EDUCATION

Water Lessons Unit 1—Water and Food

Grades 4-12

www.H2Oconserve.org | info@H2Oconserve.org | t: 212-726-9161 | f: 212-726-9160

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Project Manager:
Kai Olson-Sawyer, H_2O Conserve
kai@h2oconserve.org

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H_2O Conserve
215 Lexington Avenue, Suite 1001
New York, NY 10016
tel: 212 726 9161 | fax: 212 726 9160
info@h2oconserve.org
www.h2oconserve.org

H_2O Conserve Staff:
Kai Olson-Sawyer, Program Manager
Robin Madel, Research Associate
Regina Weiss, Communications Coordinator

Contributing Authors:
Timothy Donahue
Regina Weiss

Contributing Editors:
Regina Weiss
Robin Madel
Kai Olson-Sawyer

Water and Food

This unit explains how water is used to provide food, with primary focus on the United States.

Irrigation

Acre for acre, irrigated cropland is far more productive than rain-watered cropland. At the height of the "Green Revolution" in the late 1960s and early 1970s, irrigated land was expanding at a global rate of more than two percent per year. Since then, annual growth in irrigated acres has slowed to about one percent.

Seventeen percent of the world's cropland is irrigated, producing 40 percent of the world's food. Large-scale irrigation allows for significant increases in crop efficiency and yield, while also creating some significant environmental problems.

Thirty-four percent of all water used in the United States goes to irrigation. Here's where the rest goes, according to the U.S. Geological Survey (USGS):

- Thermoelectric Power (48 percent): Water used in generating electricity with steam-driven turbines and in cooling the machinery. Of this, about 70 percent is fresh water; the rest is salt water.
- Public Supply (11 percent): Water withdrawn by private or public water distributors, such as municipal governments, that furnish water to at least 25 people or have a minimum of 15 connections. This is where the majority of U.S. residents get their water.
- Industrial (5 percent): Water used for fabricating, processing, washing, diluting, cooling, or transporting a product. Industrial use also includes water incorporated into a product, or for sanitation needs within a manufacturing facility
- Other (Livestock, Mining, Aquaculture; 2 percent):
    - Livestock: Water associated with raising livestock (does not include water used to grow, process or transport the feed the animals consume);
    - Mining: Water used in the extraction of coal, iron, sand, gravel, natural gas, petroleum, and other in-ground resources; and

- Aquaculture: Water used to farm fish for food, restoration, conservation or sport.

Different irrigation methods vary widely in the amount of water used. While drip irrigation uses the least amount of water, flood and spray irrigation cost less to install, and are much more common.

Flood irrigation accounts for 47 percent of water used for irrigation worldwide. Water is pumped or otherwise brought to the fields and allowed to flow along the ground among the crops. However, about half of the water runs off and does not get to the crops, while more is lost through evaporation.

Efficiency measures can decrease the water loss with flood irrigation. For example, leveling scrapes fields flat, allowing water to flood the land more evenly and decreasing runoff. Runoff ponds allow farmers to capture water that would otherwise be lost so that it can be pumped back onto fields.
Surge flooding releases water at timed intervals, saturating furrows and then allowing them to dry out. The dry soil allows the next round of flooding to penetrate deeper into the furrow. It is absorbed quickly, increasing efficiency by decreasing evaporation and runoff.

Drip or micro irrigation accounts for seven percent of water used for irrigation worldwide. Water is sent through plastic pipes with many tiny holes that are either laid down along the rows of crops above ground or buried along plant root-lines underground. Drip irrigation cuts in half water loss by evaporation when compared to flood irrigation.

Forty-six percent of water used for irrigation is sprayed, generally by equipment that can be moved from place to place through the field. **Spray irrigation** systems cost less than drip irrigation, but waste more water. Particularly in dry or windy areas, a significant amount of water evaporates or blows away before it hits the ground. With typical spray irrigation about 40 percent of the water is lost.

One of the less wasteful types of spray irrigation is **Low Energy Precision Application (LEPA)**. With LEPA, small sprayers hang down from a pipe closer to crops and water is released gently from nozzles. With LEPA irrigation about 10 percent of the water is lost. Energy use is also reduced.

In 2000, of the 61.9 million total irrigated acres of cropland in the U.S., flood irrigation accounted for about 29.4 million acres, another 28.3 million acres were spray irrigated, with the remaining 4.2 million acres drip irrigated. The average application rate was 2.48 acre-feet per acre for the United States.

Table 1. Select States with Large Irrigation Areas and Percent of Irrigation Method Used

State	Acres irrigated	Percent flooded	Percent spray irrigated	Percent drip irrigated
California	10,100,000	54	16	30
Nebraska	7,820,000	53	47	0
Texas	6,490,000	37	62	1
Arkansas	4,510,000	86	14	0
Idaho	3,750,000	35	65	<1
Colorado	3,400,000	65	35	<1
Kansas	3,310,000	20	80	<1
Oregon	2,170,000	47	53	<1
Florida	2,060,000	41	25	34
Montana	1,720,000	71	29	0
Washington	1,570,000	16	81	3
Wyoming	1,160,000	84	16	<1

Source: U.S. Geological Survey

Government subsidies for irrigation

To ensure a reliable and affordable supply of food, the federal government subsidizes the cost of water used for agriculture, keeping it artificially low, thereby encouraging farmers to grow water-intensive crops in dry regions. For example, in some places, such as California's Central Valley, farmers pay only 5 percent of what their non-farming neighbors pay for water from the same source.

Similarly, while tremendous amounts of energy are used to pump water to farmland, the cost of this electricity is kept artificially low through subsidies. Thus, farms served by California's Central Valley Project (CVP) the largest taxpayer-funded irrigation system in the country, pay one-fifteenth (7 percent) of what nearby residents do for electricity. The farms use this subsidized electricity in vast quantities to pump water to irrigate their fields. Each year, CVP moves over two trillion gallons (18 percent of California's fresh water supply) through 1,437 miles of canals to thousands of farms in the area. The energy this uses could power the homes of 105,000 residents in nearby Chico for

18 months. But unlike the residential electric rates, CVP rates are not subject to the volatile energy market.

This taxpayer funding for water and the electricity used to pump it allows farmers in arid areas of the country to grow water-intensive crops even in times of drought, but does nothing to encourage water conservation. In fact, in some of the driest regions, state laws actually discourage water conservation through "prior appropriation" policies that entitle some farmers to an unlimited amount of water.

The U.S. Department of Agriculture (USDA) estimates that 10 percent of the nation's growers receive 78 percent of our annual farm subsidies, but large farms don't necessarily make the most efficient use of resources, including water.

Environmentalist and author Ken Midkiff illustrates how subsidies promote the farming of water-hungry crops in dry climates:

> For every ear of corn grown in the Central Valley (California), that means one fewer ear in the Ohio Valley, with the former requiring much government water and the latter needing no amount other than what is provided from the sky…

Another example:

> [G]rowing rice uses a lot of water. Fields are leveled, a 12-inch or so berm (dirt ridge) is placed around the fields, and then the rice fields are flooded with water. It makes little sense for rice to be raised in the desert and then to be rewarded for that by millions of dollars of federal subsidies—but that is exactly what happens. Growing rice in the Central Valley of California—a former desert in the summer—brings in literally billions of dollars to rice-growing agribusinesses. The most farm subsidies that were received in the entire state of California went to a company with its headquarters in Sacramento County, in the heart of the Central Valley. That rice-growing company received $143.5 million in taxpayers' money from 1995-2004.

Questions for assignment or discussion

- Explain the difference between efficient and wasteful crop irrigation.
- What are the benefits and costs of subsidizing water for agriculture?

For further research

Without spending more money, are there ways that U.S. farmers could irrigate more efficiently? Explain your answer.

Where is drip irrigation being used in the developing world? Describe one success story with efficient irrigation and ideas for further success in the region.

Ground water and subsidence

Ground water is water that flows or seeps downward and saturates soil or rock, supplying springs and wells. Surface water is found on the Earth's surface in streams, rivers, lakes, reservoirs and oceans.

Of all the fresh water Americans use each year, 21 percent comes from groundwater and 79 percent comes from surface water. More fresh water goes to irrigation than any other single use. In 2000, 68 percent of the ground water and 31 percent of the surface water used in the United State went to irrigation.

Stretching under the High Plains, including most of Nebraska, western Kansas, eastern New Mexico, eastern Colorado and the Texas and Oklahoma panhandles is the mammoth Ogallala Aquifer, which provides fully one-third of the water used to irrigate crops in the United States. Home to only one percent of the U.S. population, this region accounts for nearly a third of the nation's agricultural revenue. Today the Ogallala is rapidly being depleted due to ongoing water withdrawals that are too massive to be replenished by the region's precipitation.

When large amounts of groundwater are withdrawn from the Earth and are not replenished by rain and snowfall, soil begins to sink. This sinking of the soil, called subsidence, strongly suggests that aquifers are on the decline. For example, in California's San Joaquin Valley, the land surface has dropped from 20 to 35 feet over the past 50 years as both development and irrigation have increased demands on underground water supplies.

The City of New Orleans is known to be subsiding at least one inch per year, with outlying regions that pump water for oil and gas extraction having subsided at least 10 feet over the past century. Some of the levee failures during Hurricane Katrina in 2005 were in places where subsidence was the highest, suggesting that it may have played a role in the breach.

Near Picacho, Arizona, groundwater pumping has caused huge cracks in the land, one of which, in 2004, measured 10 miles long and at least 100 feet deep, varying in width from 1 to 30 feet.

According to the USGS, 17,000 square miles of the United States, an area roughly the size of Vermont and New Hampshire combined, are affected by subsidence, more than 80 percent of it due to the removal of groundwater.

Transporting water for crops

Two centuries ago, most Americans lived in the eastern part of the United States and 90 percent of the labor force was involved in farming. Westward expansion led to larger farms and, as technology evolved, mechanization of farming and large water withdrawals for crop irrigation.

Over time the United States developed a huge infrastructure to move water from one place to another. Life as we know it today could not exist without pipelines and aqueducts, which effectively bring water to wherever it is needed. Thousands and thousands of miles of aquifers and pipeline are behind just about every meal eaten in the United States, which is also home to the world’s longest aqueducts. The major ones are:

- The Catskill Aqueduct: from New York’s Catskill Mountains to New York City: 120 miles;
- The Los Angeles Aqueduct: from Owens Valley to Los Angeles: 223 miles;
- The California Aqueduct: from the Sacramento Delta to Lake Perris: 444 miles;
- The Central Arizona Project Aqueduct: from Lake Havasu City to central and southern Arizona: 336 miles; and

- The Lewis and Clark Rural Water System: a system within southeast South Dakota, southwest Minnesota, and northwest Iowa: a proposed plan calls for 337 miles of pipeline that will be more secure than the current aging system.

The ability to move large amounts of water has allowed us to develop farms and cities in the desert, but also led to the depletion of our major water sources. For example, throughout the Southwest, the once mighty Colorado River provides water for farming and development. But while the Colorado once flowed with over 20 million acre-feet of water per year, in 2002, a year of drought, just 3 million acre-feet coursed through its bed. Since 2002 the Colorado's flow has averaged just 7 million acre-feet per year, roughly a third of the water that once defined it as one of the world's great rivers. Since 1993 the river has been so depleted that it no longer reaches the Sea of Cortez. Lake Mead and Lake Powell, created to store up to four times the river's annual flow, have been at or near historic lows for many years, with no evident prospect of being replenished.

Depletion of rivers like the Colorado is a problem involving many stakeholders that will require sifting through complex political, economic, social and environmental considerations to solve. The Colorado not only feeds crops, but growing cities, hydropower plants, and wildlife – all increasingly at risk due to the river's depletion.

Food for thought

See if you can guess how water gets to the major agricultural regions, listed below. It may be more complicated than you think!

A. Nebraska Livestock Farm
B. Yuma, Arizona, 170 miles east of San Diego, the winter lettuce capital of the world
C. Central Valley, California, a 400-mile long valley in central California
D. Centerville, South Dakota, 40 miles southwest of Sioux Falls
E. Long Island Wine Country, Long Island, New York

Answers

A. Beneath more than half of Nebraska's 50-million acre land surface, about 2 billion acre-feet of good quality groundwater is available in the porous rock bed called the Ogallala Aquifer.

B. Additionally, the state receives, on average, 80 to 100 million acre-feet of annual precipitation.

C. Yuma, Arizona is right on the Colorado River. Nearby, the Imperial Dam receives river water, where it is desalinated and flows to one of three conduits, one of which is the Yuma Project Aqueduct, which provides water to the Yuma community and irrigates about 55,000 acres.

D. California's Central Valley Basin includes two major watersheds—the Sacramento River on the north and the San Joaquin River on the south—plus the Tulare Lake Basin. The Sacramento River, the state's longest at 447 miles, begins on the 14,179-foot Mt. Shasta, in the Sierra Nevada range, and flows into the Sacramento Delta. The San Joaquin River, California's second largest at 330 miles, begins on the western slopes of the Sierra Nevada Mountains. The Central Valley, the nation's richest agricultural region, is heavily dependent on snowmelt from these mountains.

E. Centerville is near the Missouri River, which forms South Dakota's border with Nebraska. Centerville's water needs are currently supplied by three wells fed by an aquifer fed by the Missouri River, a system unlikely to pass increasingly stringent water testing. When construction is completed in 2019, the $374 million Lewis and Clark Rural Water System will deliver water to Centerville by diverting river water to an aqueduct and water treatment plant near Vermillion, South Dakota. From here, the water will enter the Lewis and Clark system's 337 miles of pipeline.

F. On Long Island, the primary source of water is a vast underground aquifer. More than 1,000 wells serve the area's communities, tapping into one of the nation's most critical sole-source aquifers. Of these 1,000 wells, the three largest provide 375 million gallons of water each day. Sole-source, a term used by the federal Environmental Protection Agency, designates a groundwater source that at least 50 percent of a community relies on for drinking water, underscoring the need to protect the source from contamination.

Questions for assignment or discussion

- In Duluth, Minnesota, where the daily average temperature in January is 7°F, supermarkets can have ten different varieties of fresh lettuce for sale. What are some of the benefits and costs involved in having such a variety of produce available during Duluth's winter season?

- What kind of conflicts may arise in the future over the Colorado River among those who depend on it for water?

For further research

Considering New Orleans' consistent subsidence due to groundwater withdrawal, what factors might be used to determine whether the levees should be rebuilt there? From an engineering perspective, what is the best course for New Orleans's future?

Virtual water: The unseen water in our food

Every fruit, vegetable, and slice of meat requires water for its production, and travels, on average, 1,500 miles before reaching grocery store shelves. The water used to grow, process, package, refrigerate and transport food is generally overlooked by consumers because we don't see it when we buy and eat our food. The term "virtual water" has been coined to describe this unseen water that is inherent in the products we use, from paper to plastic to clothing and just about every item we purchase or consume. Virtual water is by far the largest part of our "water footprint."

The water in our meat

Animal protein has an especially large water footprint because vast amounts of water are used to grow the feed consumed by the animals that are then butchered and packaged to supply our meat. This is an increasingly important consideration as meat production has grown nearly 500 percent since 1950 and demand continues to increase worldwide. Even a small reduction in the animal protein we consume can reduce our water footprint without depriving our bodies of nutrition.

> We each consume something like 110 grams of protein a day, about twice the federal government's recommended allowance; of that, about 75 grams come from meat. It's likely that most of us would do just fine on around 30 grams of protein a day, virtually all of it from plant sources.
>
> — Mark Bittman, *The New York Times*

In the United States, where the annual consumption of grain as both food and animal feed averages 1,760 pounds per person, a modest reduction in the consumption of animal protein could easily save thousands of gallons of fresh water over the course of a year.

Reducing the energy required to pump the water used in meat production would also result in enormous fuel savings, as would reducing the importation of grain and meat. Furthermore, reducing energy use reduces water use because, as noted earlier, thermoelectric power plants account for 48 percent of U.S. water use.

Generally, meat, dairy, and processed foods require far more water to produce than unprocessed fruits, vegetables, and whole grains, and it's staggering to realize how water pools up behind our food. Even a seemingly harmless bread and cheese sandwich takes a flood, with 156 gallons needed to produce a pound of wheat and 600 gallons needed to make a pound of cheese. Adding a glass of milk requires another 65 gallons of water!

Estimates vary, but suggest that it takes between 7 and 15 pounds of grain to produce a pound of beef. This means that 8 percent of worldwide water use goes toward irrigating feed crops for cattle. The resulting manure from all this feed also threatens our water supply. While some manure can be an agricultural resource, the amounts produced by factory farms exceed the capacity for nearby cropland to absorb, transforming manure from an asset to a dangerous liability. Nitrates, heavy metals, and antibiotics in the manure seep into the groundwater and surface water, polluting rivers, ponds, lakes, and streams, all while creating significant health risks.

Table 2. U.S. Per Capita Meat Consumption: 1950-2007*

Year	Chicken	Turkey	Veal	Lamb	Beef	Pork	Total
	(retail cut equivalent to 1 lb. per person)						
1950	21	3	7	4	44	65	144
1955	21	4	9	4	56	62	156
1960	28	5	5	4	59	59	161
1965	33	6	4	3	70	52	169
1970	40	6	2	3	82	55	189
1975	39	7	3	2	85	43	178
1980	47	8	2	1	75	57	190
1985	52	9	2	1	77	51	194
1990	61	14	1	1	66	49	193
1995	69	14	1	1	65	51	202
2000	77	14	1	1	67	51	211
2001	77	14	1	1	65	50	208
2002	81	14	1	1	67	51	215
2003	82	14	1	1	64	52	213
2004	85	13	0	1	65	51	216
2005*	86	17	1	1	65	50	219
2006*	87	17	1	1	65	49	220
2007*	87	17	1	1	66	51	222

* Data for 2005 are estimates; data for 2006 and 2007 are projections
Source: USDA, Economic Research Service, 2006

Altogether, Americans are eating nearly 80 pounds more meat per person annually than they were in 1950, with the most significant rise coming in chicken consumption, up 66 pounds per person. Both pigs and chickens, which convert grains to meat more efficiently than cows do, have gained market share. However, beef, which needs six times as much water to produce as chicken, has also seen increased consumption.

Food industry expert, John Robbins, uses the following analogy to illustrate the virtual water in animal protein: If you shower each day for seven minutes, and this shower uses two gallons of water per minute, you use 14 gallons a day to shower, or roughly 100 gallons a week. With this as a yardstick, you would have to skip showering for an entire year to conserve the water used to produce a single pound of beef!

The water in our produce

Typically, vegetables require between 18 and 36 inches of water to grow. Eighty percent of U.S. produce is grown in the west where it requires irrigation, while 80 percent of the nation's rain falls in the east. For example, California grows half the country's vegetables, but receives less than 10 inches of rain per year.

Especially in winter, California's crops are really the nation's crops. Meanwhile, California is experiencing drought, severe water shortages and mandates for water conservation. With a population expected to swell from its current 37 million to between 44 and 48 million by 2025, California's continued agricultural viability is open to debate. More efficient watering techniques, such as drip irrigation, could improve the outlook, but these systems are expensive and are not widely used for that reason today.

As the chart below illustrates, much of the nation's food is grown in areas without insufficient rainfall to grow the crops planted there, necessitating irrigation. Is this necessary and sustainable?

Table 3. "World Capitals" for select fruits and vegetables, with average annual rainfall

Vegetable	City / State	Inches rain / year
Artichoke	Stockton, CA	16.6
Apricot	Patterson, CA	11.45
Avocado	Fallbrook, CA	13.21
Broccoli	Greenfield, CA	18
Carrot	Holtville, CA	2.87
Celery	Arvada, CO	18.17
Corn	Olivia, MN	25.9
Cucumbers	Wauchula, FL	50.4
Garlic	Gilroy, CA	20.6
Grape	Lodi, CA	18.2
Lettuce	Yuma, AZ	3
Melons	Rocky Ford, CO	11.8
Onions	Elba, NY	35.5
Pear	Kelseyville, CA	31
Prunes	Yuba City, CA	22
Radish	Long Beach, MS	65.2
Raisins	Fresno, CA	11.2
Spinach	Crystal City, TX	20.7
Strawberries	Watsonville, CA	23.2
Tomatoes	Jacksonville, TX	26
Watermelon	Hope, AR	54.3

Sources: Claims to Fame (self-proclaimed)

Fuel is required both to run farm machinery and to transport fruit and vegetables thousands of miles to market, all of which entails the use of hidden or "virtual" water. According to the National

Renewable Energy Laboratory, each gallon of fossil fuel used to make gasoline or diesel requires from 2 to 2.5 gallons of water to refine. A typical diesel tractor burns 3.5 gallons of fuel per hour, giving it a large water footprint – about seven gallons of water per hour of use.

As author Michael Pollan has explained in great detail, an organic salad from California eaten in New York takes about 57 calories of fossil fuel energy to produce for every calorie of food energy it provides.

On its way to market produce is machine agitated, power-washed, fan-dried, refrigerated, and kept from freezing, all of which takes electricity. Water used to generate that electricity adds to the virtual water in the fruits and vegetables we consume.

Plastic carrying tubs, plastic packaging, and plastic irrigation lines are also all made from petroleum, the refining of which takes a great deal of water.

Finally, some packaged vegetables are washed three times before they are sent off to market, a more direct use of water but one that is nevertheless hidden to the consumer who purchases the washed produce.

While not used for food, cotton farming provides another striking example of inefficient water use and virtual water hidden in everyday products. Arizona tops the nation's list of arid states, yet Arizona farmers grow enough cotton each year to make more than one pair of jeans for every person in the United States. This cotton, which requires from two to four feet of water to grow, is cultivated in a state with an average rainfall of only 12.7 inches, and which is currently in its second decade of a long-term drought.

How wet is your food?

Water specialists from the University of California Agricultural Extension, working with livestock farm advisors, calculated the amount of water used to produce specific foods, as shown in the chart below.

Table 4. Amount of Water Needed to Grow Select Foodstuffs

Food type (1 lb.)	Water volume to produce food type
Lettuce	23 gallons
Tomatoes	23 gallons
Potatoes	24 gallons
Wheat	25 gallons
Carrots	33 gallons
Apples	49 gallons
Chicken	815 gallons
Pork	1,630 gallons
Beef	5,214 gallons

Source: *The Food Revolution*, 2001

Water used in transporting food

There are 143,361 miles of track for freight trains in North America, and nearly 50,000 miles of superhighway in the United States, all of which facilitates the long-distance movement of our food. Trucks and trains require vast quantities of oil and electricity to run which, in turn, requires huge amounts of water to produce. For example, it takes from 35 to 90 gallons of water to refine one barrel of crude oil. On average, it takes 2.2 billion gallons of water each year to cool a coal-fired thermoelectric power plant. If the nation moves to "clean coal" technology, the amount of water used is projected to increase by 90 percent – nearly double the already huge amount required to run today's coal-fired plants. Machinery used in farming also adds to foods' virtual water footprint derived from fossil fuels, with a typical diesel tractor burning 3.5 gallons of fuel an hour.

Water and fertilizer

Today's large scale agriculture is chemically-dependent. The huge applications of fertilizers and pesticides used to grow our food contain vast quantities of virtual water used in their production. In addition, runoff of these largely toxic chemicals into groundwater, fresh surface water, and the world's oceans create myriad environmental problems.

For example, when excess plant nutrients from fertilizer enter a pond or lake, it causes algae and zooplankton to overgrow, choking oxygen from the water, effectively stealing it from the fish and other water-dwelling creatures. Such an algae "bloom" can quickly kill off all other life forms in a body of water. This process, known as hypoxia, has created a dead-zone in the Gulf of Mexico, due to agricultural runoff from the Midwest's huge cornfields. In 2008 this dead zone was the size of the State of New Jersey and growing.

Questions for assignment or discussion

- Why does it require so much more water to produce a pound of animal protein than a pound of grains or vegetables?
- Describe three different elements of the virtual water in a bowl of salad.
- Articulate a thesis and response to this statement: "In America, people have the right to eat as much meat as they want!"

For further research

It has been said that the typical food item on an American plate has traveled 1,500 miles. Test this theory. Go to your local supermarket and try to determine the origin of select food items. Then calculate the distance they traveled to your market.

Is it possible to grow and raise foods that require less water, yet maintain comparable nutrition values to those we enjoy today? Explain your answer. What role can consumers, farmers and policymakers play in reducing virtual water consumption?

Farmers markets and Community Supported Agriculture (CSA) groups offer a potentially healthier, more sustainable alternative to large-scale agribusiness. Can smaller-scale operations feed the nation? Explain.