**Uniform Criteria for
U.S. Hydropower Resource Assessment

Hydropower Evaluation Software
Status Report-II**

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Published February 1996

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**Prepared for the
U.S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy
Under DOE Idaho Operations Office
Contract DE-AC07-94ID13223**

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ABSTRACT

The U.S. Department of Energy is estimating the undeveloped hydropower potential in the United States. The Hydropower Evaluation Software is a computer model that was developed by the Idaho National Engineering Laboratory for this purpose. The Hydropower Evaluation Software estimates the undeveloped hydropower resources available in the United States, using uniform criteria for measurement. The software was developed and tested using hydropower information and data provided by the Southwestern Power Administration. It is a menu-driven software application. Hydropower Evaluation Software allows the personal computer user to assign environmental attributes to potential hydropower sites, calculate development suitability factors for each site based on the environmental attributes present, and generate reports based on these suitability factors.

This status report describes Hydropower Evaluation Software's development, its data requirements, and its application to the 20 states assessed to date. This report does not discuss or present the various user-friendly menus of the Hydropower Evaluation Software. The reader is referred to the User's Manual for specifics. This report focuses on data derivation, summarization of the 20 states (Arkansas, Colorado, Connecticut, Indiana, Iowa, Kansas, Louisiana, Maine, Massachusetts, Missouri, Montana, New Hampshire, North Dakota, Oklahoma, Rhode Island, South Dakota, Texas, Utah, Vermont, and Wyoming) assessed to date, and plans for future assessments.

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ACKNOWLEDGMENTS

The authors would like to thank Peggy A. M. Brookshier and John V. Flynn of the Department of Energy for their active participation and timely comments. We also thank all those individuals from the 20 states assessed to date who provided active participation and feedback.

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INTRODUCTION

In June 1989, the U.S. Department of Energy (DOE) initiated the development of a National Energy Strategy to identify the energy resources available to support the expanding demand for energy in the United States. Public hearings conducted as part of the strategy development process indicated that the undeveloped hydropower resources were not well defined. As a result, DOE established an interagency Hydropower Resource Assessment Team to ascertain the country's undeveloped hydropower potential. The team consisted of representatives from each power marketing administration (Alaska Power Administration, Bonneville Power Administration, Western Area Power Administration, Southwestern Power Administration, and Southeastern Power Administration), the Bureau of Reclamation, the Army Corps of Engineers, the Federal Energy Regulatory Commission (FERC), the Idaho National Engineering Laboratory (INEL), and the Oak Ridge National Laboratory. The interagency team drafted a preliminary assessment and created a database of potential hydropower resources in February 1990. This preliminary assessment indicated that there were about 52,900 MW of potential hydropower energy in the United States.

Partial analysis of the potential hydropower resource database by groups in the hydropower industry indicated that the hydropower data included redundancies and errors that reduced confidence in the published estimates of developable hydropower potential. DOE continues assessing hydropower resources in order to correct these deficiencies, improve estimates of developable hydropower, and determine future policy. To support these efforts by DOE the INEL designed the Hydropower Evaluation Software (HES).

This report considers and discusses the undeveloped conventional hydropower resource potential. This does not include pumped storage hydropower potential.

Need for Uniform Criteria

HES considers a uniform set of possible site-specific environmental attributes to assess the likelihood of developing the potential hydropower resources of regions and states. These site-specific environmental attributes, derived from the Nationwide Rivers Inventory, include whether a site has Wild and Scenic Protection or is on a tributary of a site with such protection; whether cultural, historical, fishery, geologic, recreational, scenic, or wildlife values are present; and whether threatened or endangered fish or wildlife are present. The attributes are based on the potential project's location, including whether the site is within a national park, national grasslands, national wildlife refuge, or other federal lands. HES's use of uniform criteria allows personal computer users nationwide to identify environmental attributes present at sites with undeveloped hydropower potential, calculate development suitability factors for each site based on the attributes present, and generate uniform reports based on these factors.

The HES was developed as a tool to measure the undeveloped hydropower potential by regional power marketing administrations and state energy agencies, because they are the most likely to need accurate hydropower information. HES was not intended to provide precise development factors for individual sites, but to provide regional or state capacity totals. Because the software was developed as a generic measurement tool encompassing national issues, regional and

state totals must be considered judiciously; various local issues may skew hydropower potential totals. Employing HES as a national measurement tool will smooth any local anomalies.

Model Development

HES, both a database and a probability-factor computer model, is a menu-driven software application that is intended to be user-friendly. Computer screens and report generation capabilities were developed to meet the needs of users nationwide. The software uses environmental attribute data to generate an overall project suitability factor between 0.1 and 0.9. A combination of attributes results in a lower suitability factor because multiple environmental considerations reduce the likelihood that a site may be developed to its physical potential.

The HES was developed in conjunction with the Oak Ridge National Laboratory, which provided the essential environmental evaluation support (Sale 1990). The INEL also received valuable assistance from the South-western Power Administration, which defined the database requirements and the reporting capabilities required by a power marketing administration.

Model Testing

The INEL used the HES to assess the undeveloped hydropower potential in the Southwestern Power Administration area during the HES testing stage. The states in this area include Arkansas, Kansas, Louisiana, Missouri, Oklahoma, and Texas. HES identified about 250 sites with undeveloped hydropower potential. After the HES computer model analysis was completed, the estimated Southwestern Power Administration hydropower resources were reduced 33.5%. This reduction resulted from the influence of various

environmental attributes on the reality of successfully developing a hydropower site.

After successfully developing and testing the HES in conjunction with the Southwestern Power Administration, the INEL recognized that a process was necessary to successfully integrate the evaluation process between the individual states and the DOE's Hydropower Program. With administrative relationships already in place with the individual states, the INEL believed that using the DOE Support Offices to coordinate the assessment process might prove to be a practical method to assess the entire United States. The Denver Support Office coordinated the assessments of the individual states within their administrative region (Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming), as did the Boston Support Office (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont), the Kansas Support Office (Iowa), and the Chicago Support Office (Indiana). The test assessments, including obtaining individual state input, proved to be a viable method that could be used to assess hydropower potential throughout the United States.

Model Goal

The goal of the HES is to assemble an accurate database of all sites with undeveloped hydropower potential in the United States for use as a planning tool to determine the viable national hydropower potential. The undeveloped hydropower potential is not limited to the development of new sites; it also includes the development of additional hydropower generation capabilities at sites that currently have hydropower but are not developed to their full potential. This undeveloped hydropower potential is a source of nonpolluting, renewable energy available to meet the growing power needs of the United States. The HES should make this goal obtainable and help ensure a set of uniform criteria for national assessment.

DATA SOURCES

Primary Data Sources

The FERC's Hydropower Resource Assessment database and the National Park Service's Nationwide Rivers Inventory database are the two main information databases used for hydropower site data. State input is used to validate the results of HES models.

Hydropower Resource Assessment Database. This database is maintained by the FERC and contains the best available national inventory of undeveloped hydropower potential. It contains information about all sites that have been subject to any FERC hydropower licensing action and information on project sites that have been identified by the FERC, or other agencies, as having development potential even if no licensing action has taken place. This database lists project sites and corresponding basic site data. Approximately 4,500 sites with undeveloped hydropower potential are listed in the Hydropower Resource Assessment database.

Nationwide Rivers Inventory Database. The Nationwide Rivers Inventory was initially completed in 1982 by the National Park Service and has been periodically updated since that time. Park Service regional offices systematically collected information on rivers and identified those with outstanding resources. Uniform procedures for identifying rivers for the Nationwide Rivers Inventory—including field and map verification of each river's values—were applied throughout the country. Specific outstanding resources were identified for those river reaches selected for inclusion in the Nationwide Rivers Inventory. Reaches were identified if outstanding fisheries, wildlife, geologic features, historical resources, cultural resources, recreation resources, scenic values, or other resources were present. The Nationwide Rivers Inventory also indicates the presence of threatened and endangered species (classified as fish or terrestrial wildlife) and whether the reach is part of, or considered for, inclusion in a state or federal wild and scenic rivers program.

Although the National Park Service used uniform procedures to consider rivers throughout the United States for inclusion in the Nationwide Rivers Inventory, it would be incorrect to assume that if a potential site is not on a reach listed in the Nationwide Rivers Inventory there would be few environmental impediments to development: significant changes, such as new fisheries or increased recreational use, may have occurred since the Nationwide Rivers Inventory was last updated.

State Resource and Energy Agencies.

After the information contained in the FERC's Hydropower Resource Assessment and the National Park Service's Nationwide Rivers Inventory databases were entered into the HES, the modeled results were presented to the natural resource departments or energy offices of Colorado, Connecticut, Indiana, Iowa, Maine, Massachusetts, Montana, New Hampshire, North Dakota, Rhode Island, South Dakota, Utah, Vermont, and Wyoming. Each state was then able to provide input, validate, and in many cases update the environmental and physical attributes present at each of the undeveloped hydropower sites. Additionally, the individual states were able to add previously unlisted sites that were known to state agencies as having undeveloped hydropower potential.

State input is often the result of coordinated canvassing between several state agencies within each state. For instance, water management agencies may identify sites with undeveloped hydropower potential that were not listed in the FERC's Hydropower Resource Assessment database. Or, state agencies may be aware of state historical sites such as archeological sites of early Indian societies or other historical values that would impact the probability of developing a hydropower site. This state input often results in an adjustment of a site's overall project suitability value. In the case of the addition of previously unidentified sites with undeveloped hydropower potential, a state's sum of undeveloped hydropower potential may be increased. The value of state input to the modeling of undeveloped hydro-

power potential cannot be overstated. Each state is the best source of local site knowledge.

Secondary Data Sources

Other data sources can also be used to identify project locations and to assign environmental attributes to these locations. Some of these data sources are national in coverage, while others are available only for smaller areas such as individual states. Each additional database used will need to be obtained from its source, and the environmental attributes it lists will need to be extracted.

Power Marketing Administrations. Power marketing administrations possess significant information that is important to the successful application of the HES. Each power marketing administration can verify any outside sources of data that are used; but, of greater importance, each power marketing administration can provide significant information about anything affecting potential hydropower development within its region. Power marketing administrations will be aware of possible state opposition and any local action regarding a specific project.

State Environmental Databases. Many states keep inventories of aquatic and riparian resources. These inventories can include lists of high-quality and possibly protected streams, natural areas, and recreational resources. State data is often very useful for determining the environmental feasibility of hydropower sites, but the data may require a great deal of manipulation before it can be incorporated into a regional database for hydropower evaluation. Because little state information is available in digital format, it is difficult to input state data into the HES database.

An example of a state database is the California Department of Fish and Game Wild Trout Program inventory, which lists streams identified as outstanding trout fisheries; such streams are protected from development under California law. As another example, the state of Utah has rated each of its streams by the following categories:

(a) type of fishery, (b) productivity, (c) reproductive success, (d) spawning habitat, and (e) aesthetics. Projects on streams with high ratings in these categories will have greater environmental concerns.

American Rivers Outstanding Rivers List.

During 1988, an organization named American Rivers published its Outstanding Rivers List. This list is a comprehensive, nationwide compilation of rivers that possess some outstanding ecological, recreational, natural, cultural, or scenic values. Rivers protected by legislation and rivers currently unprotected are included. The list contains an estimated 15,000 river reaches, totalling about 300,000 river miles. Each river reach is described in terms such as its upriver and downriver end points, its total length, its significance, and the source of information. Some of this information is redundant with the Nationwide Rivers Inventory, which is included within the Outstanding River List, but much of it is additional information.

Northwest Power Planning Council.

Streams under the jurisdiction of the Bonneville Power Administration have been studied by area states and rated by the Northwest Power Planning Council for the suitability of additional hydropower development. Streams were rated for values such as anadromous fish presence, resident fish populations, wildlife, natural features, cultural features, and recreation. In 1987, the Northwest Power Planning Council published a list of streams deemed unsuitable for hydropower development, which generally includes all streams containing anadromous fisheries. For projects proposed in the Bonneville Power Administration marketing area, the stream ratings are an important source of environmental attributes.

Wetlands Inventories. The presence of wetlands that could be affected by a potential hydropower project is an important environmental attribute because wetlands are protected under the Clean Water Act. The U.S. Fish and Wildlife Service has inventoried wetlands in some regions, and maps of these inventoried wetlands are avail-

able. Wetland inventories are also available from some states.

Data Sources for Threatened and Endangered Species

U.S. Fish and Wildlife Service Threatened and Endangered Species Database. Geographic information in this database is given by county and hydrologic unit—and sometimes at finer resolutions. Species information includes locations of species, life histories of species, legal histories of the designation as threatened and

endangered species, habitat use, bibliographies, contact people, and key words that identify species as aquatic, wetland, or riparian species. The database has been in transition between in-house development and contracted management (by the Nature Conservancy) for several years. It appears that a wealth of information exists but may be difficult to access.

Nature Conservancy. The Nature Conservancy has a national database of all species that identifies threatened and endangered species. This database organizes geographic information by county.

DATA REQUIREMENTS

Basic Site Data

The INEL obtained the basic site data for each of the undeveloped sites from the FERC's Hydropower Resource Assessment database. The following data fields were copied into the HES from the Hydropower Resource Assessment database for each site. The names used are the actual structural names assigned to each field in the database. (Note: "_" is used in dBASE as a separator character.)

PROJNUM. The number assigned to each project by the FERC. When a PROJNUM is not assigned for a project, the user is strongly encouraged to provide a pseudo number (see *Hydropower Evaluation Software User's Manual*).

PLANT_NM. Name of the project.

STREAM. Name of the stream where the project is located.

STATE_NM. Name of the state where the project is located.

LAT_U. The latitude of the site.

LONG_U. The longitude of the site.

CLASS_C. The owner class code:

C = Cooperative

F = Federal

I = Industrial

M = Municipal and other nonfederal

P = Private utility

R = Private nonutility.

OWNER_NM. Name of the project owner.

KWRATE_P. The Hydropower Resource Assessment database estimated potential nameplate rating (KW) of the project. This is not the current capacity at a developed site. It is the undeveloped potential capacity at a site or the potential *additional* capacity of a site that already has power generation capability.

GEN_AA_P. The Hydropower Resource Assessment database estimated potential Average Annual Generation (MWh) of a site. This is *not* the current average annual generation at a developed site but the undeveloped potential average annual generation at a site or the potential *additional* average annual generation of a site that already has power generation capability.

UNITYP_P. Type of unit:

C = Conventional

R = Reversible

Z = Missing.

PLANTTYP. The project type or type of operation:

CMB = Combined conventional and reversible units

DIV = Gravity diversion (powerhouse on different stream)

PDV = Pumped diversion (one-way pumped storage)

PMP = Pure (recycled) pump storage

RES = Reservoir only

ROR = Run-of-river (dam 10 ft high with minimal storage)

RRG = Reregulating

STG = Storage, conventional (dam > 10 ft high with significant storage)

TID = Tidal conventional
hydropower.

STATUS_C. Project status code:

DJ = Disclaimer of Federal Energy Regulatory Commission jurisdiction

EA = Exemption applied for

FA = Federally authorized

FR = Federally recommended

LE = License exception

LJ = Lack of Federal Energy Regulatory Commission jurisdiction

MA = Federal Energy Regulatory Commission major license application

MO = Federal Energy Regulatory Commission major license outstanding

NA = Federal Energy Regulatory Commission minor license application

NO = Federal Energy Regulatory Commission minor license outstanding

PA = Federal Energy Regulatory Commission preliminary permit application

PO = Federal Energy Regulatory Commission preliminary permit outstanding

XX = No status

YO = Federal Energy Regulatory Commission minor part license outstanding

ZZ = Missing.

BASIN_NM. The river basin where the project is located.

CNTY_NM. The county where the project is located.

Not all of the above 15 variables are present for each site in the Hydropower Resource Assessment database, and the information the database provides is not always accurate. Each state or power marketing administration should review these data and verify their authenticity.

Environmental Attribute Definitions

The INEL derived the following 19 environmental attributes from the Nationwide Rivers Inventory. The corresponding suitability factors are fully explained in the Suitability Factor Determination section.

Wild/Scenic Protection. This attribute identifies project sites that are included in the federal wild and scenic rivers system, under consideration for inclusion in the federal system, included in a state river protection program, in a designated wilderness area, or protected from development under another program. Relatively few sites have this status, but those that do are highly unlikely to be developed. Projects at undeveloped sites on state or federally protected wild and scenic rivers, or in wilderness areas, must be assumed to be legally protected from hydropower development. Also, projects at sites under consideration for protection are highly likely to be opposed by state and federal resource agencies, and protection will be approved at many such sites before hydropower development could occur. Since it is possible, but highly unlikely, that development could occur at a site with wild and scenic river protection, the suitability factor assigned to all such projects at undeveloped sites is 0.1.

It is highly unlikely that a project at an existing dam would be on a wild and scenic river since rivers are usually designated as wild and scenic only if they are free of developments such as dams. A suitability factor of 0.5 is assigned for such unusual cases.

Wild and Scenic Tributary or Upstream or Downstream of a Wild and Scenic Location. This attribute is assigned to a project if it is at the upstream or downstream end of a wild and scenic river reach or is on a tributary of a wild and scenic river. A project at a developed site would affect a downstream wild and scenic river if additional alterations to the flow regime resulted. A suitability factor of 0.75 is assigned for such projects. Projects at undeveloped sites are highly likely to alter the flow regime and may cause changes in downstream water quality, so a suitability factor of 0.5 is assigned to undeveloped sites.

Cultural and Historic Values. Project impacts on cultural and historic resources can often be mitigated (for example, by excavating archeological sites or relocating historic structures). Projects at existing dams are unlikely to affect such resources unless an increase in reservoir pool elevation occurs or major new structures are built. A suitability factor of 0.75 is assigned to such projects. Development of undeveloped sites is more likely to affect cultural and historic resources, so a suitability factor of 0.5 is assigned.

Fish Presence Value. A stream reach may or may not have legally protected fisheries. In either case, however, strong state opposition to new development must be expected if a valuable fishery resource exists. Relatively high instream flow release requirements can mitigate the impact on fisheries, but a high instream flow release would reduce the economic viability of the project. Projects at developed sites could have some impact, such as increased turbine mortality. A suitability factor of 0.75 is assigned to projects at developed sites. Development at undeveloped sites could have a major impact on aquatic habitat through inundation, migration blockage, turbine mortality, water quality, and altered flows. Some of these can be mitigated, but such mitigation could be expensive. A suitability factor of 0.25 is assigned to undeveloped sites.

Geologic Value. Geologic values such as rock formations are rarely protected legally and are not

generally affected by small projects. Development at existing sites is not affected by geologic resources, so a suitability factor of 0.9 is assigned. Development at undeveloped sites may inundate geologic features, so a suitability factor of 0.5 is assigned.

Recreation Value. River recreation users tend to be effective opponents of hydropower development. Development at any storage dam would affect recreation by altering flow releases; mitigation typically includes higher flow releases during periods of high recreation use. Such releases can be made through turbines, but higher flow releases tend to occur when power demands are low. Projects at existing dams would have little effect on recreation besides flow alterations, so they are assigned a suitability factor of 0.75. Projects at undeveloped sites would inundate reaches, block the passage of boats, and reduce aesthetics. Because projects at undeveloped sites are likely to be strongly opposed, a suitability factor of 0.25 is assigned.

Scenic Value. Scenic values are not legally protected but must be considered in assessing the impact of a project. Scenic values are also important to recreational river users. The addition of power to existing dams would alter scenic values only through the addition of new structures and perhaps by reducing visually attractive spillage, so a suitability factor of 0.9 is assigned. New projects at undeveloped sites would have important effects on scenic resources because views would be altered by the project. Undeveloped projects are assigned a suitability factor of 0.5.

Wildlife Value. Terrestrial wildlife and wildlife habitat are protected by fish and game agencies that are influential in determining mitigation requirements for hydropower projects. Development at existing sites would have little effect on wildlife unless reservoir pool elevations are altered or construction of major facilities is required. A suitability factor of 0.75 is assigned for projects at existing sites. Development at undeveloped sites could inundate wildlife habitat, and construction would cause a great deal of disturbance. It is difficult to mitigate for such impacts, so opposition to

such a project could be strong. Undeveloped projects are assigned a suitability factor of 0.25.

Other Value. The effects of other values, such as the presence of rare wetland communities or consideration for wilderness designation, are assigned by using the most commonly assigned suitability factor for the other values. For projects at developed sites, the suitability factor is 0.75. For projects at undeveloped sites, the suitability factor is 0.5.

Threatened and Endangered Fish or Wildlife. The presence of threatened and endangered species near a project site requires additional consultations with wildlife agencies and can result in additional studies and mitigation requirements. The presence of threatened and endangered fish species may preclude development of new storage projects because new projects can involve the greatest alteration of aquatic habitat. Terrestrial threatened and endangered species are unlikely to be highly affected by run-of-rivers projects, but storage reservoirs could affect terrestrial habitat. For existing sites, a suitability factor of 0.75 is assigned when threatened and endangered species are present. For projects at undeveloped sites, a suitability factor of 0.5 is assigned when threatened and endangered species are present.

Federal Land Code 103: National Park, Monument, Lakeshore, Parkway, Battlefield, or Recreation Area. These lands are legally protected from development. A suitability factor of 0.1 is assigned for such projects.

Federal Land Code 104: National Forest or Grassland. These lands are not legally protected from development, but the managing agency has the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned to projects at existing sites, since these projects typically have fewer impacts.

A suitability factor of 0.5 is assigned for undeveloped sites.

Federal Land Code 105: National Wildlife Refuge, Game Preserve, or Fish Hatchery. These lands are managed for fish and wildlife habitats, and hydropower development would almost always be incompatible. A suitability factor of 0.1 is assigned for such projects.

Federal Land Code 106: National Scenic Waterway or Wilderness Area. These lands are legally protected from development. A suitability factor of 0.1 is assigned for such projects.

Federal Land Code 107: Indian Reservation. These lands are not legally protected from development, but Indian tribes have the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned for projects at developed sites, and a suitability factor of 0.5 is assigned for projects at undeveloped sites.

Federal Land Code 108: Military Reservation. These lands are not legally protected from development, but the managing agency has the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned for projects at developed sites, and a suitability factor of 0.5 is assigned for projects at undeveloped sites.

Federal Land Code 198: Not on Federal Land. This variable indicates that the project is not on federal land, so there are not any development constraints based on Federal Land Codes. The value for this variable is 0.9.

Figure 1 delineates all of the data requirements presented above in a report menu option from the HES. The cultural, fish presence, historic, and scenic values combine to give the sample site a project suitability factor of 0.25.

RESOURCE DATABASE LISTING

DATE: 03/26/93

PAGE NO: 1

FERC NUMBER SW0006	PLANT NAME Kirkland	STREAM NAME Smackover Cr, Ouachita R	STATE NAME AR
	COUNTY NAME Ouachita	RIVER BASIN Ouachita-Black River Basin	
	CLASS P	OWNER NAME Downhill Water Associates	
NAME PLATE RATING (KW) 4000.00	ANNUAL ENERGY PESF PESF * KW 0.25 1000.00	PESF ANNUAL RATING (MWh) 6000.00	Energy Rating (MWh) 1500.00
Unit Type C	Plant Type STG	Project Status ZZ	Dam Status U
			Latitude 0.00 Longitude 0.00

Factor	Exist	Prob	Factor	Exist	Prob
Wild/Scenic Protection		0.90	Wildlife Value		0.90
Wild/Scenic Tributary or Upstream/Downstream of a Wild/Scenic Location		0.90	Threatened/Endangered Fish		0.90
Cultural Value	Y	0.50	Threatened/Endangered Wildlife		0.90
Fish Presence Value	Y	0.25	Federal Land Code 103		0.90
Geologic Value		0.90	Federal Land Code 104		0.90
Historic Value	Y	0.50	Federal Land Code 105		0.90
Other Value		0.90	Federal Land Code 106		0.90
Recreation Value		0.90	Federal Land Code 107		0.90
Scenic Value	Y	0.50	Federal Land Code 108		0.90
			Federal Land Code 198		0.90
			PROJECT SUITABILITY FACTOR:		0.25

Figure 1. Sample printout of resource database listing.

SUITABILITY FACTOR DETERMINATION

Suitability Factor Values

Suitability factors depend on the environmental attributes of the potential project site. They reflect the probability that environmental considerations can make a project site unacceptable, prohibiting its development. The suitability factors were developed in conjunction with the Oak Ridge National Laboratory staff who are experienced in hydropower licensing cases. Five potential values were selected, as shown in Table 1. *These suitability factors are appropriate only for the regional analysis of overall hydropower development potential and are not useful for determining the ultimate viability of developing a specific project site.*

Dam Status

The effects of environmental attributes vary by dam status. The dam status classifications follow the FERC standard, which is

W = Developed hydropower site with power.

W/O = Developed site without power generation (the site has some type of developed impoundment or diversion structure).

U = Undeveloped site (the site does not have power generation capability, no developed impoundment, nor a diversion structure).

Undeveloped sites do not have any power or civil structures in place; developed sites without power do not have any power generation capability but do have some type of civil structure such as a dam or water diversion structure; and developed sites with power have current generation and a civil structure onsite with additional, undeveloped hydropower potential.

The best way to explain the influence dam status has on a project's environmental suitability factor is to provide an example: development at an undeveloped site will have a greater impact on recreation than additional development at a site that is already developed. So if a recreation value is present at an undeveloped site, a probability of 0.25 is assigned to reflect the decreased likelihood of development. If a recreation value is present at a developed site (either with or without power), then a value of 0.75 is assigned because development of a site already having a structure, either with or without power, is less likely to be impacted by any recreation value. These factors and all the other factors used are shown in Table 2.

Table 1. Valuation of environmental attributes.

Effect of environmental attributes	Value of suitability factor
Little effect on likelihood of development	0.90
Minor reduction in likelihood of development	0.75
Likelihood of development reduced by half	0.50
Major reduction in likelihood of development	0.25
Development prohibited or highly unlikely	0.10

Table 2. Suitability factors by dam status for environmental attributes.

Environmental attribute	Suitability factors		
	Existing dam with/without power	Undeveloped site	Not applicable
Wild/Scenic Protection	0.50	0.10	0.90
Wild/Scenic Tributary or Upstream/Downstream Wild/Scenic Location	0.75	0.50	0.90
Cultural Value	0.75	0.50	0.90
Fish Presence Value	0.75	0.25	0.90
Geologic Value	0.90	0.50	0.90
Historic Value	0.75	0.50	0.90
Other Value	0.75	0.50	0.90
Recreation Value	0.75	0.25	0.90
Scenic Value	0.90	0.50	0.90
Wildlife Value	0.75	0.25	0.90
Threatened/Endangered Fish	0.75	0.50	0.90
Threatened/Endangered Wildlife	0.75	0.50	0.90
Federal Land Code 103	0.10	0.10	0.90
Federal Land Code 104	0.75	0.50	0.90
Federal Land Code 105	0.10	0.10	0.90
Federal Land Code 106	0.10	0.10	0.90
Federal Land Code 107	0.75	0.50	0.90
Federal Land Code 108	0.75	0.50	0.90
Federal Land Code 198	0.90	0.90	0.90

The “not applicable” column in Table 2 assigns the default value of 0.90 if the user indicates the attribute is not present or if the entry is left blank. Environmental concerns will exist even if no environmental attributes are assigned, so a default value of 0.90 (rather than 1.0) is used to reflect this reality.

Overall Project Suitability Factor

The final step in evaluating the environmental suitability of each project site is to combine the suitability factors for the individual environmental

attributes into a single factor for each project site. This overall suitability factor is an estimate of the probability of a project's successful development, considering only the attributes identified in Table 2 and their effects on site development. The project environmental suitability factors will be used to predict the contribution that each individual project makes to the aggregate potential energy supply for a state or region.

The overall suitability factor is a function of the suitability factors for the individual environmental attributes. The presence of more than one environmental attribute means that more than one environmental concern affects a project. *The overall suitability factor should obviously be no greater than the lowest factor for individual attributes, and it should be less than the lowest factor if multiple significant environmental constraints are present.* For example, if an undeveloped project has both fish values (suitability factor = 0.25) and recreation values (suitability = 0.25), the cumulative effects of these two concerns will make its overall suitability even less than 0.25; so an overall suitability factor of 0.1 is assigned.

If the environmental suitability factors for individual environmental attributes were truly the probability of the project's being developed, then the overall probability of development could be mathematically calculated. And, if the individual suitability factors were true and independent probabilities, then the probability of developing the project site because of environmental concerns would be equal to the product of all the individual factors. However, the FERC's licensing process is not a statistical probability function, and it cannot be assumed that suitability factors can be handled as independent probabilities (for example, there is a strong correlation between the scenic, recreational, and fishing values of a stream). In addition, environmental attributes not considered by the HES would bias the value of the overall suitability factor if it were calculated as a probability.

The procedure outlined in Table 3 is used for assigning overall suitability factors. This procedure assumes that the lowest suitability factor dominates the likelihood of a project's development. However, it also considers the reduced likelihood of development resulting from the occurrence of multiple low suitability factors.

Table 3. Overall project suitability factor computation.

Individual environmental suitability factors	Project suitability factor
No environmental attributes assigned	0.90
Lowest individual factor(s) = 0.90	0.90
Lowest individual factor = 0.75	0.75
Two or more lowest individual factors = 0.75	0.50
Lowest individual factor = 0.50	0.50
Two or more lowest factors = 0.50	0.25
Lowest individual factor = 0.25	0.25
Two or more lowest individual factors = 0.25	0.10
Lowest individual factor(s) = 0.10	0.10

LIMITATIONS AND APPLICABILITY

The HES is not intended to model the likelihood of development of any specific hydropower project. To perform this function, the HES would have had to encompass the many site-specific factors affecting a distinctive site. With so many unique sites in the nation, an unmanageable number of single-site-specific attributes would be required, and the database and software would become burdensome and unmanageable, and it would fail to provide a uniform nationwide evaluation. In the Pacific Northwest, for instance, if the HES incorporated single-site-specific criteria it would have included any outcomes from the "Salmon Summit"—the attempt to aid the migration of salmon and steelhead. This consideration would have been unique to the Northwest area only, not to the majority of the United States. Additionally, if a single state decreed that there would be no additional hydropower development within its boundaries, the HES would fail in its

mission if it included an attribute unique to that single state but not pertinent to the remaining 49 states. If there is significant state opposition, it will most likely be based on factors such as fish and recreation values, which the HES is designed to model; and if the site is undeveloped and fish and recreation values are present, then the HES would assign an overall project suitability factor of 0.1. Tests conducted with the Southwestern Power Administration, and through them several states, indicated that the HES does satisfactorily model local concerns affecting hydropower development when environmental, legal, and institutional constraints to development are present. The model provides a uniform evaluation of hydropower potential, and it should be used to accumulate regional potential, not individual project potential. Summing the regional totals provides a national aggregate of the potential hydropower resources available.

ASSESSMENT PROCESS AND ASSUMPTIONS

The assessment process uses a logical extraction of data from the two primary data sources discussed previously: the Nationwide Rivers Inventory and the Hydropower Resource Assessment databases. The basic site data is relatively easy to download. However, extracting the environmental attributes data is somewhat tedious because of the cross-referencing needed between the two database sources and the interpretation of narrative descriptions of outstanding environmental attributes.

Environmental attributes for sites on river reaches listed in the Nationwide Rivers Inventory can be assigned several ways. The first and simplest is to assign the environmental attributes of a Nationwide Rivers Inventory reach to any undeveloped hydropower project that is located in the same state and county and on the same river that is listed in the Nationwide Rivers Inventory. This method relies on the state, county, and river identifiers in the Hydropower Resource Assessment database for location; these identifiers are unlikely to be inaccurate.

A second method for assigning Nationwide Rivers Inventory attributes to projects is to (a) use the river mile designations for Nationwide Rivers Inventory reaches to locate the reaches on FERC river basin maps, (b) use the Geographic Information System to map the projects at the same scale, and (c) overlay the project maps on the Nation-

wide Rivers Inventory reach maps to see which projects fall on Nationwide Rivers Inventory reaches. This method is potentially more accurate since only the projects actually on the Nationwide Rivers Inventory reach would be identified. Sites within a specified distance upstream or downstream of the Nationwide Rivers Inventory reach could also be identified and assigned the environmental attributes of the Nationwide Rivers Inventory reach. The main disadvantage of this method is that it uses the latitude-longitude coordinates of projects from the Hydropower Resource Assessment database, which are occasionally missing or inaccurate. For this and other reasons, the first method is used. The first method also assures that any upstream or downstream impacts from development are also considered.

The application of suitability factors is straightforward once all of the environmental attributes have been identified. One simply follows the specifications in Table 2.

The underlying assumption in the evaluation process is that the suitability factors being assigned to environmental attributes represent the degree to which these attributes will decrease the likelihood of developing a site. One must also assume that the combination of suitability factors is not multiplicative but can be represented by the weighing scheme shown in Table 3.

SUMMARY OF STATES COMPLETED TO DATE

This status report reviews the 20 states whose undeveloped hydropower capacity has been assessed with the HES. As stated in the Introduction, the Southwestern Power Administration was used for model testing. The six states in this power marketing administration are Arkansas, Kansas, Louisiana, Missouri, Oklahoma, and Texas. An additional 14 states—Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming (located within the DOE Denver Support Office region), Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont (located within the DOE Boston Support Office region), Iowa (located in the DOE Kansas Support Office region), and Indiana (located in the DOE Chicago Support Office region)—have also been assessed. These latter states have provided input and verification of the site data.

Using the hydropower summary report menu feature of the HES, the 20 states are summarized in Table 4. Figures 2, 4, and 10 are photos of various hydropower projects around the U.S. Figure 3 and figures 5–9 elaborate on the capacity adjustments presented in Table 4. The figures show that the HES will adjust the potential capacity downward due to the effects of environmental attributes. The figures also demonstrate the wide variation in the number of sites and the potential capacities that are unique to each state.

Figure 3 summarizes the number of potential hydropower sites in each of the 20 states. The number of sites does not change after the HES adjustments are made. Maine has the highest total number of sites (367) and the most undeveloped sites (269). North Dakota has the lowest number of sites (14), the fewest undeveloped sites (2), and the fewest developed sites without power (10). Vermont has the largest number of sites (29) with undeveloped hydropower potential in addition to current generating capacity in place. Louisiana, New Hampshire, Rhode Island, and Wyoming do not have any sites with power that are not already developed to their full potential capacity. The

total number of sites for the 20 states is 2,052. Developed sites with existing power (157) account for less than 10% of the total number of sites (1,018 undeveloped sites and 877 developed sites without power).

Figure 5 illustrates the relative size of sites that reported their potential capacities (1,956 sites). The largest number of sites (545 sites, or 28%) have a capacity of greater than or equal to 100 kilowatts (kW), but less than 500 kW. About 67% (1,308) of the sites are smaller than 1 megawatt (MW).

Figure 6 summarizes the unadjusted and the HES-modeled total potential hydropower capacity for the 20 states. Montana has the highest unadjusted potential capacity, but it is surpassed by Maine and Texas after adjustment for environmental attributes using HES. Montana also has the biggest adjustment decrease (2,658 MW). Rhode Island shows the smallest capacity decrease (3 MW). Rhode Island also remains the state with the least potential capacity with or without modeling. Overall capacity for the 20 states decreases from 18,226 to 8,607 MW (a 53% decrease).

Figure 7 is a comparison of unadjusted and adjusted total potential hydropower capacity by site status. As expected by the probability weighing scheme, the capacity associated with an undeveloped site has the largest reduction from 8,781 to 2,995 MW, or a loss of 5,786 MW (66%). Developed sites with power (157 sites) have a reduction of 42% in potential capacity from 2,300 MW to 1,325 MW, or a loss of 975 MW. Sites without power (877 sites) have a reduction of 40% from 7,145 MW to 4,287 MW, or a loss of 2,858 MW. Developed sites without power have the greatest overall potential after adjustment (4,287 MW). The additional hydropower potential for developed sites with current power generation remains considerably less at roughly one-third (1,325 MW) of the other types of sites.

Table 4. Hydropower capacity summary modeled by HES.

State	Category	Number of projects	Name plate capacity (MW)	HES-adjusted capacity (MW)
Arkansas	With Power	13	193	174
	W/O Power	28	378	332
	Undeveloped	20	638	231
	State Total	61	1,209	737
Colorado	With Power	5	156	78
	W/O Power	91	782	377
	Undeveloped	155	1,408	209
	State Total	251	2,346	664
Connecticut	With Power	3	21	11
	W/O Power	50	27	14
	Undeveloped	15	191	19
	State Total	68	239	44
Indiana	With Power	3	16	8
	W/O Power	24	51	34
	Undeveloped	3	17	2
	State Total	30	84	44
Iowa	With Power	7	115	61
	W/O Power	69	310	219
	Undeveloped	3	30	25
	State Total	79	455	305
Kansas	With Power	1	0.06	0.03
	W/O Power	12	53	45
	Undeveloped	5	100	38
	State Total	18	153	83
Louisiana	With Power	0	0	0
	W/O Power	14	78	67
	Undeveloped	8	148	133
	State Total	22	226	200
Maine	With Power	24	83	47
	W/O Power	74	1,069	768
	Undeveloped	269	554	227
	State Total	367	1,706	1,042
Massachusetts	With Power	12	28	14
	W/O Power	87	118	62
	Undeveloped	31	179	56
	State Total	130	325	132

Table 4. (continued).

State	Category	Number of projects	Name plate capacity (MW)	HES-adjusted capacity (MW)
Missouri	With Power	6	116	104
	W/O Power	12	203	181
	Undeveloped	11	378	38
	State Total	29	697	323
Montana	With Power	7	470	235
	W/O Power	72	1,129	502
	Undeveloped	79	2,073	277
	State Total	158	3,672	1,014
New Hampshire	With Power	0	0	0
	W/O Power	63	51	25
	Undeveloped	34	65	7
	State Total	97	116	32
North Dakota	With Power	2	86	43
	W/O Power	10	13	7
	Undeveloped	2	0.04	0.04
	State Total	14	99	50
Oklahoma	With Power	9	274	179
	W/O Power	18	78	68
	Undeveloped	6	190	94
	State Total	33	542	341
Rhode Island	With Power	0	0	0
	W/O Power	27	12	10
	Undeveloped	3	2	1
	State Total	30	14	11
South Dakota	With Power	5	569	285
	W/O Power	25	548	405
	Undeveloped	3	6	5
	State Total	33	1,123	695
Texas	With Power	23	56	46
	W/O Power	26	164	140
	Undeveloped	40	1,014	832
	State Total	89	1,234	1,018
Utah	With Power	8	48	8
	W/O Power	69	900	414
	Undeveloped	245	990	472
	State Total	322	1,938	894

Table 4. (continued).

State	Category	Number of projects	Name plate capacity (MW)	HES-adjusted capacity (MW)
Vermont	With Power	29	69	32
	W/O Power	70	261	130
	Undeveloped	50	90	12
	State Total	149	420	174
Wyoming	With Power	0	0	0
	W/O Power	36	920	487
	Undeveloped	36	708	317
	State Total	72	1,628	804
Totals	With Power	157	2,300	1,325
	W/O Power	877	7,145	4,287
	Undeveloped	1,018	8,781	2,995
	Grand Total	2,052	18,226	8,607

Figure 2. An example of a 560-kW hydropower plant in New York State. This plant originally started operations in 1904, and the architecture is representative of the surrounding village.

Figure 3. Number of sites with undeveloped hydropower potential by state.

(Undeveloped sites do not have any power or civil structures in place; developed sites without power do not have any power generation capability but do have some type of civil structure such as a dam or water diversion structure; and developed sites with power have current generation and a civil structure onsite with additional, undeveloped hydropower potential.)

Figure 4. Viewed from the forebay, this developed Northeastern Massachusetts hydropower plant has a capacity of 15 MW. This plant was constructed in 1985, and it is sited on a canal that was originally constructed in 1846.

Figure 5. The number of sites having undeveloped hydropower capacity, by capacity groups.

Figure 6. Total potential hydropower capacity by state.

Figure 7. Total potential hydropower capacity by site status.

(Undeveloped sites do not have any power or civil structures in place; developed sites without power do not have any power generation capability but do have some type of civil structure such as a dam or water diversion structure; and developed sites with power have current generation and a civil structure onsite with additional, undeveloped hydropower potential.)

Figure 8 presents these same totals by site status as overall percentages in pie charts. The capacity at developed sites without power generation capability have increased from 39 to 50% of the total modeled undeveloped hydropower potential, while undeveloped sites have decreased from 48 to 35%. Developed sites with power increased from 13 to 15% percent of the total modeled undeveloped hydropower potential.

Weighing the undeveloped potential capacities by the number of sites provides further perspective to this summary. Figure 9 shows the average per site of undeveloped hydropower capacities by site status for the unadjusted and software adjusted sites. The greatest unadjusted and adjusted average potential is for developed sites with power, 9.1 MW and 5.4 MW, respectively.

The lowest unadjusted average potential is for developed sites without power (8.1 MW), but the lowest average changes to undeveloped sites after adjustment for environmental attributes (2.9 MW).

Currently, over 4,500 sites in the United States are identified in the Hydropower Resource Assessment database as having additional conventional hydropower potential. Unadjusted capacity for the United States is estimated by the Hydropower Resource Assessment database to be over 70,000 MW. A simple extrapolation of the evaluated 20 states would suggest that the actual developable potential, in light of environmental constraints, is likely to be in the 35,000 MW range for the entire 50 states.

Unadjusted potential capacity

Total – 18,226 Megawatts

Adjusted potential capacity

Total – 8,607 Megawatts

Figure 8. Percent of total potential hydropower capacity by site status.

(Undeveloped sites do not have any power or civil structures in place; developed sites without power do not have any power generation capability but do have some type of civil structure such as a dam or water diversion structure; and developed sites with power have current generation and a civil structure onsite with additional, undeveloped hydropower potential.)

Figure 9. Average undeveloped hydropower potential capacity by site status.

(Undeveloped sites do not have any power or civil structures in place; developed sites without power do not have any power generation capability but do have some type of civil structure such as a dam or water diversion structure; and developed sites with power have current generation and a civil structure onsite with additional, undeveloped hydropower potential.)

Figure 10. This Massachusetts water diversion structure, which today uses plywood for flashboard, is part of a canal system that has National Historic Site protection. Parts of the canal system were originally constructed in 1792. In the picture's foreground, is a railing over a modern fish ladder. As the reader can see, parts of the railing have been removed by vandals for its aluminum resale value.

SUMMARY

There will always be a decrease in potential hydropower capacity when environmental attributes are factored into the suitability for development. After loading hydropower data for 20 states into the HES and checking the data with the respective states, the analysis indicates that potential hydropower capacity will drop by more than half. The greatest decrease for any state is always at undeveloped sites. This result changes the greatest potential capacity to developed sites without existing power, though developed sites with existing power still have the greatest average additional undeveloped hydropower potential capacity per site.

The results of the HES can be used by developers as a preliminary means for identifying developable sites. Sites with an overall project suitability factor of 0.1 have significant constraints to development. These constraints may include wild and scenic legislative protection that would literally require an act of Congress before development could occur. Other constraints could include fisheries, wildlife, or recreation attributes that members of the public value significantly. Any attempt to develop sites with these attributes would likely encounter delays and costs that would make the licensing

process tedious and the economics unthinkable. Similar conditions, though perhaps not as overwhelming, would likely be encountered if development of a site with a value of 0.25 were attempted.

The actual probability of development of individual sites with values of 0.5, 0.75, and 0.9 could also depend on nonsite events such as regional electrical capacity surplus margins, political philosophies, or other external factors such as oil shortages and resulting legislative incentives. Development probability of a site with a value of 0.9 is not a known certainty because unknown interest groups or environmental attributes may make development implausible. In spite of possible unknowns, HES-modeled results can be used as a "first-cut" vehicle to identify individual developable sites. It is also useful as a regional and national power planning tool.

The results of the HES are obtained in a viable, low-cost manner. These results provide a peerless means for identifying the undeveloped hydropower potential whose development is essential for ensuring continued energy growth, which is necessary for the continued viability of the economic strength of the United States.

PLANS FOR FUTURE ASSESSMENTS

Depending on future funding allowances, the resource assessment of hydropower potential should continue for the remaining states in order to obtain an informed estimate of national hydropower potential. The administrative aspect of coordinating individual state review and input of the hydropower potential assessment through DOE support offices should be continued given the preexisting relationships between the support offices and the individual state energy agencies. These close relationships greatly expedite the administrative coordination when several agencies are cooperating on the resource assessment endeavor.

Application of the HES to current data significantly reduces state and regional totals for potential new hydropower. However, an abundance of feasible potential sites remain. Strategies may need to be formulated to further assess those sites with the most potential for development. For example, developers would need to know if transmission lines are nearby and easily accessible.

OBTAINING INDIVIDUAL STATE INFORMATION

The HES results for the 20 states assessed to date are available and can be obtained by writing or calling the authors or the National Technical Information Service (NTIS). Reports of DOE sponsored projects or reports received on foreign exchange agreements can be ordered from Oak Ridge, Tennessee. Reports are available in paper, microfiche, computer disks, and magnetic tape formats.

Telephone Orders. (703) 487-4650. NTIS sales desk and customer services are available between 8:30 a.m. and 5:00 p.m., Eastern Standard Time.

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ADDITIONAL HYDROPOWER EVALUATION SOFTWARE INFORMATION

Additional information concerning the HES can be obtained by contacting Ben Rinehart or Jim Francfort at the addresses provided below. Copies of the software and the User's Manual may also be obtained from these individuals.

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