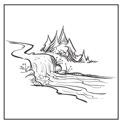
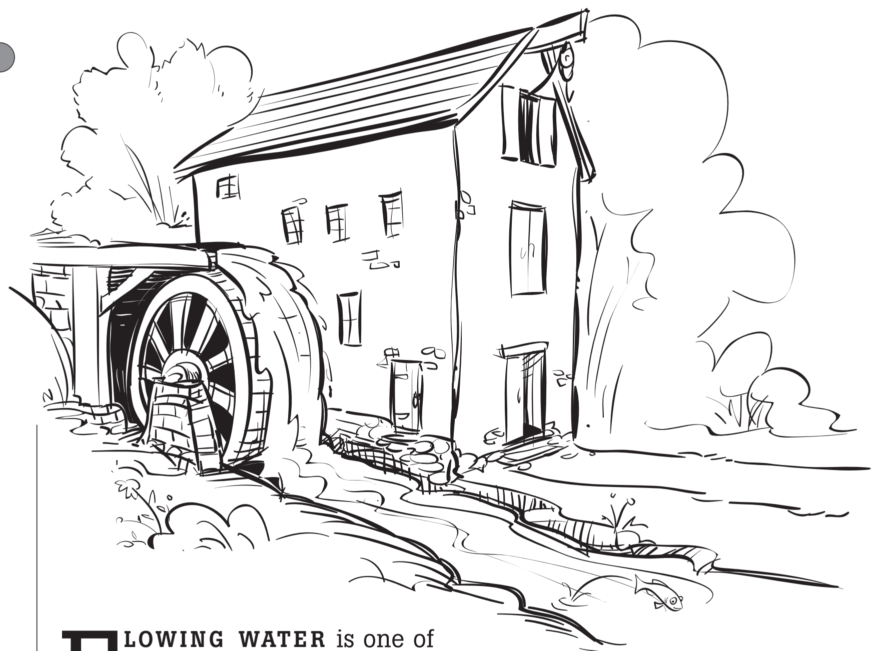


Renewable Energy Source: HYDROPOWER

TERMS IN GLOSSARY

flow
head
headrace
horsepower
impoundment
micro-hydro
penstock
pumped storage
run-of-river (diversion)
tailrace
water cycle



FLOWING WATER is one of nature's most powerful forces. Humans began harnessing this energy force several thousand years ago. By the first century B.C., waterwheels were working in many parts of the world, including Greece. (In fact, the term hydro comes from an ancient Greek word for water.) For centuries waterwheels in many countries provided the energy to grind grain and saw lumber. By the 1700s, more than 10,000 waterwheels were hard at work in colonial New England alone.

During the Industrial Revolution, waterwheels were also used to run textile mills and other factories. By the late 1800s water turbines were driving a new device – the generator – to produce electricity. Before the end of that century several commercial water-driven electrical stations were operating, including the largest at Niagara Falls, New York. The era of hydroelectric power was born.

THE HYDROPOWER RESOURCE

The hydropower resource is the force of flowing water, provided to us naturally by the earth's water cycle and by gravity. The force of the flow of a medium-size river is equal to several million horsepower. (One million horsepower, if converted to electricity, would equal the power of 746 MW.) You can imagine the appeal when this much force can be put to work driving waterwheels or water turbines.

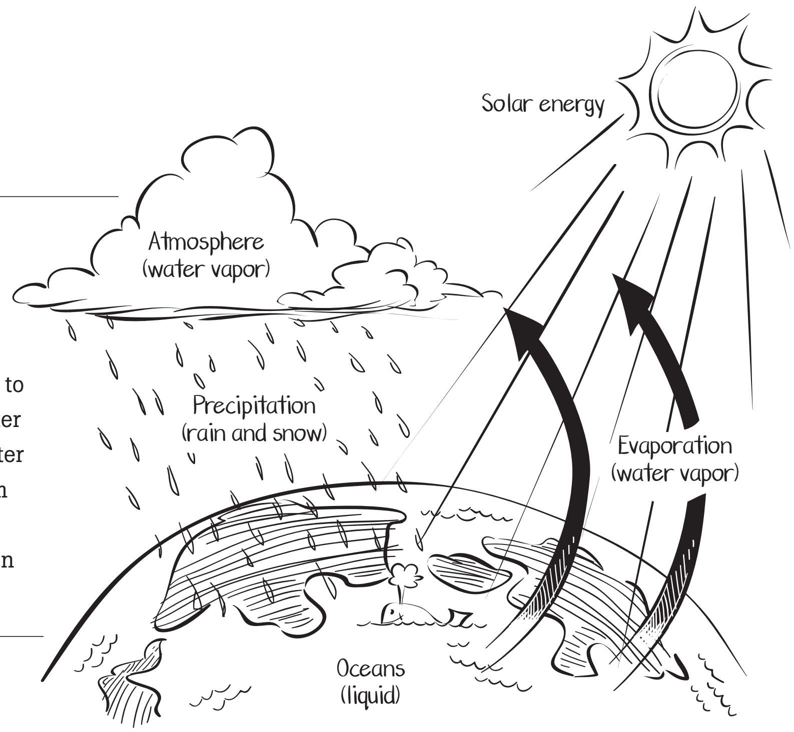
REMINDER

W = watt
kW = kilowatt = 1,000 watts
MW = megawatt = 1,000 kilowatts

1 megawatt can serve about 1,000 homes in the United States.

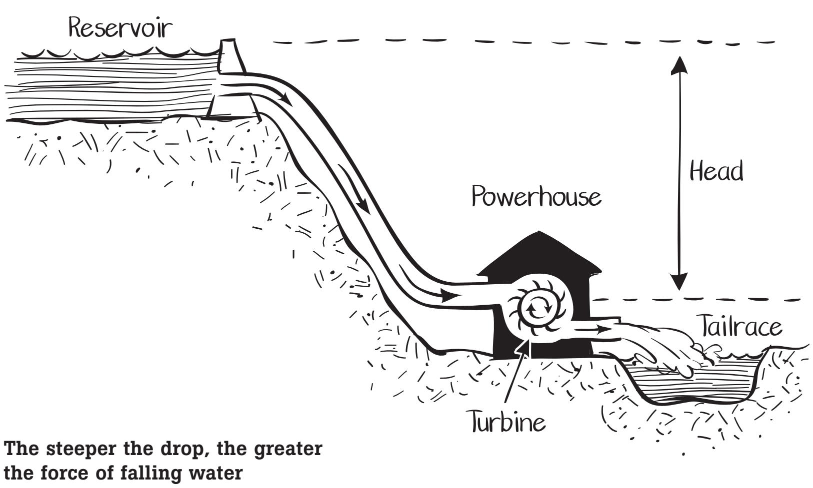
THE WATER CYCLE

Energy from the sun (solar energy) causes evaporation of water from the land and from the oceans, rivers, and lakes. This puts water vapor into the atmosphere where it can condense to form clouds, which then return the water to the earth as rain, snow, and ice. Water runoff is pulled down by gravity to form streams and rivers, which flow to lakes and to the sea. This cycle of evaporation and precipitation is continuous.



The Steeper the Better

The amount of force that water can impart depends on two factors: the head — the vertical distance the water falls; and the flow — the volume (amount or mass) of the water per second. The greater the head and the flow, the more water energy is available. So hydropower systems work best with a steep drop (high head) and a large flow. One gallon (3.8 liters) of water falling 100 feet (30 meters) in one second can generate about 1 kW of electric power. No wonder waterfalls, with their naturally steep drops, were chosen as the sites for the world's first hydroelectric power plants.



The steeper the drop, the greater the force of falling water

GENERATING ELECTRICITY FROM HYDROPOWER RESOURCES

All hydropower plants, large or small, use a water turbine and a generator to produce electricity. The water turbine is at the heart of any hydroelectric system. Resembling its wooden ancestor, the water-wheel, it is far more streamlined and spins much faster. Interestingly, the first model is still in wide use. Its bucket-like metal paddles are enclosed in a shell into which the water flows. Today's water turbines are designed for maximum efficiency. They come in many shapes and sizes to work with varying conditions of head and flow. Hydropower generators resemble those used in many other electric power plants.

Most hydropower systems use some type of water passageway, channel, or pipe, called a penstock. The passageway concentrates the water's force by increasing the pressure as it approaches the turbine. That force turns one or more turbine-generators, which are usually enclosed in a powerhouse (to protect the equipment and to make maintenance possible). Water leaving the turbines is channeled downstream through a tailrace, back to the river.

HARD-WORKING WATER

The ambitious Big Creek hydropower project in California, begun in the early 1900s, now sends the water of Big Creek through a series of dams, lakes, tunnels, and powerhouses — all built into the steep mountainsides of the Sierra Nevada between Yosemite and Sequoia national parks. Nine power-houses have been added, which together generate over 1,000 MW of electricity, prompting some to call this river system the "hardest working water in the world."

POWER SKETCH: Power in Paradise

Members of a family living in the hilly rainforest many miles from Quito, Ecuador, have always treasured their lush, natural environment. After many years of roughing it, they wanted to enjoy a few conveniences that required electricity. But they lived far from power plants and transmission lines. They solved this dilemma by installing a small hydroelectric system that uses water diverted from a fast-flowing stream on their property. This "run-of-river" system does not disrupt the flow of the river feeding the waterfall and pool below. It generates enough electricity to run a small refrigerator and electric lights. It even provides power to run a computer, which is used for their exotic plant-seed business. The forest has almost covered the power-generating equipment with foliage, so they enjoy the convenience of electricity without disturbing the beauty of their little piece of paradise.

Two Common Hydropower Systems

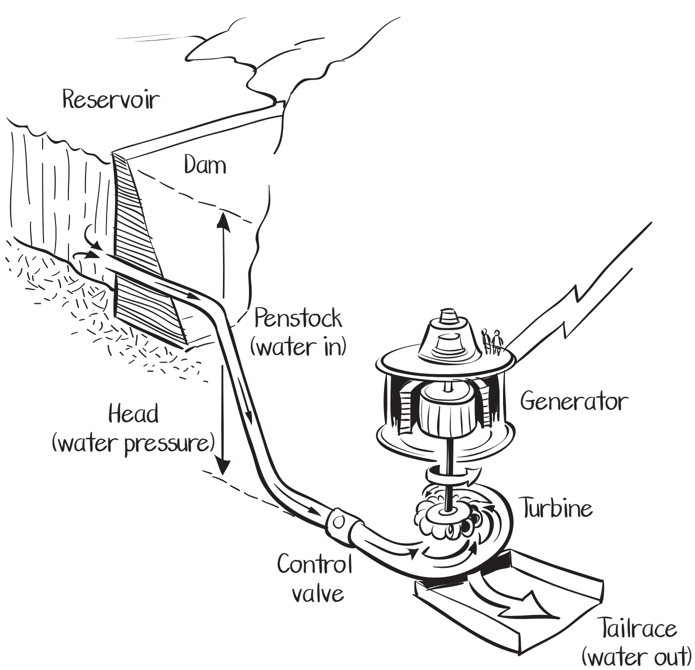
There are basically two ways that hydropower facilities use the force of flowing water: storage systems and run-of-river (diversion) systems.

Storage Hydropower Systems. The hydropower plants we're most used to seeing are called "storage" hydropower plants. These plants use a dam to hold back water, creating a reservoir and an artificially steep drop (high head). The dam is placed across a river, causing it to back up to form a reservoir or lake. The water is held back until it is needed. When released, it flows down through the penstocks to turbines in the powerhouse below. After the water passes through the turbines it is discharged into the river.

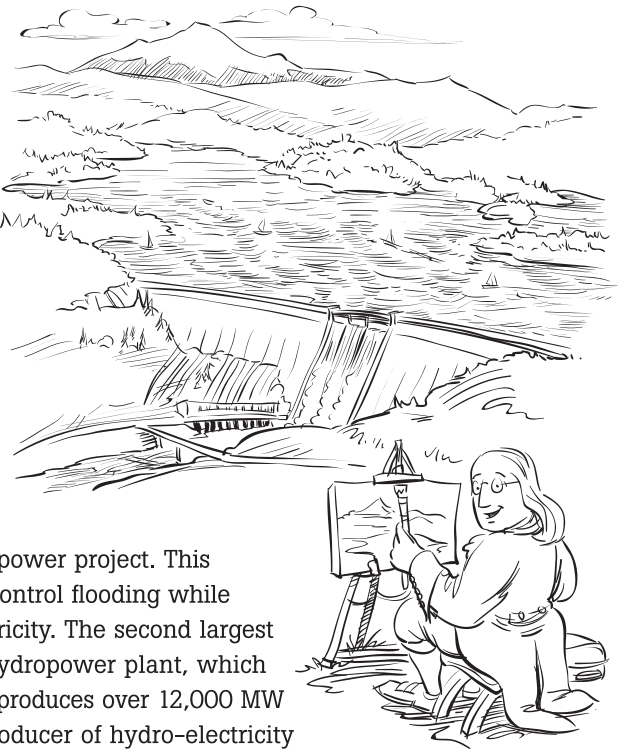
U.S. hydropower power plants produce almost 95,000 MW of power, much of which currently comes from storage hydropower facilities. About 60 percent of all electricity used in the Pacific Northwest is generated from hydropower. The largest storage hydroelectric facilities in America are found in this region. The Grand Coulee Dam, on the Columbia River, alone produces over 6,000 MW, making it the fifth largest storage hydropower facility in the world.

STORE NOW, USE LATER

Some dams use a pumped storage system to move water between an upper and a lower reservoir. During times of peak electricity demand, water is released from the upper reservoir to generate electricity and ends up in the lower reservoir. When electricity is plentiful, and this plant is not needed, electricity generated elsewhere is used. An example of this type of system is the Eastwood power plant in the Sierras of California.

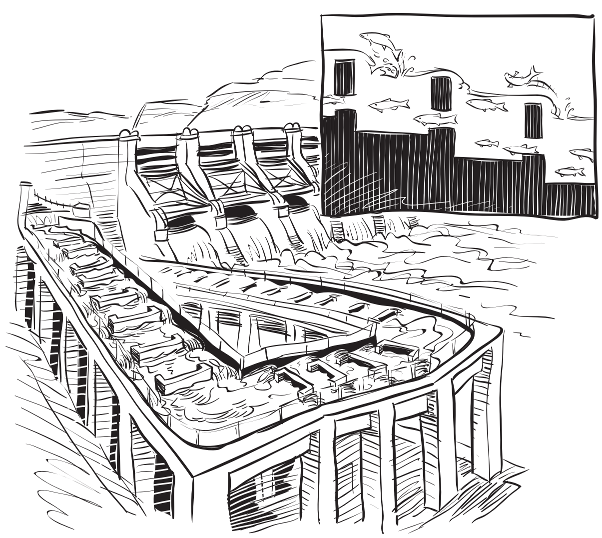


Inside a storage hydroelectric plant



Hydropower projects have had multiple roles in American history. With hydropower, the Tennessee Valley Authority (TVA) brought electricity to many rural homes and farms — the first time in the 1930s. Hoover Dam, near the Grand Canyon, helps control flooding along the mighty Colorado River and provides power to the southwest. The U.S. Bureau of Reclamation oversees multipurpose hydro projects nationwide for flood control, recreation, irrigation, and electricity.

China can claim the world's largest hydropower project. This project, on the Yangtze River, is designed to control flooding while producing an anticipated 22,500 MW of electricity. The second largest hydropower plant in the world is the Itaipú hydropower plant, which sits on the border of Brazil and Paraguay and produces over 12,000 MW of power. In fact, Brazil is the third largest producer of hydro-electricity in the world. Only Canada and the United States generate more. Western Europe, Japan, and Russia are also top hydropower producers.



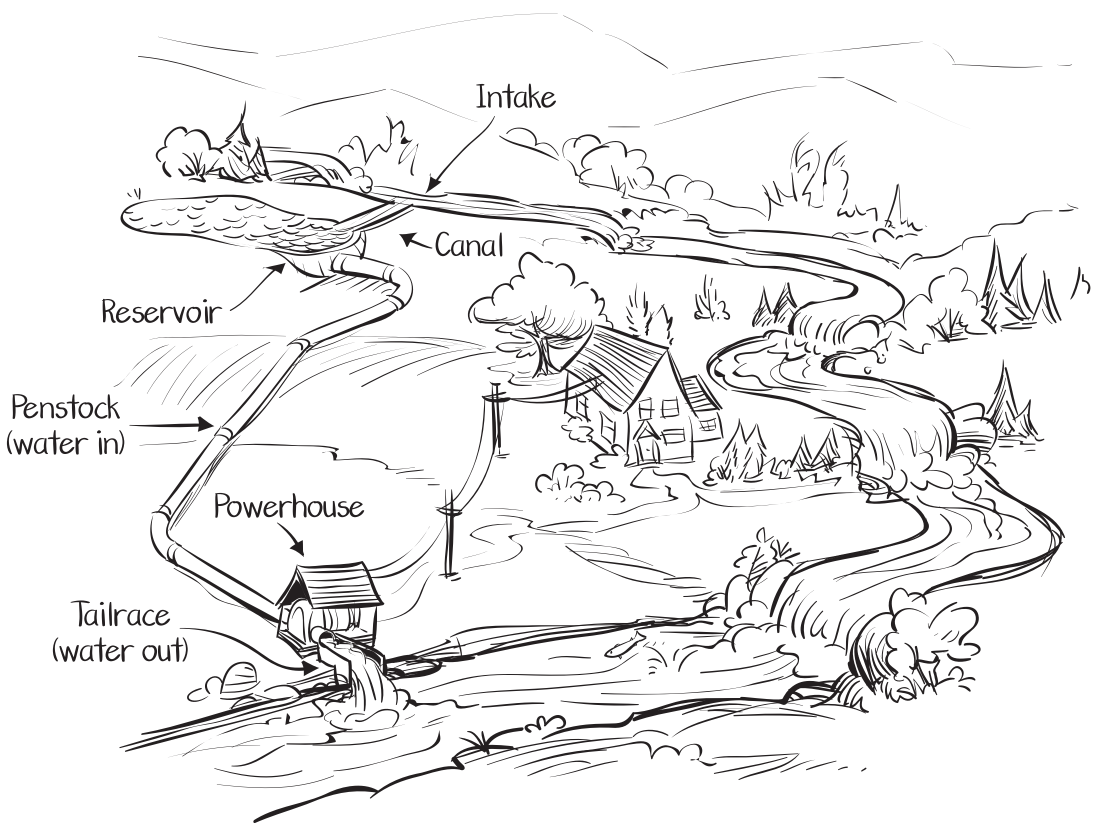
CHUTES AND LADDERS

There are a number of ways to avoid damage to fish caused by large storage hydropower plants. Innovative methods include fish ladders for adult salmon migrating upstream to spawn, flashing lights to alert night-migrating fish, screens to shield the turbines, and surface collectors that guide juvenile fish through chutes that go around the project.

Run-of-River (Diversion). Run-of-river systems are today's hydropower systems of choice, because they are designed to maintain the natural flow of a river and therefore are more wildlife-friendly than storage projects.

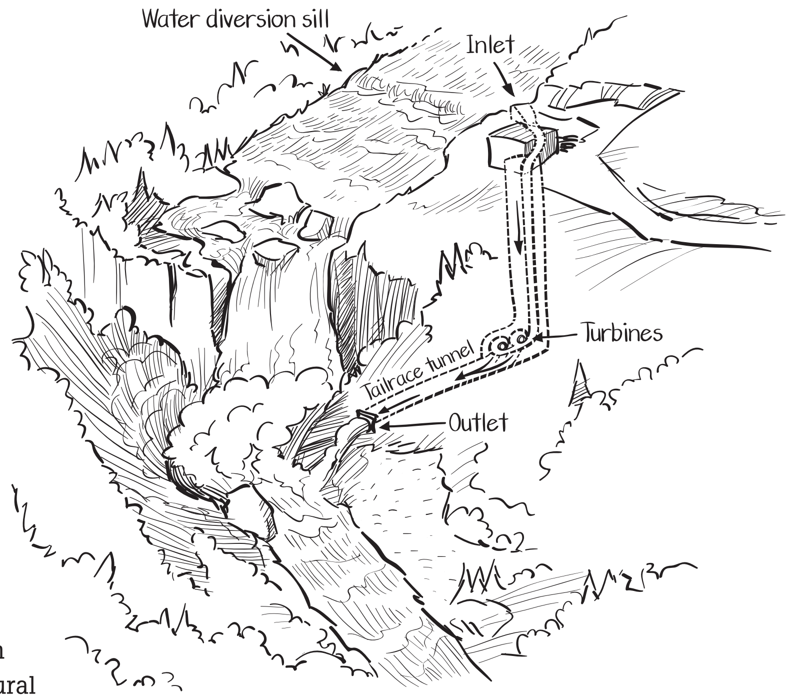
With these systems, the river generally continues to run its natural course while some of its water is directed off, or diverted, into a penstock. Once the diverted water has done its work, it is sent back to join the river through a tailrace. There are a number of ways this is accomplished.

In the simplest type of facility, a small dam directs water into a powerhouse at one end of the dam. After spinning the turbines, the water returns directly to the river. Sometimes the powerhouse is located further down the river at the end of a short canal, or headrace, to develop more head. In another type of facility, a penstock takes a steeper, more direct path than the river, rejoining the river downstream. There are also systems that combine these elements.



A diverted run-of-river system

One method that is favored in scenic areas uses a tunnel that is cut through rock alongside a steep drop. Nothing on the surface is disrupted as most of the system is placed underground. Snoqualmie Falls, providing the first hydropower to Seattle, Washington, was originally built that way. The Tazimina Hydroelectric Project near Anchorage, Alaska, uses the long vertical drop of a vigorous waterfall without marring its flow or its rugged surroundings. Some of the upper river's flow is diverted through a vertical pipe installed in the rocky cliff alongside the waterfall. The water rushes down the pipe to turbines in a powerhouse below and then rejoins the river's main flow.



This run-of-river hydroelectric project in Tazimina, Alaska, does little to disrupt its natural surroundings.

Run-of-river hydropower is useful in many places. Because there is no large dam or reservoir, it limits disturbance to the natural setting. Also, it can provide electrical power for people living far from transmission lines. In the Gold Rush country of the western United States, some small run-of-river plants were built where water had originally been diverted by miners to "wash" gold out of gravel.

Sometimes storage and run-of-river systems are combined. For example, at Bishop Creek Hydropower Project in California's eastern Sierra Nevada, spring runoff from melting snow is collected in two reservoirs, built to prevent flooding of the Bishop Creek area below. Throughout the year, a moderate amount of water is released into the creek, where it eventually spills through four run-of-river powerhouses. The first use of this hydropower was to provide electricity for gold and silver mining in the early 1900s. These powerhouses still provide plenty of electricity today.

There are hundreds of run-of-river projects in the United States, and most new hydro projects being built in the U.S. are run-of-river. Many are hailed for preserving a river's flow while providing electrical power. One project is located just off the Mississippi River near Vidalia, Louisiana. It maintains the flow of the "Mighty Mississippi" (a main artery for transportation), helps control flooding, and supplies electricity.

Many small run-of-river projects are now being awarded coveted "low impact" certification for producing hydropower without disturbing the local environment. One example is the Lower Robertson hydro project on the Ashuelot River in New Hampshire. Many other facilities have also received this award, including one at Falls Creek in the Willamette National Forest of Oregon.

Worldwide, there is great interest in run-of-river projects for both remote and grid-connected areas. For example, mountainous Nepal, which features over 6,000 rivers and streams, is interested in using these systems to provide rural villages with electricity. China has plans to provide up to 75 million people with electricity from diversion projects. Many hilly areas in Europe are already dotted with run-of-river hydro systems.

Project Size

Today's hydropower systems range from those that provide energy for one home to mammoth, multi-megawatt installations. A common definition of a large-scale hydropower facility ("large hydro") is one that generates more than 30 MW of electricity. Most large-scale hydropower installations use a storage system, which creates the greatest environmental concerns. (See "Considerations," next page.)

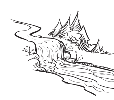
Small-scale hydropower projects are often divided into small-scale hydro and micro-hydro. Small-scale projects range from 100 kW to 30 MW, while micro-hydro projects usually produce 100 kW or less. Small-scale projects can be run-of-river or storage-type facilities. Micro-hydropower systems are run-of-river, considered to be gentler on the environment.

Most experts say that nearly all new hydropower facilities will be small-scale and/or run-of-river facilities. Many potential locations exist for these types of power plants. Also, some older small-scale hydro projects that were shut down in the 1930s and '40s have recently been reopened. For example, a small hydro facility operated by Cornell University at Fall Creek in Ithaca, New York, was reopened in the 1980s after a 30-year shut-down. It is once again supplying 1.5 MW of power to the university, a small but eloquent testimonial to the value of using a local, renewable energy resource.

CONSIDERATIONS

- Hydropower produces no air pollution. It is very efficient and — once installed — inexpensive. Storage hydropower plants run reliably all year long, providing good baseload power, though long-term drought can reduce overall capacity. They can be started up relatively fast when needed for peaking power.
- Run-of-river hydropower systems are considered by many to be the preferred hydropower technology because they are easier on the environment. Run-of-river projects could contribute a significant amount of electricity worldwide.
- A drawback of run-of-river systems is that the flow in the rivers and streams fluctuates by season, and in low rainfall or drought years, less electricity can be produced. Low rainfall levels can also reduce seasonal electricity output of storage systems.
- Large-scale storage hydropower projects are expensive to build, but can provide many megawatts of electricity to an area for decades.
- The installation of a dam across a river for a large-scale storage project can cause the river water to back up over hundreds to thousands of acres, flooding significant land areas. There are impacts to water quality, fish, and wildlife. The flooding can also ruin important cultural, religious, and archeological sites and can displace hundreds or even thousands of people. The large Three Gorges project in China has created a lake 400 miles (644 kilometers) long and required the relocation of 1.2 million people.

(*continued*)



Hydropower Data File*

United States

- The United States gets about 6 percent of its electricity from hydropower.
- Washington, Oregon, California, and New York are the states currently producing the largest amount of hydroelectricity.

Worldwide

- About 20 percent of the world's electricity is generated by hydropower.
- Sixteen countries get about 90 percent of their electricity from hydropower, including Norway, Brazil, Paraguay, Albania, Ethiopia, Ghana, and Zambia.

*Data available in 2010

CONSIDERATIONS (continued)

- Most dams serve multiple purposes, like flood control, water supply, transportation, and recreation. In fact, fewer than 3 percent of the dams in the United States have hydropower plants, and for many that do, electricity is a secondary purpose.
- Currently, a number of large projects around the world have been canceled or placed on hold due to public concern about the environmental impacts of the dams. In recent years, some consideration has been given to removing dams in highly sensitive areas. Some smaller, older dams in sensitive areas of the U.S. Pacific Northwest have already been removed.

Creating Electricity from Hydropower Resources

Run-of-River at Ashuelot, New Hampshire
This is a low impact certified project on the Ashuelot River. Its three turbine generators, with a capacity of 960 kilowatts, are deep under the water. *(Photo courtesy of Bob King, Ashuelot River Hydro, Inc., Keene, NH)*

Oregon Fish Ladder
The Vine Street Hydro project in Oregon features a fish ladder to bypass the 6-foot high concrete diversion dam. A fish screen deters migratory fish from straying into the canal. *(Photo courtesy of the City of Albany, OR)*

Penstock
A 10-ft. diameter penstock at the Millpond Project in New York diverts water from Catskill Creek. The penstock run carries water directly to the powerhouse, through the turbine, and right back into the river. *(Photo courtesy of Bob King, Ashuelot River Hydro, Inc., Keene, NH)*

Run-of-River in Maine
This is a 15 MW hydro project in Kennebec, Maine. The turbine generators are inside the little powerhouse on the right. The force of the water going from the higher to the lower elevation spins the turbine. *(Photo courtesy of Brookfield Renewable Power, Marlborough, MA)*

Creating Electricity from Hydropower Resources

Low Impact in New York
This run-of-river project is on the Racquette River. In this photo you can see the "head pond," a small dam, a little power house with four turbines, and the tail race (at a lower elevation), where the water, having done its job, rejoins the river. *(Photo courtesy of Brookfield Renewable Power, Marlborough, MA)*

Sharing Nature in Yosemite National Park
A curved gravity dam captures the snowmelt on the Tuolumne River, creating the Hetch Hetchy Reservoir. This storage reservoir provides water and electricity to San Francisco hundreds of miles away. Generating facilities and transmission lines — concealed to protect the valley's famous scenery — produce about 500 MW of electricity. *(Photo from Wikipedia)*

Pumped Storage
These are pumped storage hydropower facilities. Above left is the Jack Cockwell pumped storage hydro facility on the beautiful Deerfield River in Massachusetts. The facility on the right is in Muddy Run, Pennsylvania. During off peak hours the power house pumps water to the upper reservoir; during times of peak power demand the water is directed down through the turbines to generate electricity. *(Cockwell photo courtesy of Brookfield Renewable Power, Marlborough, MA; Muddy Run photo courtesy of Exelon Corporation, Chicago, IL)*