The Hydropower Resource

On Earth, water is constantly moved around in various states, a process known as the hydrologic cycle. Water evaporates from the oceans, forming into clouds, falling out as rain and snow, gathering into streams and rivers, and flowing back to the sea. All this movement provides an enormous opportunity to harness useful energy.

The United Nations estimates that the total "technically exploitable" potential for hydropower is 15,090 terawatt-hours per year, or 15 trillion kilowatt-hours, equal to half of projected global electricity use in 2030. Only about 15 percent has been developed so far. While much of the remaining potential may not be economically or environmentally suitable to develop, there are still significant opportunities for new development in regions like the former Soviet Union, South Asia, and South America.

Converting Moving Water to Electricity

In order to generate electricity from the kinetic energy in moving water, the water has to be moving with sufficient speed and volume to turn a generator. Roughly speaking, one gallon of water per second falling one hundred feet can generate one kilowatt of electrical power.

To increase the force of moving water, **impoundments** or dams are used to raise the water level, creating a "hydraulic head," or height differential. When water behind a dam is released, it runs through a pipe called a penstock, and is delivered to the turbine.



An impoundment. Source: DOE Office of EERE

Hydroelectric generation can also work without dams, in a process known as **diversion**, or run-of-the-river. Portions of water from fast-flowing rivers, often at or near waterfalls, can be diverted through a penstock to a turbine set in the river or off to the side. The generating stations at Niagara Falls are an example of diversion hydropower. Another run-of-the-river design uses a traditional water wheel on a floating platform to capture the kinetic force of the moving river. While this approach is inexpensive and easy to implement, it doesn't produce much power. The entire Amazon River, if harnessed this way, would produce only 650 MW of power.

Another type of hydropower, though not a true energy source, is pumped storage. In a pumped storage plant, water is pumped from a lower reservoir to a higher reservoir during off-peak times, using electricity generated from other types of energy sources. When the power is needed, it is released back into the lower reservoir through turbines. Inevitably, some power is lost, but pumped storage systems can be up to 80 percent efficient. There is currently more than 90 GW of pumped storage capacity worldwide, with about one-quarter of that in the United States.  Future increases in pumped storage capacity could result from the integration of hydropower and wind power technologies. Researchers believe that hydropower may be able to act as a battery for wind power by storing water during high wind periods.

There are a variety of turbines employed at hydropower facilities, and their use depends on the amount of hydraulic head at the plant. The most common are Kaplan, Francis, and Pelton wheel designs. Some of these designs, called reaction and impulse wheels, use not just the kinetic force of the moving water but also the water pressure.

The Kaplan turbine is similar to a boat propeller, with a runner (the turning part of a turbine) that has three to six blades, and can provide up to 400 MW of power. The Kaplan turbine is differentiated from other kinds of hydropower turbines because its performance can be improved by changing the pitch of the blades. The Francis turbine has a runner with nine or more fixed vanes. In this turbine design, which can be up to 800 MW in size, the runner blades direct the water so that it moves in an axial flow. The Pelton turbine consists of a set of specially shaped buckets that are mounted on the outside of a circular disc, making it look similar to a water wheel. Pelton turbines are typically used in high hydraulic head sites and can be as large as 200 MW.

The ability to meet power demand fluctuations is an advantage of hydro plants with reservoirs. Unlike run-of-the-river plants, which produce power around the clock, hydro plants with dams are typically used only when the power is most needed. Utilities save up the water, letting it loose only during peak times. Hydro plants, especially the large older plants built from the 1930s to the 1950s, are commonly the least-expensive source of electricity.

Environmental Concerns

Although an inexpensive and nonpolluting energy resource, the environmental damage caused hydropower can be serious. The most obvious effect is that fish are blocked from moving up and down the river, but there are many more problems.



Coho salmon fingerlings. Source: NREL

When a dam is constructed, a river habitat is replaced by a lake habitat. While this may not sound so bad -- fish and birds like lakes, too -- it can cause a number of environmental problems. In the Pacific Northwest, large federally owned dams have blocked the migration of coho, chinook, and sockeye salmon from the ocean to their upstream spawning grounds. The number of salmon making the journey upstream has fallen 90 percent since the construction of four dams on the lower Snake River. Some steps are being taken to help the fish around the dams, such as putting them in barges or building fish ladders, but this only helps so much. Also, when young fish head downriver to the ocean, they can be chewed up in the turbines of the dam. As of 2002, 71 percent of the area of Washington and 50 percent of Oregon contain watersheds with salmon and other related species that have been listed as threatened or endangered.

Dams can create large reservoirs submerging what used to be dry land, producing many problems. The Balbina dam in Brazil, for example, flooded 2,750 square kilometers (965 square miles), an area the size of Rhode Island. This land is often composed of wetlands, which are important wildlife habitats, and low-lying flood plains, usually the most fertile crop land in the area. Population density is typically higher along rivers, leading to mass dislocation of urban centers. The Three Gorges Dam in China is expected to dislocate up to 1.9 million people.

Wildlife habitats destroyed by reservoirs can be especially valuable. In South America, 80 percent of the hydroelectric potential is located in rain forests, one of the most rich and diverse ecosystems on Earth. The Rosana dam in Brazil destroyed one of the few remaining habitats of the black-lion tamarin, a rare and beautiful species of long-haired monkey.

Another problem can occur when the land area behind the dam is flooded without proper preparation. In Brazil, the Tucurui dam was built creating a reservoir in a rain forest region, without the forest first being cleared. Later, as the plants and trees that were submerged began to rot, they reduced the oxygen content of the water, killing off the plants and fish in the water. Moreover, the rotting plants gave off large quantities of methane, a powerful global warming gas.

A similar problem has occurred in Canada, in hydro projects built by Hydro Quebec. The stones and soil in the flooded area contain naturally occurring mercury and other metals. When the land was flooded, the mercury dissolved into the water, and then into the local fish populations. The creatures that eat the fish—from bears and eagles, to the native Cree people—are suffering from mercury poisoning. Mercury poisoning can cause brain damage, birth defects, liver disorders, and other ailments.

Impoundments used for hydropower can cause many other effects on water quality and aquatic life. Rivers and lakes can be filled with sediment from erosion. Water falling over spillways can force air bubbles into the water, which can be absorbed into fish tissue, ultimately killing the fish. By slowing down rivers, the water can become stratified, with warm water on top and cold water on the bottom. Since the cold water is not exposed to the surface, it loses its oxygen and becomes uninhabitable for fish. And as illustrated by the Colorado River in the Grand Canyon, fast-moving rivers can be filled up with sediment when they are slowed down. In an effort to mitigate this problem, the Department of Interior has flushed huge amounts of water out of dams in an attempt to clear away the sediment.

Another important habitat disruption comes from the operation of the dam to meet electric demand. Water is stored up behind the dam and released through the turbines when power demand is greatest. This causes water levels to fluctuate widely on both sides of the dam, stranding fish in shallow waters and drying out the habitat. There are many competing pressures on dam operators -- to produce power, to provide water for recreational use both on the reservoir and downstream, to provide drinking and irrigation water, to allow Native Americans to carry out traditional religious practices, and to preserve habitat for fish and plant species. In many cases, nature loses out to boaters, farmers, and electric customers.

The risk of a dam breaking should also not be ignored. The great Johnstown flood in Pennsylvania was the result of a dam break (although not a hydroelectric dam); 2,000 people were killed. In northern India and Nepal, in the Himalayas, huge hydroelectric projects are planned that would create large reservoirs in a geographically unstable region. Frequent earthquakes make the dam a risky venture for heavily populated areas downstream. This is compounded by the fear that large, heavy reservoirs would put additional pressure on the plates in the region, causing even more earthquakes. Finally, breakage could also result from war or terrorism, as dams have been considered potential military targets in the past. The environmental and social effects of hydropower can be immense. But while hydropower has its problems, it can still be a safe and sustainable source of electricity if proper measures are taken. By upgrading and improving the equipment at plants, by increasing fish-friendly efforts at dams, and by improving run-of-the-river turbine technology, it may be possible to reduce the environmental effects of hydropower. Nonetheless, remediation may be impossible at some sites, and wild rivers should be unshackled.

It is also important to compare the environmental effects of hydropower with alternatives. The damage to aquatic habitat from dams may be significant, but acid rain, nitrogen deposition, and thermal pollution from coal plants also lead to aquatic damage, as well as to air pollution and global warming. Provided we dismantle the worst hydropower facilities, and improve the sustainability of the others, we will be better off.

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