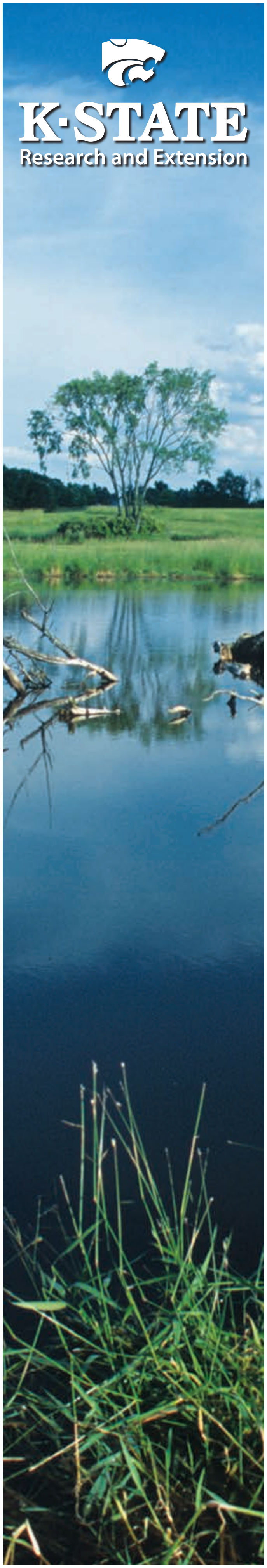

Water Primer: Part 9

The Kansas Water Budget and Water Footprint

Earth's overall water supply is fixed, as discussed in the water primer chapter on the hydrologic cycle (MF3021). Later chapters also discussed surface and groundwater supplies available in Kansas (MF3023 and MF3022, respectively). This discussion examines the Kansas portion of the hydrologic cycle and interaction of water supply sources and water-use demands, which can be called a water budget or water balance. This publication also discusses the concept of water footprint.

Water is a vital resource necessary to sustain most plant and animal life on Earth. The human demand for water, however, goes far beyond basic hygiene and water sustenance needs. The combination of direct and indirect water requirements used to maintain a society, whether highly industrialized or developing, is often referred to as the water footprint.

The idea of considering water use along supply chains has gained interest after the introduction of the "water footprint" concept by Hoekstra in 2002 (Hoekstra, 2003). The water footprint is an indicator of freshwater use that looks at the direct water use of a consumer or producer and at the indirect water use. Indirect, or virtual, water use is the water requirement to produce a product or service that a consumer is using.

It is difficult to measure these various sources directly, but Kansas agencies measure various hydrologic parameters that shed light on the total volume of these water resources.

Surface water is distributed unevenly across Kansas mainly because of the state's climate. With few exceptions,

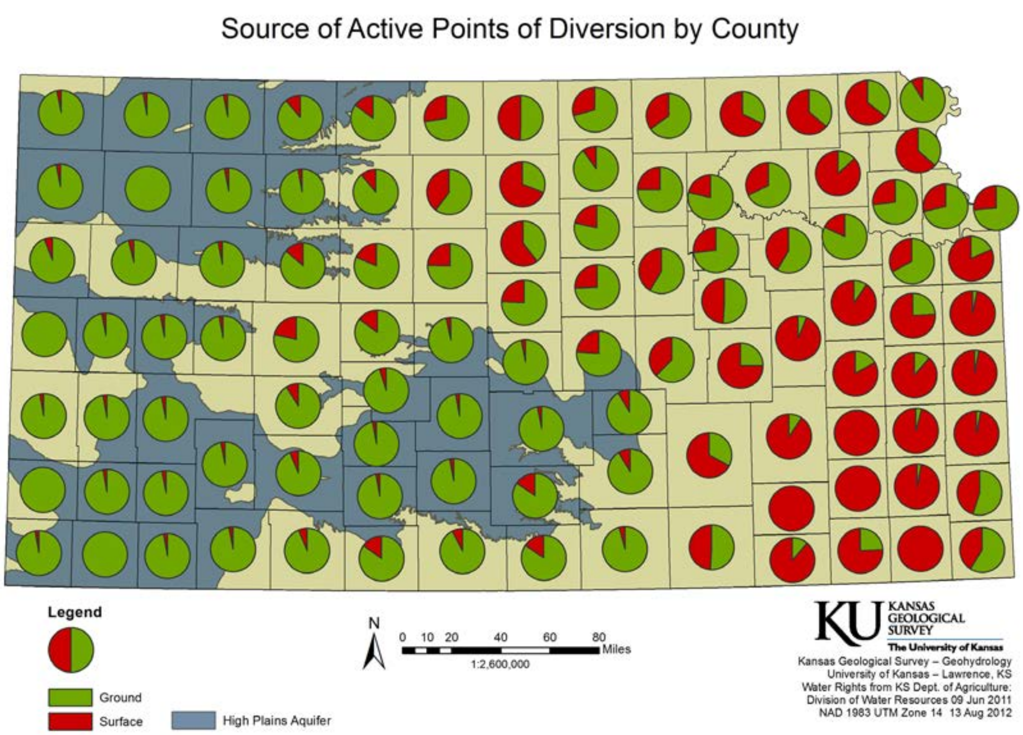

Figure 1: Proportion of surface and groundwater rights for counties in Kansas, year 2011 data (KGS, 2012).

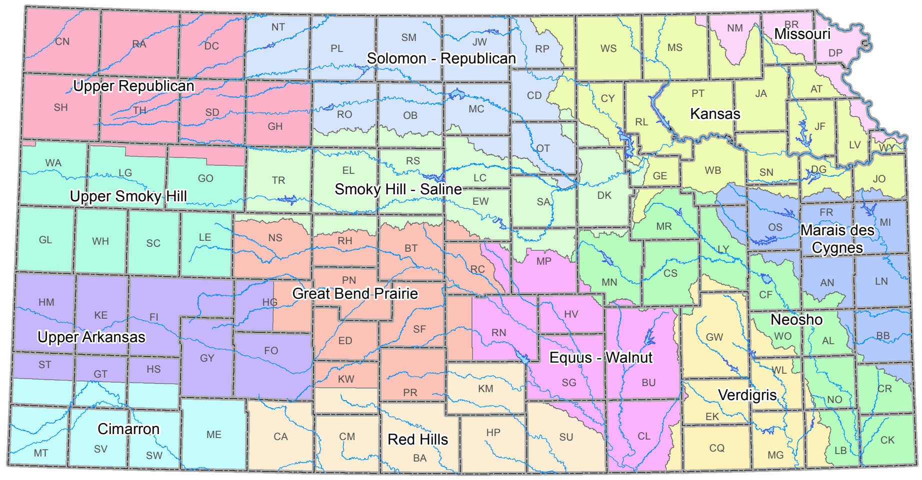

Figure 2a: Kansas river basins (Kansas Water Office, 2015).

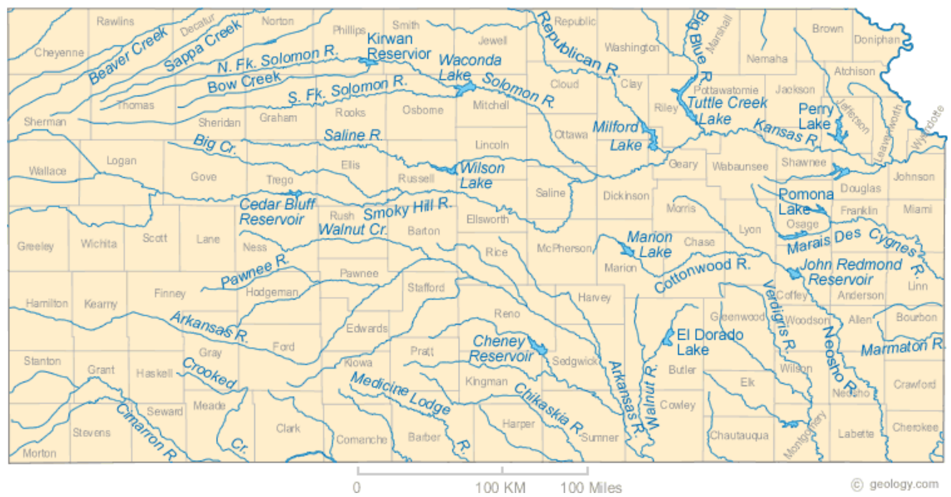

Figure 2b: Kansas rivers and reservoirs (Kenney and Hansen, 2004).

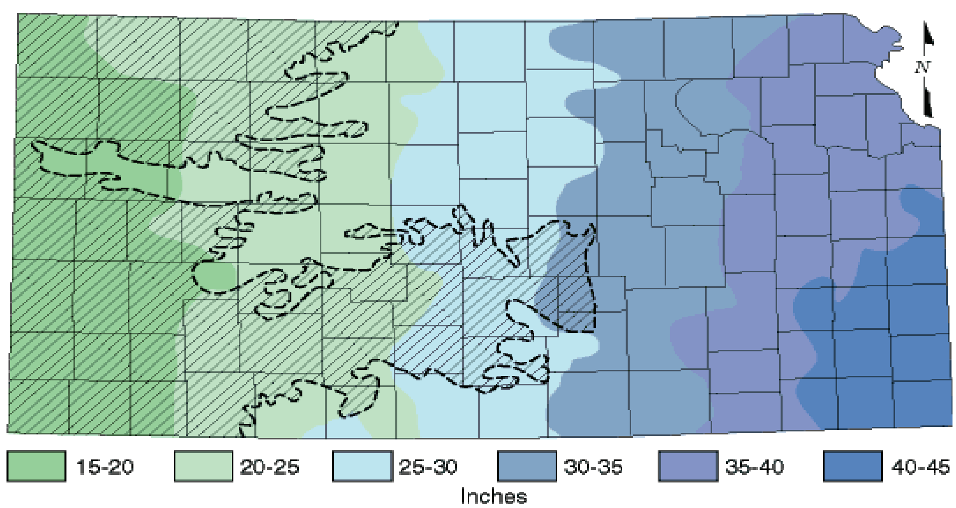

Figure 3: Normal annual precipitation (1960–1990) in Kansas. The area west of the dashed line shows the extent of the High Plains aquifer in Kansas (from Goodin, et al., 1995).

western Kansas has little surface water. Groundwater is the principal source of fresh water in most of this area. In contrast, groundwater is not easily accessible or available in sufficient quantity in most of eastern Kansas, where surface water is the principal source of large supplies (Figure 1).

To manage its water resources, Kansas is divided into 14 major river basins (Figure 2a), divisions based on the philosophy that areas drained by the same stream have many similar water issues.

Average annual rainfall ranges from 15 to 18 inches per year in far western Kansas to more than 40 inches per year in southeastern Kansas. Although this rainfall variation is significant (Figure 3), average annual runoff across the state varies much more than the precipitation. By comparison, the average runoff ranges from approximately 10 inches in the east (25 percent of precipitation) to 0.1 inch in the west (less than 0.6 percent of the precipitation), a 100-fold change in the runoff across the state (Figure 4).

Measured streamflow entering Kansas averages 1.7 million acre-feet annually. About 90 percent of this incoming streamflow is from southeastern Nebraska (Republican and Blue rivers); the semi-arid High Plains of eastern Colorado contribute little runoff to Kansas (Arkansas River). The flow in ungauged streams entering the state adds little to this total since most of the streams are dry except immediately following heavy rains. Precipitation falling over the state amounts to 118.7 million acre-feet in an average year, and about 13 million acre-feet per year leave the state as streamflow. The streams annually accumulate 11.3 million acre-feet of runoff within the state. Figure 5 illustrates these water-budget components for the state of Kansas.

Water Budget

A rough water budget for the state can be developed using information from Figure 5.

For a long-term balanced water budget, water supply or water inputs equal water outputs or:

Water Balance = Inputs – Outputs = 0.

Inputs, or supply components, for the state budget are precipitation and streamflow in. Outputs, or use components, for the state budget are streamflow out and ET (evapotranspiration or plant water use). In an undisturbed natural system over a long time period, these components are balanced or:

Water Balance = (Precipitation + Streamflow In) – (ET + Streamflow Out) = 0

However, even natural systems have water balance fluctuations. For example, in a naturally occurring lake, there are times when the lake is completely full and any flow to the lake is passed through to the water course below, but in periods of low inflow, the water level drops if inflow is less than the evaporative and seepage losses from the lake. At the end of a drought, when lake levels are low, the first high inflows into the lake are not passed through until the lake is full.

A groundwater aquifer can function like a surface reservoir by supplying water to a surface water stream. Water flowing from an aquifer to a stream is called baseflow. This is important during dry periods as it keeps water in the stream but decreases water in aquifer storage. The aquifer is recharged during wet periods and high water flow in the stream. Therefore, the water balance budget often includes a change in water storage as a term to balance the water budget or:

Water Balance = (Precipitation + Streamflow In) – (ET + Streamflow Out) + Change in Storage = 0

Figure 5 includes a component to represent a use directly influenced by human activities, labeled in the figure as "Water Use." Examples of water use include water diverted or managed by human activity for irrigation, municipal, industrial, recreational, and livestock watering uses. This adds an additional term to the water balance equation in the output portion of the equation as:

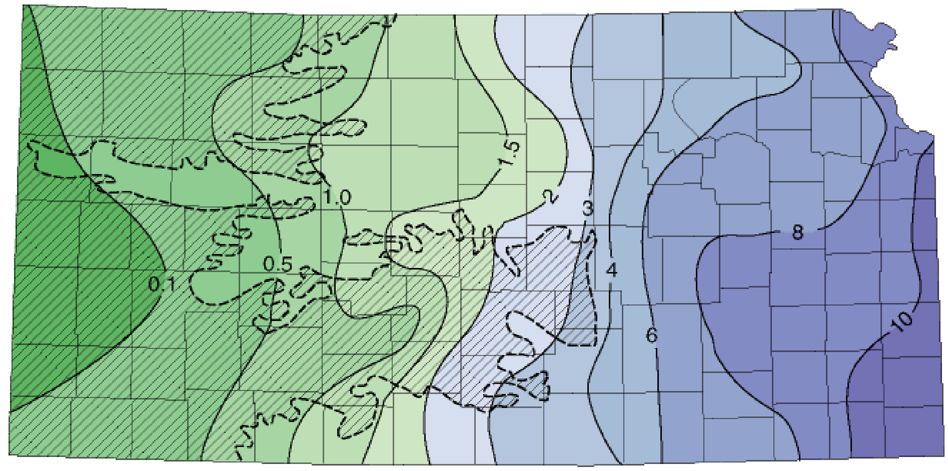

Figure 4: Mean annual runoff (in inches) in Kansas. The area west of the dashed line shows the extent of the High Plains aquifer in Kansas (adapted from Wetter, 1987).

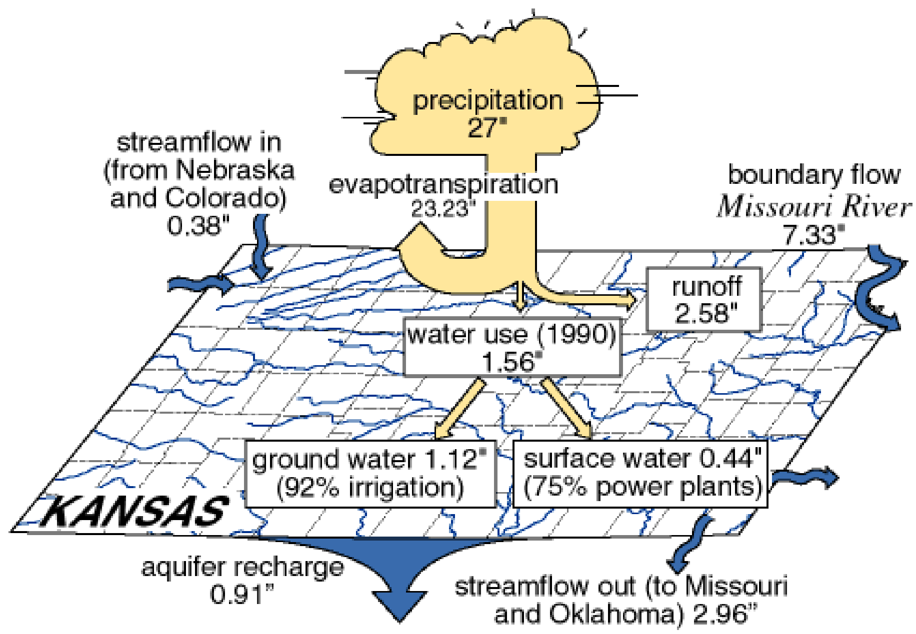

Figure 5: Water budget components for Kansas. Values are in inches per year and million acre-feet per year (adapted from Sophocleous, 1998).

Water Balance = (Precipitation + Streamflow In) – (ET + Streamflow Out + Water Use) + Change in Storage = 0

Substituting values from Figure 5 into the water balance equation results in the following:

Water Balance = (118.73 + 1.66) – (101.93 + 2.96 + 6.82) + Change in Storage = 0

Water Balance = 8.68 + Change in Storage = 0 or

Change in Storage = - 8.68 MAF (million acre feet)

This indicates use is in excess of supply, which is probably true in a general sense, although the actual numerical value is likely not correct due to the oversimplification of general water budget terms. For example, human water use for many municipal and industrial applications measures the water use as the amount of water diverted to the use but would not reflect the amount of water returned to the stream as return flow and then diverted again by another user downstream.

Another component of the water budget depicted in Figure 5 affected by human activity is the amount of groundwater recharge available to contribute to the baseflow of streamflow. In an undisturbed system, groundwater recharge is equal to outflow from the aquifer to surface streamflow. However with most aquifers tapped by wells for water use (e.g. irrigation, drinking water, livestock, or industry) some water being recharged to the aquifer would be replacement water for water withdrawn by wells. In some Kansas aquifers, the withdrawals by wells exceed the long-term natural recharge and the amount of water stored in the aquifer is reduced, which is true for the Ogallala aquifer in western Kansas.

Surface water storage is an important feature in managing the surface water supplies of Kansas. Few natural lakes occur in Kansas. The largest bodies of water in Kansas are human-made impoundments formed behind 24 dams built by the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation. These reservoirs store water for flood control, irrigation, municipal and industrial water supply, and other uses.

The 24 reservoirs have a storage capacity of 11 million acre-feet, of which 2.35 million acre-feet are available for conservation (water supply) capacity to regulate surface water supplies for sustained use in times of drought. Because of the high variability of streamflows, the state government has contracted with the federal government for water-supply storage in 12 of these reservoirs. The state makes water available to municipal and industrial water users through contracting procedures established by statute.

The two traditional methods of obtaining water in Kansas are the Water Appropriation Act (for water rights) and the Water Marketing Program, involving 12 Corps of Engineers reservoirs where the state currently owns storage. The Water Marketing Program, in concert with the Water Assurance and Multipurpose Small Lakes programs, provides surface water supplies to approximately 61 Kansas communities, 68 rural water districts, and three public wholesale water supply districts, as well as to commercial and industrial water users. These surface-water supplies serve part or all of 29 Kansas counties.

View across Rocktown Cove, Wilson Lake, Russell County. (Photo by John Charlton, Kansas Geological Survey.)

Although the distinction between surface water and groundwater seems simple, they are connected in a way that surface water can become groundwater and vice versa. Such surface-groundwater interactions generally are difficult to observe and measure. Aquifers are often fed partially by seepage from streams and lakes, and such surface water bodies are known as losing streams or lakes. In other locations, these aquifers may discharge through seeps and springs to feed the streams, rivers, and lakes. These water bodies are known as gaining streams, rivers, and lakes. Many streams in Kansas gain water from such groundwater seepage, and this streamflow contribution from groundwater is known as baseflow. Baseflow keeps the streams flowing during dry periods.

For groundwater to discharge into a stream channel, the water table near the stream must be higher than the stream-water surface. Groundwater pumping may lower the water table near the stream, in which case groundwater seepage to the stream decreases; in cases of extensive groundwater pumping, the water table near the stream may drop below the stream-water surface, causing the stream to lose water to the underlying aquifer. This seems to be happening in many regions of Kansas, especially in western Kansas.

Many streams in western Kansas have experienced a progressive reduction in flow during the past five or six decades (See *Water Primer, Part 4: Surface Water,* MF3023).

Trends are most dramatic in the upper Arkansas, Cimarron, and Smoky Hill river basins, where irrigation development has lowered the water table and significantly reduced baseflow contributions to streams from shallow aquifers. Modern conservation farming and upstream users in tributary waters also influence the flow conditions.

Agricultural conservation practices reduce runoff from fields to levels similar to the historical amount of runoff when the land was in native grasses. Declines in flow impact surface-water quality by reducing the dilution base available to effluents from sewage treatment plants and other pollution sources. Reductions in streamflow aggravate problems associated with the intrusion of highly mineralized groundwater, such as occurs in the Saline River and in Rattlesnake Creek. In an attempt to prevent a reduction in quantity and quality because of declines in baseflow, water diversions, and pollution sources, the state established Minimum Desirable Streamflow (MDS) and Total Maximum Daily Load (TMDL) limits in selected streams in Kansas.

To evaluate surface-water supplies, continuous records of streamflow for several years are necessary. Reasonable estimates of the quantity and variability of flow available can be made from records. Stream gauging stations have been maintained in Kansas for many years to collect the information needed for evaluating the state's surface-water supplies.

Streamflow information and water elevations are currently being collected from 143 complete-record stream-gauging stations and 19 lakes and reservoirs as the result of cooperative agreements between the U.S. Geological Survey and various state and federal agencies. Near real-time water-level information is currently available on the Internet for stream-gauging stations and lakes (*http://ks.water.usgs.gov*). Additional information on the water marketing, water assurance, and multipurpose small lakes programs can be found in the Kansas Water Office web page (*http://www.kwo.org*).

While this discussion of the Kansas water balance is an over-simplification of a large, interconnected, and complex process, it helps explain the fundamental concepts of a water budget.

Water Footprint

Humans' water footprint is minimal if only considering the water needed for subsistence survival. For example, the minimum recommended daily water intake is 8 fluid ounces, but for emergency planning purposes, the EPA (2007) assumes an adult ingestion rate of 68 fluid ounces per day. The activity level and environmental conditions surrounding an individual cause significant variance: a construction worker employed in the summer sun has a higher water intake requirement than an office employee working in an air-conditioned building.

Another direct water requirement contributing to the water footprint is the water used for cooking and cleaning. In the developing world, several gallons a day or less per person may be required, especially when the water must be transported by hand from a water source to the place of use. In an industrialized society, the water-use rate is much higher. In Kansas, for example, the average gallons per capita per day (gpcd) is 118 gpcd (KDA 2009), based on water delivered to homes and businesses via public water supplies. Approximately half the water is often used outdoors for lawn watering, while indoor uses including cooking, washing, bathing, and toilets use the other half.

Most indoor water usage is associated with maintaining hygiene, bathing, laundry, and dish washing, although the largest indoor, direct water requirement is generally for toilet flushing. Historically, home water use has not been of great concern, but increasing water demands and increasing costs associated with treatment and delivery have caused many public water suppliers to implement programs designed to curb home water use, including programs to encourage low-flow shower heads, low-volume toilets, and less-frequent lawn watering schedules. Home water use, however, is only a small portion of the total water footprint of an individual.

Since plants used for food require water, the water used for food production is an example of indirect water use. Wheat is a grain crop largely consumed by humans. Under well-watered conditions, either naturally via precipitation or artificially via irrigation, Kansas wheat might have a seasonal crop water use of around 18 inches (ac-in/ac) and an average yield of 60 bushels per acre. Yields from individual fields can vary considerably due to factors such as insect damage and disease outbreaks. Climate conditions such as excessive temperatures during grain formation and filling also contribute to production variations.

Water use associated with plant growth is often called evapotranspiration, or ET. Evaporation occurs as water moves directly from the soil surface and plant leaf surface to the atmosphere, while transpiration refers to water that moves from the soil into the roots and eventually through the leaves to the atmosphere. Most transpiration occurs to cool the plants, although a small amount is used for photosynthesis. The water requirement for plants can be met by dew, precipitation, or irrigation. The amount of water consumed by the plant divided by the yield component, such as pounds or bushels, is called water use efficiency or water productivity.

The water use efficiency or water productivity for the example wheat crop can be calculated by dividing the yield by the water use. For example, 1 acre-inch of water is 27,154 gallons. Therefore, the water productivity is

60 bushels/ac ÷ 18 ac-in/ac × 27,154 gal/ac-in
or 1.2×10^{-4} bu/gal

The water footprint created in the production of a bushel of wheat is the inverse of the water productivity, or 8,146 gallons per bushel. A typical bushel of wheat weighs 60 pounds, so the water footprint of wheat is 136 gallons per pound.

A 1-pound loaf of bread is mostly flour by weight, so:

8,146 gal/bushel × bushel/60 lbs of flour × 1 lb of flour/1-lb loaf of bread = 49 gals/1-lb loaf of bread

A 1-pound, 4-ounce loaf of bread normally yields 20 slices of bread. Therefore, in order to produce the wheat for a single slice of bread, approximately 3 gallons of water are needed when grown in typical Kansas conditions.

This type of analysis can be calculated for all food products, thus determining the water footprint for food production. The all-American meal of a hamburger, french fries, and a soft drink requires about 1,400 gallons to produce. Table 1 shows the water requirement for production of various foods and agricultural-based products.

Similarly, consumer goods also have a water footprint. Some production processes are relatively easy to estimate a water footprint, but the water footprint of the raw materials, the amount of water taken into the factory, and the amount of water discharged must all be known factors. The combined water footprint of the raw materials and the water consumed then would be divided by the number of created production items in order to determine the water footprint of that singular item. Accounting for the water inputs of items with many components can become tedious, such as the production of an automobile. Industry is also constantly updating and upgrading processes and water recycling, which drastically changes water needs and complicates water footprint calculations. Nonetheless, every consumer goods product has a water footprint. Water footprints for various manufactured items are shown in Figure 6.

Power production has a water footprint as well. However, the water footprint of electrical generation varies greatly depending on the method of production. For example, the footprint of electrical power generation using coal depends greatly on the type of coal used and the emission standards in effect at the time of construction. Reductions in greenhouse gases and other emissions are possible with various scrubbing technologies but require additional power to run. As a result,

Table 1. Water footprint for various agricultural products based on global water use averages (*National Geographic*, 2010).

Animal/Meat Products	Gallons of Water per Pound of Product
Beef	1,857
Sausage	1,382
Pork	756
Processed Cheese	589
Chicken	469
Eggs	400
Fresh cheese	371
Yogurt	138

Manufactured Goods	Gallons of Water per product item
1 pair blue jeans	2,900
1 cotton bed sheet	2,800
1 cotton t-shirt	766

Food	Gallons of Water per serving size
1 hamburger	634
1 glass of milk	53
1 cup of coffee	37
1 glass of wine	32
1 glass of beer	20
1 cup of tea	9

Fruits/Vegetables	Gallons of Water per pound of product
Figs	379
Plums	193
Cherries	185
Avocados	154
Corn	109
Bananas	103
Apples	84
Grapes	78
Oranges	55
Strawberries	33
Beans	43
Potatoes	31
Eggplants	25

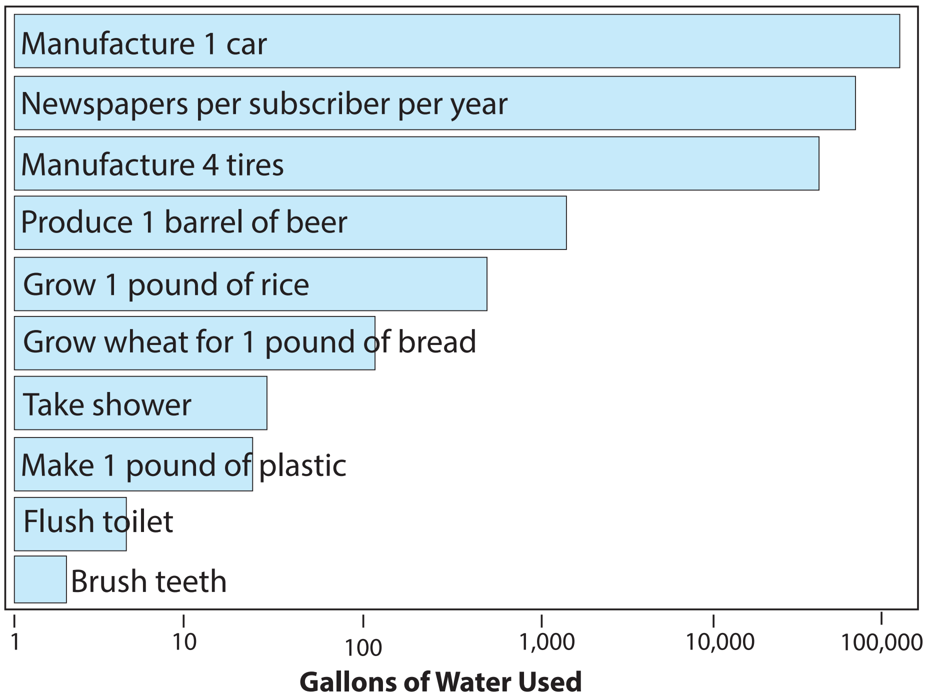

Figure 6: Typical water use requirements for various activities. (Rogers and Sothers, 1995).

the amount of electrical power available for delivery to consumers is reduced, thereby increasing the water footprint of power production. Some electrical power production technologies, such as wind and solar, have low water footprints but have other limitations, such as noncontinuous production, when servicing a large continuous power demand.

Reducing an individual's water footprint involves considering all aspects of life. Change could begin, though, with water conservation in the home, such as reducing direct water consumption with water-saving faucets, fixtures, toilets, and landscape irrigation scheduling or xeriscaping where no or little outside water is needed.

Since food production is water intensive, minimizing food waste is one method to reduce an individual's water footprint. Reducing energy consumption also has a corresponding water footprint reduction. Recycling programs also may reduce the water footprint for certain products.

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