Hydropower: Potential Energy for Minnesota?
by Robert J. Geisen

The transformation of water power into mechanical energy or electricity played a significant role in the early settlement of Minnesota. A number of communities formed along rivers where hydropower was used to operate flour and sawmills. In 1882, the world’s first central hydroelectric generating facility was installed in Appleton, Wisconsin. In Minnesota, hydroelectric plants were constructed as early as 1885. Since then, hydroelectric technologies have become well-established.

Abundant and cheap fossil fuels brought about a decline in hydropower use. Large steam generating plants produced electricity for less money and with higher reliability than small hydro facilities. By the early 1950s, many hydroelectric stations had closed down, though the larger, more cost effective plants survived. At present there are thirty-two hydropower plants operating within the state.

Minnesota has 853 existing dams with a structural height of six feet or more. Obviously, the thirty-two generating dams are not tapping all of the water power flowing within the state. But are they converting a majority of the available water power into electricity? How much water power is there available in the state? This study sought to develop an overall picture of Minnesota’s hydropower and to estimate the physical limits of hydropower in the state.

Power from Existing Dams

The hydropower potential from a dam is directly related to the hydraulic head and the stream flow rate by the following equation:

$$ P = \rho g Q H $$

where $P$ is the potential power or power available; $\rho$, the density of the water; $g$, the acceleration due to gravity; $Q$, the volumetric flow rate; and $H$, the hydraulic head.

For this study, it was assumed that the hydraulic head was the same as the hydraulic height of the dam. In actuality, the net available head will often be less than this and can fluctuate with the season. The hydraulic heights listed in the National Dam Safety Inventory were used for all 849 Minnesota dams, since no record of net available heads has ever been compiled. Average annual flow rates were used in the computations. Again, flow varies with the season, so these numbers are only approximate, yet they will suffice for the purposes of this study.

The U.S. Geological Survey (USGS) maintains 105 gauging stations in Minnesota. The flow rate of a stream or river is measured by the volume of water flowing through the channel over a specific unit of time. Gauging stations are seldom near a dam; therefore, the flow rate at the dam must be correlated to data from the gauging station on the same stream.
liver, researchers at the St. Anthony Falls Hydraulic Laboratory, determined that the most accurate means of calculating average annual flow rates at any location on a stream is to use USGS gauging station data (on the same stream) and scale the results according to the drainage area.*

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<tr>
<th>Q (at site)</th>
<th>Drainage Area (at site)</th>
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<td>Q (at USGS gauge)</td>
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Many dams are on ungaged streams. For these dams, the average annual flow rate was estimated by correlation with the drainage area. The state was divided into eight major drainage basins. The average annual flow rate was plotted against the drainage area for each basin using USGS gauging station data. This provided an adequate correlation for each drainage basin, which was then used for estimating flows at dams on ungaged streams within each basin. Dotan and Gulliver tabulated the estimated average annual flow rate for 254 dams within the state. Flow rates were not calculated for nearly 600 other dams because of their small drainage areas.

In this study raw data from Dotan and Gulliver's report were analyzed using a unique algorithm; the results are presented here. Figure 1 shows the distribution of 849 dams in Minnesota by their hydraulic height. The figure omits the Thomson Dam, just south of Duluth outside Jay Cooke State Park, in order to maintain graphic resolution. The Thomson Dam outscals all the other dams in the state with its hydraulic height of 363 feet. The vast majority of Minnesota's existing dams have very low heads. Many were created in order to maintain a lake level. Over 50 percent of the 849 dams in the state have a hydraulic height of 10 feet or less. With a ten foot head, a relatively large flow rate of 120 cubic feet per second is required for every 100 kilowatts of available power. Only 10 percent of all the dams in the state are above 30 feet. The majority of Minnesota's existing dams have very low hydraulic heights.

Figures 2 and 3 are based on the 254 dams for which average annual flow rates have been estimated. Figure 2 shows the distribution of these dams with respect to their hydraulic height and also the distribution of dams which have electric generating facilities. No dams under twelve feet have been modified into hydroelectric power plants. A number of the dams with higher hydraulic heights, however, do have hydroelectric plants in operation. This includes the Thomson Dam, not shown in Figure 2. A large hydraulic height does not necessarily ensure that a dam is appropriate for hydroelectric development. Sufficient stream flow is also necessary. To illustrate this, the power available at all 254 dams was calculated using the estimates for their annual average flow rates. The results are shown in Figure 3 along with the actual installed power capacity for the dams at each hydraulic height. The top fifty dams, in terms of potential power, are also shown on the accompanying map. The dams are ranked ordered on the map with 1 indicating the dam with the highest power and 50 the dam with the lowest potential power. Dams with electric generating facilities already in place are shown in black. The numbers used for rank ordering also appear hereafter (in parentheses) to assist the reader in locating the dams under discussion.

In combination, Figures 2 and 3 lend insight into where further development is possible among the 254 dams. For instance, at low hydraulic heights (12 feet or less) there are a large number of dams (156) which have a relatively low amount of power available (79.1 megawatts in total). At these low heights, a very large flow of water is required to generate a sizeable amount of power. Dams on main rivers, such as the Mississippi, can be targeted as the best places for hydroelectric development within this category. In this manner, it has been found that redevelopment of four dams along the Mississippi would tap over 70 percent of the total available hydropower from dams with a height of twelve feet or less. Only one of these dams has generating facilities in place. Lock and Dam No. 2 (13 on the map) at Hastings has an installed capacity to produce 4.0 megawatts of electricity. The other three dams are at Lock and Dam No. 5 (5 on the map) just south of John A. Latsch State Park; Lock and Dam No. 5a (12) at Goodview; and Lock and Dam No. 7 (7) north of La Crescent.

The figures show instances where considerable power is available at a few dams.

*Avry Dotan and John Gulliver, Hydropower Potential at Existing Dams in the State of Minnesota. (Minneapolis: St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Project Report No. 225, June 1983).

Figure 1. Distribution of Minnesota Dams by Height*

*The Thomson Dam has been omitted.
Top Fifty Dams for Hydropower Potential in Minnesota

* Three of Minnesota’s thirty-two dams with generating facilities (Redwood Falls, Lanesboro, and a dam northwest of Fergus Falls) are not among the top fifty but are included here as well.
For example, there are seven flow rate
dams that have heights between nineteen and twenty-one feet. Together they represen
t 22.4 megawatts of available power. Two of these dams (those at Brainerd (19) and Grand Rapids (27)) have generating stations with a combined capacity to pro
duce 5.4 megawatts of electricity. The substan
tial power available at this height suggests that redevelopment of one or
more of the remaining five dams is viable. In
fact, the dam at Coon Rapids (11), which is twenty feet high, has the potential to gener
te 10.9 megawatts. Redevelopment of the
Coon Rapids dam would triple the installed
capacity for power generation of the dams with structural heights between nineteen and twenty-one feet.

Figures 2 and 3 show where no further
development can occur. The dams at Zumber
Lake (31) and Lake Blythesby (28) have hydralic heights of fifty-five and fifty-seven feet respectively. Their combined potential power is 3.8 megawatts. Both these dams have developed generating facilities that give an installed capacity of 6.8 megawatts, more than the actual power available. Simila
ry, the dam at Rapidan (21), southwest of Mankato, which has a height of sixty-two feet, already has an installed capacity for generating power that is larger than its actual potential power. The dam that is not shown in the figures, the Thomson Dam (1), falls in this same group. Its potential power is 73.0 megawatts while its installed capacity for generating power is 87.6 megawatts.

All together the total water power that is available at these 254 dams is 393.0 megawatts. At present, the sumed capacity for power at the thirty-two dams that have generating stations is 216.6 megawatts. These numbers can be misleading, how
ever. The calculations for available power assume that both the water flow and the ensu
ing power are constant throughout the year. The installed capacities of hydroelec
tric generators at these dams are sized to accommodate the seasonal fluctuations in flow rates; thus, the installed capacity for any given dam tends to be larger than its annual average of potential power available. The parameters of importance are the annual energy available and the electric energy generated in a year.

Since energy is power per unit of time, energy is calculated by multiplying power by an appropriate unit of time. The units for electrical energy are typically kilowatt
hours. For example, a 1,000 watt appliance (power) operating for one hour consumes one kilowatt-hour of electric energy. This report lists the annual energy available from hydropower and the electric energy gener
ated by Minnesota dams in units of gigawatt-hours. One gigawatt-hour equals one
million kilowatt-hours or one thousand megawatt-hours. The potential water en
ergy from these dams is estimated to be 3,443 gigawatt-hours a year. In 1985, total net electrical generation from these thirty-two dams was 1,045 gigawatt-hours.

Clearly, a small number of dams are making use of approximately 30 percent of the estimated water energy available at these 254 dams. These numbers, along with the Figures 2 and 3, present an overall perspective on the limits of hydropower at existing dam structures.

Power from Sites Without Dams

There are sites on rivers where electricity could be generated if a dam were built. At present, these sites are completely undeveloped. The Institute for Water Resources has listed sixty-eight such sites in Minneso
ta and provided estimates of their hydraulic height and the annual average flow rate of the water at each site.** An analysis, similar to that used on existing dams, shows that approximately 287 megawatts of water power flows past these sixty-eight sites.

These sites and the average annual power available at them are depicted in Figure 4. A few of the sites represent a large portion of the total power available: the site at 215 feet, for example, which is west of Mankato on the Blue Earth River, and the site at 78 feet, which is near Sandstone on the Kettle River. The top ten sites, in terms of power available, would produce 50 per
cent of the total energy that might be reali
zed from these 68 sites if they were developed. The top twenty sites represent 75 percent of the total available hydropower. Figure 4 shows where it would be best to pursue new projects.

Limits for Hydropower in Minnesota

Based on the data for the 254 existing dams and the sixty-eight potential dam sites, Minneso
ta's potential water power totals 5,957 gigawatt-hours per year. Approximately 3,443 gigawatt-hours of this potential is present at existing dams, while an esti
mated 2,514 gigawatt-hours flows past the sixty-eight undeveloped sites where no

dams have been built.

The total consumption of electricity in Minnesota, averaged for the years 1981 through 1985, is 29,864.4 gigawatt-hours a year. In 1985, the thirty-two existing hydropower plants produced 3.5 percent of this annual demand. Theoretically, Minnesota
might have produced 5,957 gigawatt-hours a year from hydropower. This would repre
sent 20 percent of the total annual demand for electricity.

In actuality, redevelopment of existing
dams to include electric generating facilities and construction of new dams with generat
ing capabilities could easily double the

Robert Geisen is completing his Ph.D. in mechanical engineering at the University of Minnesota. For his thesis, he is preparing an analysis of renewable energy systems in Minnesota. He com
pares the current energy use of each system with its potential and with current energy consumption in the state. This paper presents his analysis of hydropower. His work on hydropower was funded by CURA. Geisen teaches mechanical engineering as an assistant professor at Mankato State University.


neers, July 1979).