hunt layers, rules and coordinates. Add a one-page instruction sheet for each game and a short paragraph on which game taught you the most about real geography and why.

- **Accuracy:** Distances, bearings, sea days, date brackets and coordinates are correct and clearly labeled.
- **Playability:** Rules are clear enough that another family could play each game without help.
- **Records:** Race results, trade ledgers and case files are complete, dated and correctly added.
- **Care and reflection:** Maps and boards are neat and colorful, and the closing paragraph explains clearly what each game shows about real geography.

Answer key

1. (a) $3.5 \text{ cm} \times 10,000 = 35,000 \text{ cm} = 350 \text{ m}$, about 1,150 ft. (b) $300^\circ - 180^\circ = 120^\circ$.

2. An attack point is an easy-to-find feature close to the control from which you make a short, careful approach on a bearing. A catching feature is something just beyond the control (a road, fence or shore) that tells you that you went too far. Together they let you run fast for most of the leg and still find the control without wandering.
3. (a) $18 \times 24 = 432$ nautical miles a day; $9,000 \div 432 \approx 20.8$, about 21 days. (b) $9,000 \times 1.852 \approx 16,700$ km; $9,000 \times 1.151 \approx 10,400$ miles.
4. Any four in order: the Strait of Malacca (Singapore Strait), Bab-el-Mandeb, the Suez Canal, the Strait of Gibraltar, the Strait of Dover (English Channel). If Suez is closed, the owner must weigh waiting against sailing about 3,500 nautical miles (about a week) farther around the Cape of Good Hope: extra fuel and wages, late deliveries and tied-up ships versus saving the canal toll.
5. Not before 1914 (the Panama Canal opened, and the city took the name Petrograd that year). Not after 1924 (the city became Leningrad). The map was made between 1914 and 1924.
6. (a) $0.8977 \times 60 = 53.862'$; $0.862 \times 60 \approx 51.7''$, so $38^\circ 53' 52''$ N. $0.0365 \times 60 = 2.19'$; $0.19 \times 60 \approx 11.4''$, so $77^\circ 02' 11''$ W. (b) An overlay stacks map layers that share the same coordinates to find places that meet several conditions at once; for example, planners find land that is near roads but outside flood zones for a new school.