THE UNDEVELOPED HYDROELECTRIC POTENTIAL OF VERMONT

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List of Acronyms

ANR: Vermont Agency of Natural Resources

COE: U.S. Army Corps of Engineers

DPS: Vermont Department of Public Service

DOE: Department of Energy

FERC: Federal Energy Regulatory Commission

HPRA: Hydropower Resource Assessment, a publication of FERC

HP: Horse power

KW: Kilowatt

kWh: Kilowatt-hour

MW: Megawatt

mWh: Megawatt hour

NERBC: New England River Basin Council

Executive Summary

This review is the most recent in a series of studies of undeveloped hydroelectric potential in Vermont. Vermont has more than 1,000 dams, almost 200 of which are owned by the state or by local entities such as municipalities and fire districts. But these sites offer more than potential power sources. Many serve additional purposes, such as flood control, water supply, recreation, or fish and wildlife habitat.

In 1910, Vermont had 2000 turbines producing 170,000 horsepower – approximately 119 megawatts. During the early part of the 20th century, when there was an incomplete grid, many small hydroelectric facilities shut down as the grid developed. Re-development of these plants would provide distributed generation.

Many historic village dams pre-date other infrastructure (bridges, roads and buildings) and provide structural grade control. The US Army Corps of Engineers maintains five flood-control dams in the state, only one of which, the North Hartland site, currently generates any power. The Army Corps' Ball Mountain, Townshend, North Springfield and Union Village dams have all been investigated for power potential. Some have gone through much of the FERC licensing process but were not developed.

Vermont has lost more than 20 MW of hydroelectric generation between 1941 and 2005. The last hydroelectric plant was redeveloped in 1987. Twenty-two active developed sites – producing 54 MW of power in 1988 – could yield an additional 62.7 MW of hydropower with increases in efficiency and the addition of turbines (Federal Energy Regulatory Commission, 1988). Three of these sites, with an installed capacity of 1.7 MW and an undeveloped capacity of 0.8 MW, are no longer operational. The Vermont Agency of Natural Resources' hydroelectric database (June 2006) lists seven hydroelectric sites that are no longer operating and eight sites where the status is unknown. These inactive sites total at least 5,450 KW of capacity.

Existing databases from 1980 to 2006 were used to determine undeveloped hydropower potential in the State of Vermont. Each previous study used different assumptions that yield different results for power potential. There is no reliable estimate of the undeveloped hydroelectric potential in the state. The most important product of this study is a spreadsheet that integrates the limited and conflicting data sets available.

These studies show that there is anywhere from 25 MW of undeveloped hydroelectric at existing un-breached dams with greater than 50 KW capacity (New England River Basin Council, 1980) to 420 MW of undeveloped hydroelectric (Department of Energy, 1998) at 149 sites. A synthetic database developed based on the flow and topography of rivers estimates that Vermont has 1,022 MW of undeveloped hydroelectric potential, of which 322 MW of hydro-capacity is feasible to develop (Department of Energy, 2006).

This study tried to eliminate redundancy in the datasets. This was difficult because of the limitations of the existing data. A conservative analysis identified over 93,000 KW of undeveloped hydroelectric capacity at 332 existing dams.

Fifty-one sites of existing or breached dams were visited. Some of these sites have the entire infrastructure in place – trash racks, intakes, penstocks, turbines, generators and powerhouses. Other sites have some of the infrastructure in place. These sites could be redeveloped.

An economic analysis of developing these sites was not a part of this study. However, recent estimates for installation of hydroelectric are approximately $2,500 per kilowatt installed, exclusive of permitting costs.[1] Solar installations can cost up to $10,000 per kilowatt installed and wind up to $4,500 per kilowatt for small wind. Hydro-electric development can effect aquatic resources. This must be addressed to minimize impacts on aquatic biota.

[1] Mike Scarzello, Central Vermont Public Service, presentation at August 2006 Conference by the Vermont Center for Rural Development.

Introduction

Vermont has an abundance of the two principle components for generating local, hydroelectric power – hills and water. Indeed, the state has up to 1,022 megawatts (MW) of undeveloped hydroelectric potential (Department of Energy, 2006). No new hydroelectric site has been developed or re-developed in Vermont since 1987. An economic analysis was not part of this study, but recent estimates by Central Vermont Public Service show hydroelectric installations at $2,500 per installed kilowatt (KW).[2] Smaller installations are relatively more expensive.

Hydroelectric power – because of the potential impact on aquatic resources – is the only renewable energy source required to gain approval from numerous state and federal agencies. These include: the Vermont Public Service Board; the Vermont Department of Environmental Conservation, including its Facilities Division and Water Quality Division, and its Hydrology, Wetlands, Lakes, and River Corridor Management sections; the Vermont Department of Fish and Wildlife; and its Vermont Non-game and Natural Heritage Program; the Vermont Division of Historic Preservation; the U.S. Fish and Wildlife Service; and the Federal Energy Regulatory Commission (FERC).

Vermont has more than 1,000 dams, almost 200 of which are owned by the State or local entities such as municipalities and fire districts. In order to determine the undeveloped hydroelectric potential at existing dams in the state, the Vermont Department of Public Service requested that Community Hydro produce a synthesis of existing studies and data. This study examined and compared existing data sets from the Federal Energy Regulatory Commission, the Department of Energy (DOE)[3], the U.S. Army Corps of Engineers (USACE), the New England River Basin Council (NERBC), and the Vermont Agency of Natural Resources (ANR). The results of this synthesis of data are in a spreadsheet (Appendix A). This spreadsheet is the most important product of this study.

Despite this seeming abundance of sources, in the course of compiling this report it became clear that necessary detailed information on the majority of these sites was limited or unavailable.

A Brief History of Hydroelectric Power in Vermont

Vermont was built on hydropower, as mills and other small generating plants were a regular feature along the states waterways. In the 18th and 19th centuries, Vermont relied on hydro-mechanical power to operate the sawmills, grist mills and woolen mills that were the core of vital villages. Toward the end of the 19th century, mills began to produce electric power as well. The following chronology gives a brief overview of the rise and fall of hydroelectric generation in Vermont.

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[2] Mike Scarzello, Central Vermont Public Service, personal communication, August 2006.

[3] The results of the DOE studies are included. However, the 2004 and 2006 studies were developed on the basis of topography and hydrology. Therefore, they do not necessarily intersect with existing dams, so the results could not be integrated into the final estimate of undeveloped hydroelectric potential. The DOE studies (2004 and 2006) use hydro-potential. Hydro-potential numbers are doubled to arrive at installed capacity.

Chronology of Hydroelectric Generation in Vermont.

Year	Hydroelectric Development
~ 1740	First sawmill established in Westminster [1]
1810	269 water-powered mills in addition to saw- and grist-mills located in most communities [2]
1823	706 water-powered mills [2]
1885	Rutland First electric company established [3]
1886	Standard Light and Power, first power company – with 330 lights [3]
1888	Standard Light and Power with 2,500 lights in Montpelier and Barre [3]
1890	1,249 manufacturing establishments using 75,674 HP of water power [4]
1900	93,845 HP at sites that generate over 1000 HP [5]
1910	2000 hydro-turbines generating 170,000 HP [6]
1912	47 utilities producing 20,350 KW of hydroelectric generation [7]
1914	846 hydro-turbines producing 80,400 HP [8]
1929	241 hydro-turbines producing 39,900 HP [9]
1941	93% of Vermont's electrical demand supplied by in-state hydroelectric; 158 MW of hydroelectricity (not including Connecticut River and Deerfield Basin) [10]
1978	91 megawatts of hydroelectric power with 10 utilities [11]
2005	53.4 MW -Vermont Independent Power Producers 84 MW - Vermont Utility owned [12]
2005	Connecticut River Hydroelectric Projects (468 MW total): ▪ NH: 369 MW: Moore (192 MW), Comerford (164 MW), McIndoe Falls (13 MW). ▪ VT: 99 MW: Wilder (36 MW), Bellows Falls (41 MW), Vernon (22 MW). Deerfield River Hydro Electric Project (38 MW in Vermont, 7 MW in Massachusetts); Searsburg Reservoir(4 MW), Harriman Reservoir (34 MW), Sherman Reservoir (7 MW) [12]

1 - History of Vermont, Walter Crockett, Vol. 1, 1921
2 - History of Vermont, Walter Crockett, Vol. 3, 1921
3 - The Vermonter, January 1898
4 - History of Vermont, Walter Crockett, Vol. 4, 1921
5 - Industrial Vermont, 1914
6 - USGS Preliminary Report on Hydrographic Investigations in Vermont, 1910
7 - Thirteenth Biennial Report of the Public Service Commission.
8 - US Census, 1914
9 - US Census, 1929
10 - State of Vermont Water Resources and Electrical Energy, 1941
11 - New England River Basin Council, 1980
12 - Vermont Electric Plan, Department of Public Service, 2005

Background Information on Hydroelectric Capacity

Hydroelectric capacity is determined by measuring the height of the dam or, if there is no dam, the amount of head and the amount of flow. The amount of flow is a function of the size of drainage area or watershed. Dams with higher heads and higher flows can generate more power than dams with lower heads and flows. In assessing the economic potential of hydroelectric generation, it is important to remember that capital costs for equipment will be relatively lower with *higher* heads and *lower* flows.

All of the studies, except for the Department of Energy studies (2004, 2006) refer to the undeveloped potential as installed capacity. However, the DOE (2004, 2006) studies refer to hydroelectric potential. For the DOE studies, hydroelectric potential is doubled to arrive at installed capacity. For example, 100 KW of potential is 200 KW of installed capacity. This assumes a 50% capacity factor.

The Vermont Public Service Board's *Vermont Hydroelectric Development Handbook* (1980) provides an overview of the factors that go into development of hydroelectric power, including the basic theory, site evaluation, licenses and permits, feasibility studies, social and environmental concerns, marketing and financing, construction, and operations and maintenance.

The Vermont Agency of Natural Resources' *Hydropower in Vermont - An Environmental Impact Guidebook* (1983) discusses the environmental impact of hydroelectric power and includes a seven-page environmental-impacts checklist for compliance. The Vermont Agency of Natural Resources' two-volume *Hydropower In Vermont: An Assessment of Environmental Problems and Opportunities* (1988) provides an overview of impacts of hydroelectric generation at active hydroelectric sites in Vermont.

Methodology

The goal of this study is to use existing studies with some ground-investigation to identify undeveloped hydroelectric capacity at dams or dam sites in Vermont. No original work to determine capacity or hydro-potential was conducted as part of this study. The chief methodology was to combine databases and look for redundancy. This analysis of undeveloped hydro-capacity is intentionally conservative. If several sources calculated power potentials for the same site, the most conservative number was used. The limitations of the databases and study are discussed in a subsequent section.

Below is a summary of the 17 existing data sources reviewed in the compilation of this report (including web links if available). The most comprehensive Vermont database is the Vermont Dam Inventory (VDI) maintained by Brian Fitzgerald of the Facilities Division of the Vermont Agency of Natural Resources. This database was used as the foundation of an Excel spreadsheet (Appendix A). Other data sets were linked into the VDI using this integrated spreadsheet.

Data Sources

1. Virtual Hydropower Prospector, Department of Energy

This interactive web-based mapping software allows a user to identify potential hydroelectric sites in Vermont and throughout the country. The Department of Energy studies (2004, 2006) use hydro-potential. Hydro-potential is directly transferable to megawatt-hours (mWh) by multiplying the potential MW output by the number of hours in a year (8,760). According to the methodology used by DOE, the installed capacity for a hydroelectric plant is about double the hydro-potential – or 200 KW of installed capacity for 100 KW of hydro- potential.

> **Links:**
> Specific hydroelectric sites can be searched using the virtual hydropower prospector:
> http://hydro2.inel.gov/prospector/r_selector.shtml
> The manual on how to use the Virtual Hydropower Prospector is titled *The User's Guide: Virtual Hydropower Prospector Version 1.1* by Douglas Hall, Sera White and Julie Brizzee. November 2005. This can be downloaded at:
> http://gis.inel.gov/prospector/vhp_user_manual.pdf

2) Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants, Department of Energy, January 2006

This is a synthetic database derived from combining the geographic information system (GIS) digital elevation models and using half of the available stream flow. The majority of projects are not located at existing dams and would be developed using damless diversions and penstocks adjacent to the river. This study identifies 1,022 MW of undeveloped hydroelectric potential in Vermont. Of this, 606 MW is of high power potential (greater than one MW) and 416 MW is of low power potential (less than one MW). A detailed feasibility analysis of developing this hydro-potential further limits the amount of developable power. Feasibility was determined by using half the available flow, and penstocks that were the length for typical penstocks in the region (generally less than 2,000 feet in Vermont). This more restrictive feasibility study identified 112 MW potential of high power projects (at 41 sites), 71 MW of low power projects (at 259 sites) and 34 MW at 901 microhydro electric sites (greater than 10 KW and less than 100 KW) for a total of 217 MW of hydro-potential or 434 MW of installed capacity. 22 of these high power projects with 56 MW of hydro-potential have not been developed.[4] This leaves 161 MW of undeveloped hydro-potential -which is equivalent to 322 MW of installed capacity that is feasible to develop.

> **Links:**
> http://hydro2.inel.gov/resourceassessment/pdfs/main_report_appendix_a_final.pdf
> http://hydro2.inel.gov/resourceassessment/pdfs/appendix_b_2_final.pdf (Vermont specific data)

3) US Army Corps of Engineers Flood-Control Dams, 2006

The flood-control dams generally have the potential to develop between 1 MW and 3 MW of installed capacity. These are some of the largest undeveloped hydroelectric sites in the state. North Hartland dam is the only site currently generating power. The Ball Mountain, Townshend, North Springfield, and Union Village dams proceeded through some or all of the

[4] Douglas Hall, DOE, personal communication, 2007.

FERC licensing process, but were never built.[5] The hydroelectric potential depends on the operating regimen of the flood control dam.

Link:
Information on operating regime at the flood control dams is available at:
https://rsgis.crrel.usace.army.mil/nae/pls/nae/nae_web.nae_realtime.ProjectStatistics

4) Federal Energy Regulatory Commission Electronic Library, 2006
This searchable website lists all documents available as either microfilm or as portable document format (PDF) for all FERC filings in the nation. Many sites that were not built have existing license applications, site-specific flow and fish studies, and detailed documentation. The VDI does not reference most of the information available through the FERC electronic library. Many of these existing studies and permit applications could be adapted or used to allow the development of hydroelectric power at many sites without new studies. For example, some of the undeveloped flood control dams have almost 50 filings, and some have gone through licensing, but were never developed.

Link:
The older information is available for a fee off of microfilm and the newer information can be downloaded at: http://elibrary.ferc.gov/idmws/search/fercgensearch.asp

5) Active Federal Energy Regulatory Commission Sites
FERC publishes a Microsoft Excel spreadsheet of sites. It lists 45 licensed sites and 17 sites with exemptions in Vermont. Exempt sites do not require license renewal. Three of these sites are not currently active.

Links:
http://www.ferc.gov/industries/hydropower/gen-info/licensing/licenses.xls
http://www.ferc.gov/industries/hydropower/gen-info/licensing/exemptions.xls

6) Vermont Agency of Natural Resources Hydroelectric Database – June 7, 2006
The Microsoft Access database maintained by Brian Fitzgerald of ANR lists 86 operating hydroelectric facilities, 13 hydro-storage dams, and three sites that produce hydroelectric power without dams. These three sites use diversion structures and are not considered dams. Therefore, they do not have VDI identification numbers and cannot be linked with the VDI. This database includes 482 MW of installed capacity on the Connecticut River and 49 MW of installed capacity on the Deerfield River (531 MW total). This differs from the Department of Public Service (2005) total of 506 MW on these two rivers. The database contains information on ownership, gross head, power generated, license and federal 401 water-quality permit status (a requirement of the Federal Clean Water Act), stream name, dam name, and FERC and Vermont identification numbers. Installed capacity totals 707 MW, of which 5.5 MW is not presently operating. The power potential listed is not always correct. The sites operate with a range of state or federal oversight. The Lamoille River dams owned by Central Vermont Public Service Corporation (CVPS) are noted as having a license issued in 2005 without a 401 water-quality certificate. The table below summarizes the jurisdictional status of existing hydroelectric plants.

[5] Interest rates were up to 21% at that time (David Deen, personal communication, 2006).

Jurisdictional Status Existing Vermont Hydroelectric Plants	Number of Sites
Sites with FERC licenses and 401 certificates	38
Sites with FERC licenses without 401 certificates	6
Sites with FERC exemptions and 401 certificates	14
Sites with FERC exemptions without 401 certificates	4
Sites with no FERC license and with 401 certificates	4
Sites with no FERC jurisdiction and no 401 certificate	16

7) Vermont Dam Inventory (VDI), Vermont Agency of Natural Resources – June 7, 2006

This Microsoft Access database is maintained by ANR's Brian Fitzgerald. For 1,210 dams, including 170 breached dams, the VDI contains information on ownership, watershed size, dam construction, and regulatory agency. It does not contain information on power generated or potential. While it is the most complete dataset in Vermont, it is nevertheless incomplete. For example, this database does not contain information on some dams with more than 50 KW of potential that were visited and mapped as part of the New England River Basin Council study in 1980. Information in the VDI database (VDI.mdb) and another database (Hydro.mdb) is linked through a state identification number, although some hydroelectric sites are not in the VDI because they were developed without dams. One-third or more of the dams in this database contain extremely limited information, with little or no information on drainage area, dam construction, or waterbody. The database has specific location information (latitude and longitude) for 1,034 sites, but much additional work is needed to verify and correct the locations. This database does not reference existing information that is available through the FERC electronic library nor existing studies within ANR files.

8) Vermont Center for Geographic Information (VCGI), 2005

This geographic information system (GIS) layer contains a subset of the information available in the VDI. It locates approximately two-thirds (880) of the dams listed in the VDI and contains some of the fields available in the VDI. The attribute information was taken directly from VDI, so it is a snapshot of the inventory information as it existed in 2005. Like the VDI, the dam locations require further verification and correction as well as siting information for the VDI dams that are not in the VCGI layer.[6] It is not updated on a regular basis.

Link:
http://www.vcgi.org/dataware/ (as the emergency dam layer)

9) National Inventory of Dams (NID), US Army Corps of Engineers, 2005

The NID database is available both as a GIS layer and a Microsoft Access database. The NID may contain different names and different identifying numbers for the same dams as the Vermont Dam Inventory in the GIS layer. The NID contains information on 363 dams. There

[6] Brian Fitzgerald, ANR, personal communication.

is no information on power potential or generation. ANR has confirmed the entries in the NID. The NID GIS layer and the VCGI layer do not place all the dams in the same location. When ANR verifies and relocates the dams in the VDI and the VCGI layer, it will incorporate that into the NID.

Link:
http://crunch.tec.army.mil/nid/webpages/nid.cfm

10) Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources, US Department of Energy, April 2004

This is a synthetic database derived from combining the geographic information system (GIS) digital elevation models and using half of the available stream flow. The results are given in hydro-potential –which is roughly half of the hydro-capacity. The goal was to identify the areas that could produce the most power with the shortest bypass. It identifies 1,144 MW of total power potential, of which 128 MW has been developed and 49 MW has been excluded, leaving 967 MW of hydroelectric to be developed. It breaks the undeveloped potential into: 538 MW of high power potential; 345 MW of high head/low power potential; and 84 MW of low-head/low-power potential. Many of these sites could be developed using damless diversion techniques. The majority of sites do not intersect with existing dams. The methodologies used in developing this model require detailed field investigations to confirm power potential. This database cannot be easily incorporated into the dam databases. This study was further refined in the 2006 analysis by DOE. The 2006 study should be used in place of the 2004 study.

Links:
A state-by-state list can be found at:
http://hydro2.inel.gov/hydrofacts/undeveloped_potential.shtml
The main report is at: http://hydro2.inel.gov/resourceassessment/pdfs/03-11111.pdf
Vermont specific data is at:
http://hydro2.inel.gov/resourceassessment/pdfs/appendix_b-pt2.pdf

11) US Hydropower Resource Assessment Final Report, 1998: Vermont Hydropower Resource Assessment by River Basin, December 1998. US Department of Energy.

These DOE studies are based on the FERC Hydropower Resource Assessment (HPRA). They list the dam and name-plate rating for undeveloped hydroelectric capacity. They conclude that there are 420,700 KW of undeveloped hydroelectric capacity at 149 dams in Vermont. It gives the kWh potential associated with each site. Only limited information is given about the sites. Sites fall into three categories: 1) with developed infrastructure, 2) without developed infrastructure, and 3) undeveloped. Some of these dams are breached; some were never built. Mathematical assumptions were made on an environmentally sustainable potential (based on an environmental suitability factor and a multiplier). The environmental suitability factor changes the estimate of undeveloped hydroelectric capacity from 420.7 MW to 173.6 MW. Latitude and longitude are incorrect. This data set may contain different FERC numbers than the VDI or NID. The subsequent studies (2004 and 2006) by DOE rely on hydro-potential and not hydro-capacity.

Links:
Vermont specific data can be found at:
http://hydro2.inel.gov/resourceassessment/app_c/index_states.shtml?vt
The final report is at: http://hydro2.inel.gov/resourceassessment/pdfs/doeid-10430.pdf

12) Hydroelectric Generating Facilities in Vermont, 1991
Authored by Martha Bowers, this study covers the history of hydroelectric power in Vermont. There is no summary of hydroelectric potential or capacity. It does list previously active sites that could be re-developed.

> **Link:**
> http://www.culturalresourcegroup.com/pdf/vermonthydro.pdf

13) Hydropower In Vermont – An Assessment of Environmental Problems and Opportunities, Volume 1: Summary of Study and Results; Volume 2: Project Site Reports, Vermont Agency of Natural Resources, May 1988
Volume 1 gives an overview of environmental problems and opportunities of hydroelectric generation in the state. Volume 2 lists hydroelectric sites by basin that provide either storage or generation. It contains a narrative on each site. Each site has a range of information on stream classification, license status, 401 water quality certification status, habitat designation, project features (dam construction, turbine rating, drainage area), operational regime, bypass flows, length of bypass, fisheries, water quality and recreation/aesthetic issues, and recommendations for future studies. Not all of these hydroelectric sites are currently active.

14) Hydroelectric Power Resources of The United States: Developed and Undeveloped, Federal Energy Regulatory Commission, 1988
This study gives developed and undeveloped KW rating and kilowatt hours (kWh) generated in addition to gross static head. It concludes that there are 351 MW of undeveloped hydroelectric capacity at 225 developed and undeveloped sites, including breached dams. It details 82 developed hydroelectric sites with 248 MW of developed capacity. Of these developed sites, 22 sites that currently generate 54 MW have undeveloped capacity that could be redeveloped to generate an additional 62.7 MW of power. Nine of these sites generating 2.3 MW (in 1988) are no longer active. The Connecticut River dams with powerhouses in New Hampshire are not included in this database. In addition, this database lists 30 sites where the dams are breached, there is no dam, or the dam is located in New Hampshire. These sites are predicted to yield 67 MW of capacity. There is no location information. The total undeveloped capacity from these sites –exclusive of the dam in New Hampshire and breached dams – is 284 MW. Some of the dam names do not correspond to either the primary or secondary names on the VDI. Some of the developed sites are no longer active. The most recent HPRA database is not available publicly, but can be obtained with a non-disclosure agreement through FERC. This can take up to a year to obtain.[7]

15) Hydroelectric Power and the Development of the Utility Industry in Vermont: A Study in Historical Geography, M.A. Thesis of Robert Tucker, University of Vermont, 1986
This study identifies 7.7 MW of hydroelectric capacity at 29 sites that are no longer active.

16) Potential for Hydropower Expansion at Existing Dams in New England, Volume VIII, State of Vermont, New England River Basin Commission, 1980
This comprehensive study used eight existing databases as well as a survey of town clerks to identify 999 dams in Vermont, including breached dams. It lists the town, stream, site name,

[7] Douglas Hall, Department of Energy, personal communication.

drainage area and gross head available at each site. It identified 151 dams with 58.8 MW of baseload capacity (70% plant factor (60% capacity factor)) or 134 MW of peakload capacity (40% plant factor). The plant factor is typically the ratio of mean annual output (over a number of years of operation) of a power station to its maximum annual output if it operates at full capacity for the whole year. Sites were selected if they had over 50 KW of capacity and over five feet of head. At least 16 of these sites with approximately 18 MW of capacity were subsequently developed. Within the database are 64 breached dams that have 13.9 MW of capacity. Some of these are only partially breached. This leaves approximately 25 MW capacity that remains to be developed at 55 sites with more than 50 KW capacity. In addition, it lists 323 dams with between one and 49 KW of capacity that could generate 2.9 MW at baseload. The majority of the power at small sites with less than 50 KW of capacity is generated at 67 dams that can generate 1.8 MW at baseload.
The study ran an economic analysis at three interest rates and calculated the amount of oil that would not have to be consumed. It contains an identifying number for each dam that does not conform to the NID or VDI. Some of the potential sites mapped on the NERBC study do not show up in the GIS layers of the VDI or the NID. The study contains three maps: 1) all dams in Vermont, 2) dams with peak power potential generating more than 50 KW, and 3) dams with baseload power potential generating more than 50 KW. There are dams in the NERBC study that are not in the VDI. The NERBC source data includes:

- Green Report, Vermont State Energy Office, 1977
- Inventory of Dams in the United States, US Army Corps of Engineers, 1977
- Biennial Report of the Public Service Commission, 1952
- Steven Haybrook Report, Public Service Commission Water Conservation Report, 1951(map from 1952)
- List of Retired Hydro Sites, CVPS, 1978
- Operating Hydro Sites, CVPS, 1978
- Division of Historic Preservation, Inventory of 14 Dams, 1978
- Vermont Yearbook, List of State-owned Dams, 1977

17) Industrial Vermont: The Mineral, Manufacturing, and Water Power Resources of the Green Mountain State, Essex Junction, Vermont Bureau of Publicity, 1914
This study references an earlier study that identified 2 million horsepower (approximately 1,492 MW) of undeveloped hydroelectric potential in the state. This conforms reasonably well to the 2006 DOE study that identified roughly 1,100 MW of undeveloped hydro-potential in the state. In 1914, less than 80,400 HP (about 60 MW) of this potential had been developed for hydroelectric power. This book has a listing of developed and potential hydro-sites in each town.

Field Visits

In November and December of 2006, 51 sites with potential undeveloped hydroelectric capacity were visited. Selection criteria included the NERBC base maps (40% and 70% plant factor), and conversations with Robert Finucane of the ANR Facilities Divisions. This was a cursory survey. During site visits, the following information was noted for each dam:

- Town
- Name of dam
- Name of river or pond
- Dam construction
- Condition of dam
- Historic resources
- Presence of bedrock in the river or the banks
- Existing or remnant civil works, including intake, tailrace, powerhouse foundation and penstock
- Distance to transmission and method of transmission (single-phase or three-phase). Single phase transmission can handle generation of up to 20 KW.

Photos of each site are in Appendix B. These photos can supplement the photos of these sites taken for the 1980 NERBC study available from the Public Service Board.

In summary, two of the dams are currently being rebuilt (without hydroelectric), nine sites had breached dams, and four sites had some leakage around the right or left bank or the dam. The remainder of the dams appeared to be in good condition. Most of the dams had some level of civil works still in place. Only four of the sites had single-phase transmission nearby, the remainder had three-phase.

Although some dams were breached or partially breached, there is still hydroelectric potential. For example, in Windsor at the American Precision Museum, the upper and middle penstocks were lost when the dam breached, but a lower penstock is still in place. In other cases, the dams were fully breached, but a damless diversion at the natural head of the falls could be used to develop power (Thetford, Coventry).

The results of the fieldwork are in Appendix C.

Summary of Published Studies

The table below summarizes the published results of undeveloped hydroelectric capacity from previous studies. The power potential from breached dams (NERBC) is not included. The largest undeveloped capacity at existing dams in Vermont is found by re-developing existing sites to increase efficiency. The DOE 2004 study lists gross potential, while the DOE 2006 study lists feasible potential. Feasibility is based, in part, on the length of the penstock and the amount of power that can be generated using half the available flow in the river.

Summary of Undeveloped Hydroelectric Potential and Capacity in Vermont (from previously published studies)

Source Data	Number of Sites	KW Developed	mWh Developed	KW Undeveloped	mWh Undeveloped
NERBC 1980 Undeveloped sites only less than 50 KW and greater than 5' head. 70% plant factor - baseload. Breached sites not included.	89			45,094	270,363
FERC HPRA 1988 Undeveloped Sites	138			289,541	957,508
FERC HPRA Developed Sites	81	249,577	1,049,821	62,680	147,386
DOE 1998	149			420,700*	934,725
DOE 2004[1] Gross Power Potential. Figure B-222[1]				967,000	8,470,920
DOE 2006[1] Feasible Sites. Small Hydro and Low Power Feasible power potential. Figure B-92	300			183,000[2]	1,603,080
DOE 2006[1] Feasible Sites-Microhydro Feasible power potential. Figure B-92	901			34,000	297,840
ANR Hydro.mdb (includes CT River sites)	93	707,735	1,869,995		

[1] The DOE 2004 and 2006 studies use KW of hydro-potential. This is directly transferable to KWH by multiplying by 8760 (the number of hours in a year). The developable hydro-capacity is roughly double the hydro-potential, i.e., 100 KW of hydro-potential equals 200 KW of installed capacity.

[2] This study identified these same dams with 174,000 KW of environmentally sustainable potential.

Limitations of Data Sources

In the attempt to combine data sets, the goal was to have a single data set in order to evaluate and compare the undeveloped hydroelectric potential. Only three sources included undeveloped hydroelectric potential at existing dams, the NERBC (1980), DOE (1998) and HPRA (1988). These three datasets were integrated into the most comprehensive database – the VDI. The following datasets were used in the consolidated data.

- The Vermont Dam Inventory (VDI) and Hydro.MDB (ANR)
- Hydropower Resource Assessment (Federal Energy Regulatory Commission, 1988)
- Department of Energy Study (1998)
- New England River Basin Council Study (NERBC, 1980)

The combination of data sets from wide-ranging sources is, as to be expected, fraught with obvious complications and caveats. In short, these databases are not easily merged into a single, functioning relational database. An attempt to do so would be beyond the scope of this project. Below are examples of difficulties encountered in combining various databases:

Numbers: The VDI, NERBC and DOE studies all use different identifying numbers. Many of these unique identifying numbers are truly unique and do not conform to any previous studies or maps. The VDI and NID numbers generally conform. The FERC numbers do not conform between the Department of Energy study (1998) and the VDI. The 1980 NERBC numbers do not conform to subsequent studies.

Names: Dams have different names and multiple names are listed. Dams with the same name do not always conform to the same site. Although the VDI lists secondary names, these names do not always conform to other databases.

Watershed: Some databases list the river or watershed, others do not. Some databases list the wrong river and wrong watershed. The VDI lists drainage area in acres, while all the other databases list drainage area in square miles.

Town: The NID and HPRA do not list the town.

Ownership: Much of the ownership data is either out of date or differs among databases.

Status: There are sites identified as active hydroelectric in one database but when visited were found to be inactive hydroelectric. Other databases list undeveloped hydroelectric potential that has subsequently been developed. The State of Vermont maintains a Microsoft Access database (Hydro.mdb), which lists hydro-generation and storage. The capacity factors for developed hydroelectric power in that database are not all correct. The status of these sites differs from the FERC Excel spreadsheets of sites with licenses and exemptions. The NERBC maps and HPRA data do not differentiate between breached and un-breached dams for power potential. The final spreadsheet did not include hydropotential from breached dams nor from proposed dams

Location: The HPRA (1988) and DOE (1998) studies either include no locations, or latitude and longitude that are incorrect, sometimes placing the dams well into New York State or

Massachusetts. The majority of the locations in the VDI have been field-verified, but even some of the verified sites are not located correctly. Some of the NID locations overlap the VDI locations, but not all. Site locations still need to be verified. The NERBC sites are mapped, but no latitude or longitude is associated with the sites. The VCGI dam layer contains only about two-thirds of the sites in the VDI.

Construction: Of those studies that list dam height, structure height, hydraulic height or gross static head, different studies show a range of heights for the same dam. Because power potential is dependent on head, this variation can affect the actual power potential of a given site. Some of the dams listed as breached are only partially breached and still have some power potential.

Power Potential: The NERBC data for the more conservative 70% plant factor (baseload) was used in this analysis. The peak power factor data (40% plant factor) was not used. There is a range of accuracy in the power estimates. At the flood control dams, the assumptions behind the power potential are not clearly defined. The power potential appears to have been calculated for a static head. Some flood control dams are maintained with a permanent pool elevation, others have changing seasonal pool elevations, others are operated as dry-bed seasonally. The HPRA and DOE (1998) study have some overlap on power potential. When sites overlapped, the undeveloped power potential was only counted once.

The HPRA data and DOE (1998) data offer scant documentation on how the power potential was calculated. The published power generation potential from HPRA, DOE (1998), and NERBC was used in the Excel integrated spreadsheet (Appendix A) created as a result of this study. No attempts were made to recalculate power potential. The baseload capacity from NERBC is more conservative than the peak power potential and was therefore used.

The Department of Public Service (2005) and the Agency of Natural Resources (Hydro,mdb) may list different power potential for the same developed sites. Connecticut River sites are all claimed to be in Vermont. However, many of the Connecticut River sites, including the largest, such as McIndoe, Comerford, and Moore, have powerhouses located in New Hampshire. New Hampshire owns to the high water mark of the Connecticut River on the Vermont side.

Professional judgment and choices came into play on which published power capacity data to use. In all cases, the most conservative estimate of power potential was selected. For example, if a site was developed and had undeveloped power potential in HPRA (1988) that was less than what is listed in ANR's Hydro Access database, and that undeveloped power capacity was still shown in the DOE (1998) study, then the undeveloped capacity was included. If a site was developed after the 1980 NERBC study, then the NERBC potential was not used. In some cases, the undeveloped power potential for a former dam (such as the American Woolen Mill dam in Winooski on the Winooski River) was not included because this site was subsequently developed as Chace Mills. In some cases - such as on the Neshobe River (DOE, 1998), near Brandon - the estimated power potential was so large compared to the watershed that the undeveloped power potential was not included.

The 2004 and 2006 DOE databases are based on topography and hydrology and therefore could not be easily integrated into the dam database. On my request, Douglas Hall of DOE reviewed the feasible potential small hydro project sites in Vermont. Their approach was to intersect potential project penstocks with a 0.5 mile radius buffer around the plants in the VCGI database. DOE found that 20 of the sites previously identified as undeveloped sites matched with existing hydroelectric plants, and corresponded to 57 MW of erroneously claimed potential power. Douglas Hall concluded that at least 22 small hydro sites are not developed. These sites could yield 56 MW of potential or 112 MW of installed capacity.[8]

A cursory analysis of the low-power sites showed approximately 60 sites where existing dams intersect the 2006 DOE database. The hydro-potential from expanding penstocks below these dams was not determined. Instead the NERBC capacity based solely on the height of the dam with no penstock. For example, Caspian Lake is determined to have 7 KW capacity (NERBC); however, recent work by the Greensboro Town Energy Committee has determined that with a penstock below Caspian Lake, the power generation could be increased to over 60 KW.[9]

Prior to developing a site, it is recommended that a detailed pre-feasibility study to accurately assess power potential is conducted. This study is a synthesis of existing studies. Each have their limitations. The results should serve as a guide for detailed feasibility studies.

Undeveloped Hydroelectric Capacity at Existing Dams and Damless Diversions

The data was combined into a Microsoft Excel spreadsheet (Appendix A). The VDI was used as the foundation of the spreadsheet. The published developed and undeveloped hydro-potential from the NERBC (1980), HPRA (1988), DOE (1998) studies and ANR's Access hydro database (Hydro.mdb) was integrated into the VDI. The VDI and the hydro database have identification numbers that can be easily linked (except for the three damless diversions that are not considered dams and do not have VDI identification numbers). The remainder of the datasets were linked to the VDI using as many fields as possible (name, town, dam height, drainage area) to try to match the published hydroelectric potential with the correct dam in the VDI. The data from the DOE studies (2004, 2006) was not linked to any dam. This is because these studies rely on the topography and hydrology and the data is not associated with a specific dam.

Hydroelectric capacity from dams that are listed as breached in the VDI or the NERBC study was not used in the calculations. Hydro-capacity from dams that were proposed, but not built, from the HPRA was not included as developable hydroelectric.

The table below is a summary of the undeveloped hydroelectric capacity at existing dams (that are not breached). If a dam had several listings for undeveloped hydroelectric capacity, the most conservative or lowest possible capacity was always selected. The results from this study are intentionally conservative. Dams with less than one KW capacity were not included. The NERBC data only uses the height of the dam itself to calculate hydroelectric capacity. Additional power could be gained with the installation of a penstock in some case. The DOE study (2006) can be used to estimate increased potential that would come with the installation of a penstock below an existing dam.

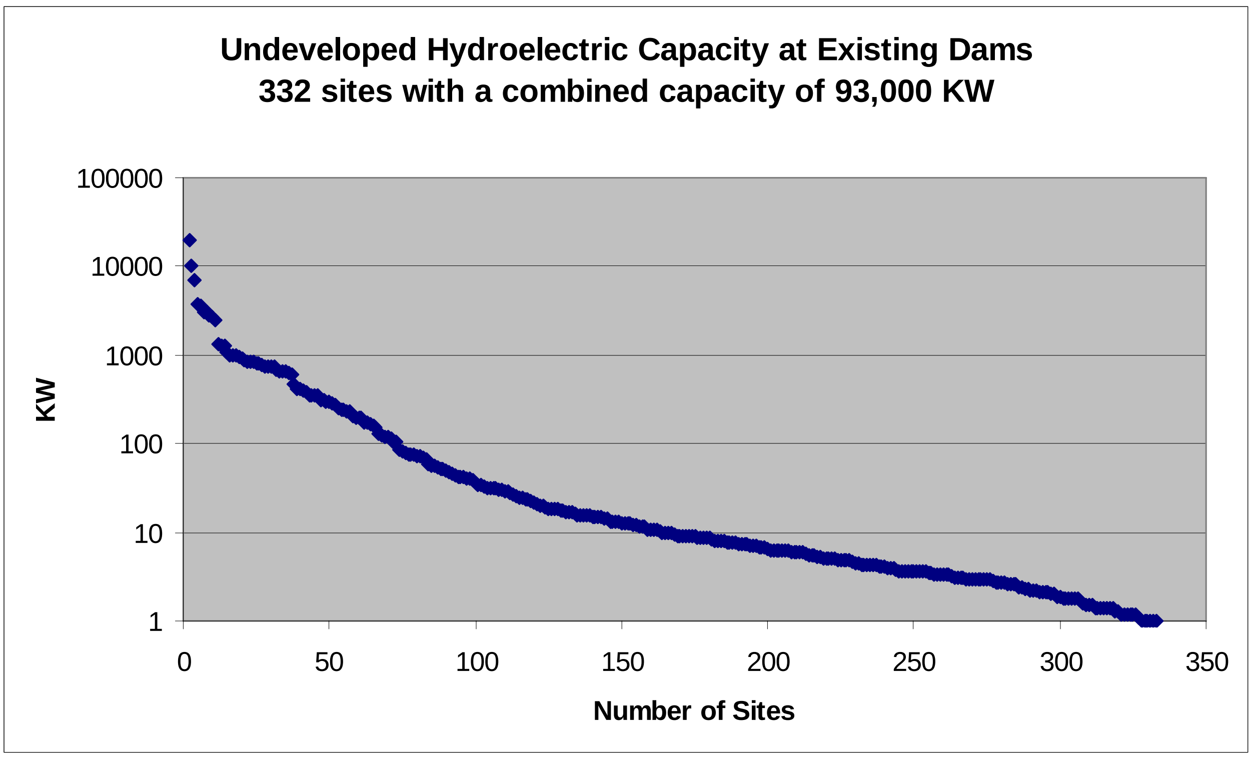
[8] Doug Hall, DOE, personal communication 2007.
[9] Anne Stevens, Greensboro Selectboard, personal communication, 2006

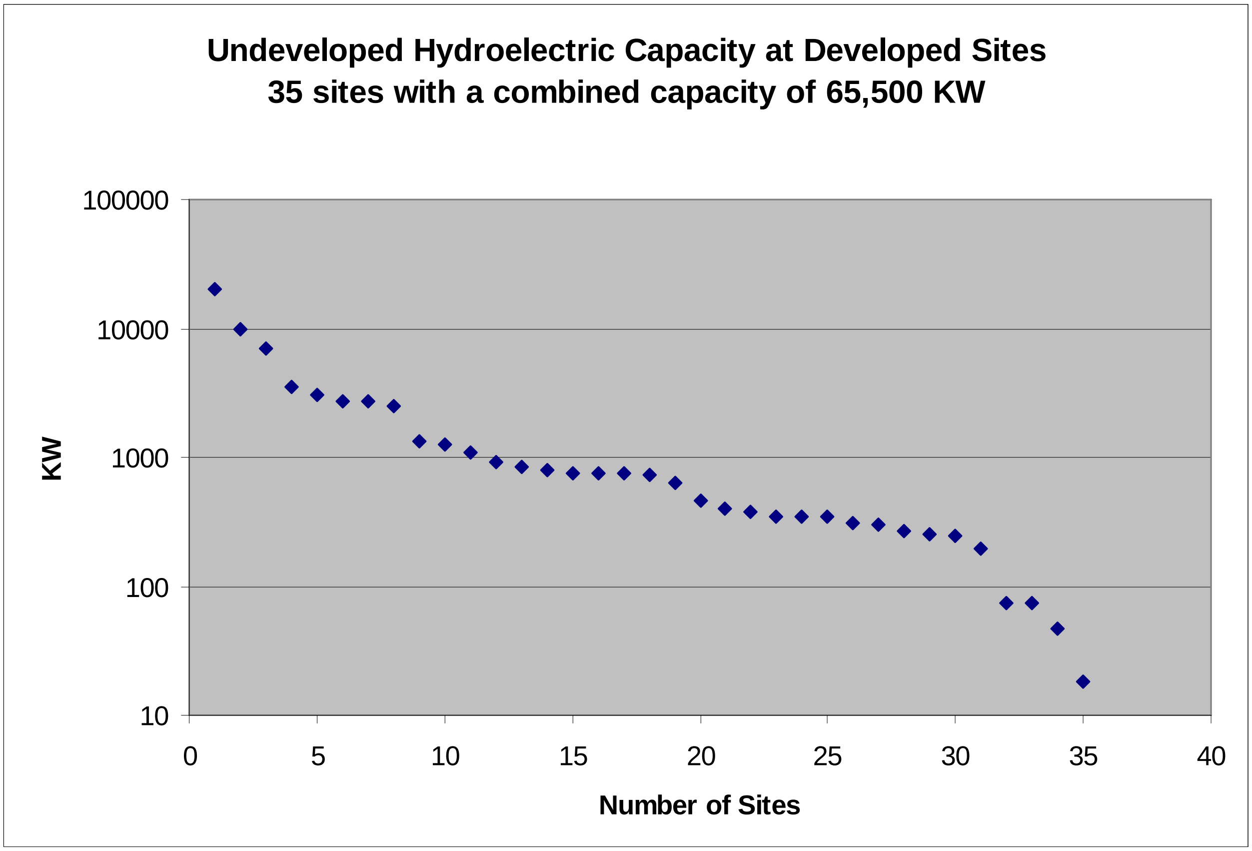
Due to the limitations of the data sets (discussed above), the accuracy is not verifiable without additional field work and analysis of each site.

Conservative Summary of Integrated Spreadsheet

Source Data	Number of Sites	MW Undeveloped
Greater than 50 KW at existing dams	89	91
Less than 50 KW at existing dams	244	2.3

The two charts below summarize undeveloped hydroelectric capacity at existing dams. In all cases, the most conservative assumptions were used to determine undeveloped hydroelectric capacity. The top chart includes all sites, developed and undeveloped, for a total of 93,400 KW of undeveloped hydroelectric capacity. The bottom chart breaks out the undeveloped power potential at developed sites. Some of the sites that were developed in 1988 are no longer producing power.





Conclusions

The loss of small-scale hydroelectric projects started early in the century. And no new hydroelectric power has been redeveloped in Vermont since 1987. Turbine technology has developed since the turn of the 20th century. Nor is the resource limited. Vermont has water and hills and the ability to produce hydroelectric power in an environmentally sound manner.

In 1910, Vermont had 2000 turbines producing 170,000 horsepower of power (approximately 119 MW). During the early part of the 20th century, many small hydroelectric facilities shut down as the state's electric grid developed.

Vermont has lost more than 20 MW of hydroelectric generation between 1941 and 2005. The last hydroelectric site was redeveloped in 1987. Many existing hydroelectric facilities are not developed to their potential. Twenty-two active developed sites – producing 54 MW of power – could yield an additional 62.7 MW of hydropower with increases in efficiency and the addition of turbines (Federal Energy Regulatory Commission, 1988). Three of these sites, with an installed capacity of 1.7 MW and an undeveloped capacity of 0.8 MW, are no longer operational.

While the basic turbine technology has not changed, the operational efficiencies of small hydroelectric sites has changed with the development of advanced controls. Hydroelectric sites can now be remotely controlled from the operator's home or office. Mechanized trash racks and compressed air systems to keep trash racks clear can keep systems operating efficiently. The increasing price of oil can change the economics of operating small hydroelectric sites. Two people can typically run five hydroelectric sites in the same region. The barriers to the development of small-scale hydroelectric generation are not technical nor resource based. They include concerns about dam safety, historical resources, fisheries, water quality, permitting and the interconnectedness of a grid. An interconnected grid allows for system reliability and multiple generation sources and was not available early in the 20th century.

Permitting is one of the largest challenges due primarily to the cost associated with the time and planning required to gain approval from numerous state and federal agencies including the Vermont Public Service Board; the Vermont Department of Environmental Conservation, including its Facilities Division and Water Quality Division, and its Hydrology, Wetlands, Lakes, and River Corridor Management sections; the Vermont Department of Fish and Wildlife; and its Vermont Non-game and Natural Heritage Program; the Vermont Division of Historic Preservation; the U.S. Fish and Wildlife Service; and the Federal Energy Regulatory Commission. Unlike solar power or wind power, hydroelectric generation facilities, regardless of their size or impact, must obtain permits from all of these entities.

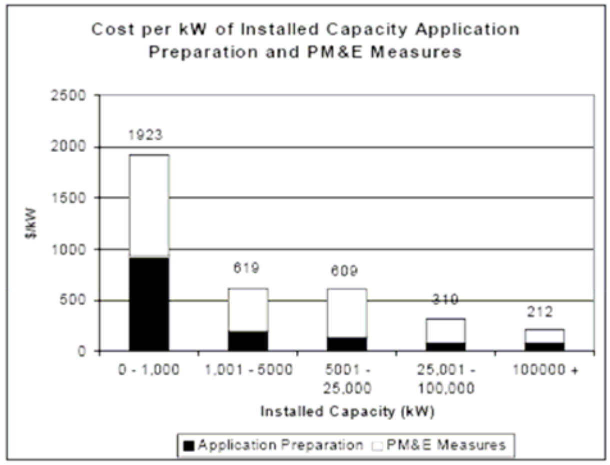
The regulatory system involves public participation. In some cases, small projects can have many interested parties. Yet for large and very large projects, fewer parties have the ability to engage in the process. Appropriate measures must be taken to address concerns about dam safety, historical resources, fisheries and water quality.

FERC estimates that the permitting, protection, mitigation and enhancement costs associated with small-scale hydroelectric development can add almost $2,000 per KW to the development costs (see the figure below). This makes small hydroelectric unaffordable.

Other countries have helped to encourage the development of small hydroelectric generation. The European Small Hydro Association helps to encourage the development of small hydroelectric generation. England offers reduced requirements for systems that are smaller than 500 KW. In addition, they offer grants of ₤1.000 per KW to a maximum of ₤5,000 per project. Municipalities can receive grants of up to 50% of project costs up to ₤100,000 (British Hydropower Association, 2005).

Hydroelectric's most recent heyday was in the early 1980s. At that time, oil prices and interest rates were high but tax and other incentives under the Public Utility Regulatory Policy Act (PURPA) were available. Vermont has the potential to develop 93 MW of power at over 300 existing dams and more through damless diversions. The redevelopment of small, environmentally sound, hydroelectric could help ensure the safety of the grid through increasing distributed generation.

Cost per KW of Installed Capacity for Permitting, Protection, Mitigation and Enhancement (Federal Energy Regulatory Commission, 2001)



Recommendations

It is important to carefully address concerns about dam safety, historical resources, fisheries and water quality. However, the state needs to decide that it wants to rebuild this renewable infrastructure.

In order to monitor and develop the state's undeveloped hydroelectric generating potential, we offer the following three recommendations:

Undeveloped Hydroelectric Generating Potential: The Department of Public Service might consider creating and maintaining a database of potential hydroelectric projects. This project may involve the following:

- The Department of Public Service should obtain a copy of the most recent HPRA database from FERC.
- The State of Vermont should establish and maintain an active database for developed and undeveloped hydroelectric capacity. The VDI is the most comprehensive active database. The newest HPRA data should be incorporated into the VDI along with undeveloped hydroelectric capacity.
- The Hydro.mdb data could be combined in the VDI as well. One problem with combining the Hydro.mdb data in with the VDI data is that some sites have been developed with damless diversions and do not show up in the VDI.
- The VCGI dam layer should be updated regularly from the VDI and should include developed and undeveloped hydroelectric capacity.
- Better coordination between federal and state agencies for dam name and number conventions would help to link databases.

Economics and Financing: This study did not include an economic or financial analysis. An economic and financial feasibility study should be conducted for five typical sites, such as a: flood control dam; mill dam; former hydro dam; damless diversion; and a water supply dam. Since no new hydroelectric has been developed in the State in 20 years, this study would address development costs at current prices with current conditions such as: the cost of fossil fuels; the availability of renewable energy credits and; greenhouse gas emission credits.

Permitting: Development of hydroelectric involves many state and federal regulatory agencies. An analysis of permitting associated with existing hydroelectric plants and recommendations to address the complex permit requirements should be completed to promote re-development of hydroelectric and ensure the protection of aquatic resources.

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