Hydropower Resource Assessment of Brazilian Streams

Douglas G. Hall, Idaho National Laboratory, USA

ABSTRACT

Idaho National Laboratory (INL) has performed a comprehensive assessment of the hydropower potential of all Brazilian natural streams. The assessment was performed in collaboration with the U.S. Geological Survey (USGS) and with assistance of the Empresa de Pesquisa Energetica (EPE) and the Agencia Nacional de Energia Electrica (ANEEL). The methodology by which the assessment was performed is described. The results of the assessment are presented including an estimate of the hydropower potential for all of Brazil, and the spatial distribution of hydropower potential thus providing results on a state by state basis.

The assessment results have been incorporated into a geographic information system (GIS) application for the Internet called the Virtual Hydropower Prospector (VHP) do Brasil. VHP do Brasil displays potential hydropower sites on a map of Brazil in the context of topography and hydrography, existing power and transportation infrastructure, populated places, political boundaries, and land use. The capabilities of the application, which include tools for finding and selecting potential hydropower sites and other features and displaying their attributes, are fully described.

INTRODUCTION

Idaho National Laboratory (INL), in collaboration with the U.S. Geological Survey, performed a hydropower assessment of all U.S. natural streams (Hall et al. 2004). As a means of providing hydropower stakeholder access to individual site information in a format that would support initial site evaluation, the assessment results were incorporated into a geographic information systems (GIS) application on the Internet called the Virtual Hydropower Prospector (VHP 2011). The application was first released in July 2005 and most recently was upgraded in June 2011.

A counterpart to the U.S. study was undertaken to assess the hydropower potential of Brazilian streams. The objectives of this U.S. government-funded study were to encourage cooperative renewable energy development between U.S. and Brazilian firms and agencies and to facilitate the reduction of greenhouse gas emissions worldwide. As with the U.S. study, the full benefit of the assessment could not be realized without access to site-specific information. For this reason, a GIS application for the Internet was developed to display assessment results in the context of features affecting site development. The application called the Virtual Hydropower Prospector (VHP) do Brasil was developed using the platform that had been developed for the U.S. application. VHP do Brazil was first launched on the Internet in July 2011.

Hydropower assessments of rivers in Brazil (river inventories) were undertaken in the 1960s. These assessments required field surveys to estimate the power potential of individual sites along selected rivers. The methodology described in this paper allowed a comprehensive assessment of all of the streams in Brazil. What was previously performed selectively by field measurements was performed comprehensively in the current study using modern GIS analysis and stream flow modeling. What has been gained in completeness using analytical means may not be as accurate as previous potential estimates based on field measurements. However, the present study provides relative indicators of development opportunities and information about opportunities for small hydropower and distributed generation that have not previously been available on a national scale.

The present assessment and subsequent production of the VHP do Brasil application required extensive information about Brazilian stream gaging and flow modeling and multiple context features such as hydrography, existing transportation and power infrastructure, populated places and political boundaries, and land use. This information was obtained through the support of two Brazilian agencies: Empresa de Pesquisa Energetica (EPE), and the Agencia Nacional de Energia Electrica (ANEEL). EPE provided introductions to various Brazilian agencies from which Ecology Brasil obtained needed data and GIS data layers. ANEEL provided consultation on the assessment, access to Brazilian stream flow modeling, and GIS data layers via its SIGEL Internet application.

This paper describes the methodology used to assess the hydropower potential of Brazilian streams, the results of the assessment both in terms of magnitude and spatial distribution, and a description of the VHP do Brasil application (including the features it displays and the tools it provides for selection of features and display of their attributes). The assessment was performed and the results are provided in VHP do Brasil for individual stream segments (reaches). The basic results are calculated in units of annual average power (kWa or MWa), but are reported in units of capacity potential (kW or MW), since it was found from the U.S. study that hydropower stakeholders are more familiar with and relate to capacity potential.

ASSESSMENT METHODOLOGY

The fundamental approach of this study was to calculate the power producing potential of mathematical analogs of every Brazilian stream reach (synthetic streams). Reach gross power potential was calculated by combining the elevation change from the upstream to the downstream end of the reach (gross hydraulic head) with an estimate of reach average flow rate. A reach was generally the stream segment between two confluences. The synthetic streams were validated by comparison to mapped hydrography. The validated version of the stream reach dataset that included the power potential attribute was filtered to account for waterways in conservation areas and aboriginal lands (exclusion zones) where hydropower development is thought to be unlikely. Additional filtering produced subsets corresponding to various power classes. Summing the resulting subsets of reach power potentials produced totals of power potential of interest. Developed hydropower capacity and also hydropower potential capacity in exclusion zones were deducted from total power potential to determine “available power potential.”[1]

The calculated reach power potential values were annual mean power values because the flow regression equations produced estimates of annual mean flow rates as a result of being based on

[1] The terminology “available power potential” simply equates to total power potential minus the sum of developed and excluded power potentials with no assessment of economic or development feasibility and with the recognition that local land use restrictions may preclude development of some the “available” potential.

gaged flow rates over multiple years of record. Use of annual mean power for power potential has the advantage of being directly convertible to ideal energy production by multiplying power values by the number of hours in a year (8,760 hr). However, annual mean power is not as readily recognized by hydropower stakeholders as is nameplate capacity. Therefore, power potential values are reported in estimated installed nameplate capacity produced by assuming a typical hydropower capacity factor of 0.5 (i.e., estimated installed nameplate capacity = annual average power potential/capacity factor).

Synthetic hydrography

The calculation of the stream flow rate, hydraulic head, and subsequently, power potential requires a three-dimensional representation of the hydrography and related drainage basin information. The three-dimensional hydrography provides the extent of stream networks and the elevation differences required to calculate hydraulic heads. Related drainage basin information provides essential data for the calculation of stream flow rates. While mapped hydrography provides the best two-dimensional depiction of hydrography, it does not provide the required elevation information or related drainage basin information. In order to obtain the required hydrography parameters, digital elevation models (DEMs) based on 90 meter Shuttle Reconnaissance Topography Mission (SRTM) data were used to derive three dimensional synthetic hydrography with associated reach elevation values and reach catchment areas, which were summed to calculate the drainage basin area supplying runoff to reach pour points (downstream end of the reach).

Flow rate estimates

Annual mean flow rates were calculated using regression equations developed specifically for individual or groups of the 77 Brazilian sub-basins. Regression equations for 12 of the sub-basins were provided by Brazilian-authored reports while the equations for the remaining 65 sub-basins were derived by the U.S. Geological Survey using Brazilian stream gage data, which had varying periods of record (Figure 1). The flow rate regression equations are of the form:

$$Q = \eta * f(A, P, T, S, E, R)$$

where

η = is a constant or the base of natural logarithms raised to a power and the principal physical independent variables are:
Q = annual mean flow rate in cubic meters/second
A = drainage basin area in square kilometers
P = mean annual precipitation in millimeters
T = mean annual temperature in degrees Centigrade
S = mean basin slope, dimensionless
E = mean basin elevation, in meters
R = basin relief (the difference between the minimum and maximum basin elevations), in meters.

The function is a product of the variables each raised to a power with equations for the various sub-basins containing only a subset of the above listed variables.

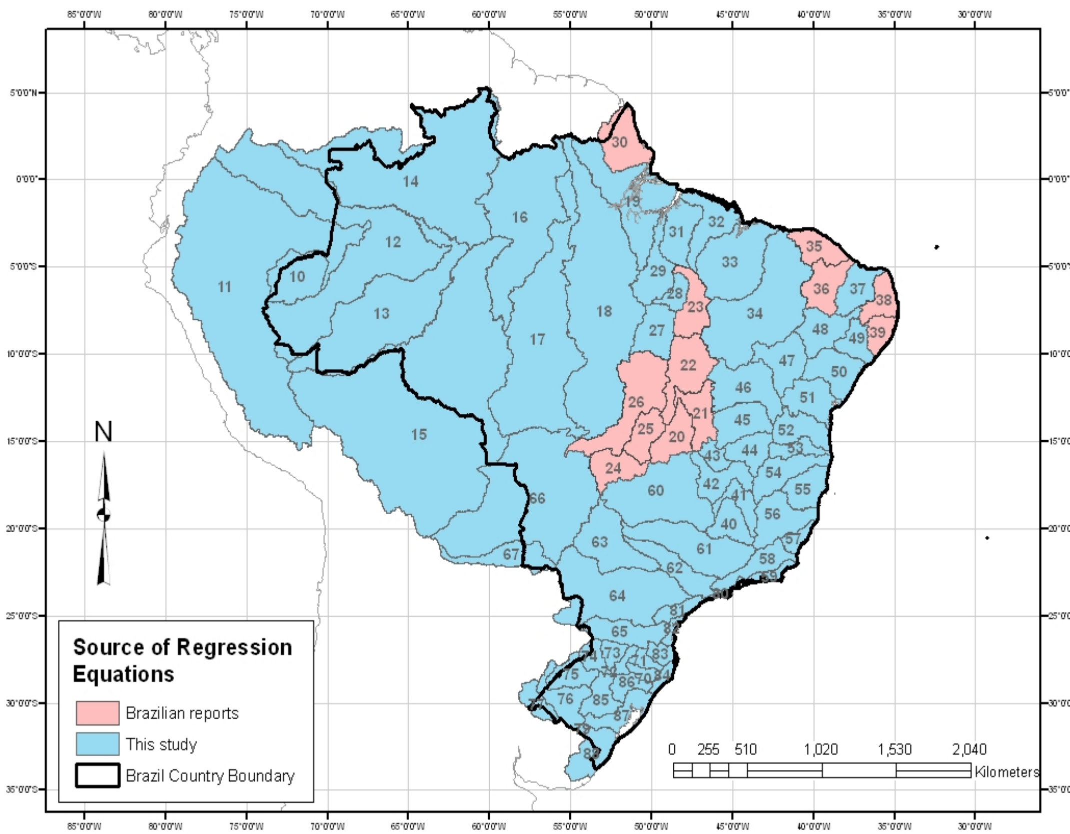

Figure 1. Brazil hydrologic sub-basins and sources of flow rate regression equations.

Power potential

The power producing potential (power potential) of a stream reach was calculated using the hydraulic head and estimated annual mean flow rates at the inlet and outlet of the reach. The hydraulic head associated with each stream reach was obtained using the elevation data in the synthetic hydrography dataset. The dataset provided the elevation at the upstream and downstream ends of the reach. The difference of these two elevation values was the reach hydraulic head. While this was the correct value for the flow that entered the reach at the upstream end and transited the reach converting potential to kinetic energy, it was not the correct value for the portion of the flow at the reach exit or downstream end that was contributed by runoff from the local catchment. This added flow had hydraulic heads varying from the total reach hydraulic head to zero depending on where the runoff entered the reach. To account for this, the following equation was used to calculate the power potential of the reach:

$$P = \kappa \, [Q_i * H + (Q_o - Q_i) * H/2]; \; H = z_i - z_o$$

where

P = power in kilowatts
κ = 9.80
Q_i = flow rate at the upstream end of the stream reach in cubic meters per second
Q_o = flow rate at the downstream end of the stream reach in cubic meters per second

H = hydraulic head in meters
z_i = elevation at the upstream end of the stream reach in meters
z_o = elevation at the downstream end of the stream reach in meters.

Algebraic manipulation shows that this equation reduces to:

$P = \kappa H(Q_i+Q_o)/2$.

The calculations described above produced a master dataset containing the following parameters for each stream reach:

- Reach characteristics (length, upstream and downstream elevations)
- Related catchment characteristics
- Reach outlet flow (catchment pour point flow)
- Reach hydraulic head
- Reach power potential.

This master dataset was subsequently filtered to:

1. Remove stream reaches that were not validated using mapped hydrography
2. Identify reaches that were unlikely to be developed because of land use or ownership
3. Identify reaches having power potentials within power classes[2]:
   - Usina hidrelectrica (UHE) – capacity potential > 30 MW
   - Pequenas centrais hidrelectrica (PCH) – capacity potential > 1 MW and ≤ 30 MW
   - Centrais geradora de energia (CGH) – capacity potential ≤ 1 MW

RESULTS

This section first presents nationwide assessment results by power category and power class both in terms of numbers of sites and gross capacity. The number of sites and their corresponding total capacity that have not been developed and are not in exclusion zones ("available") are presented by power class to show the distribution of available capacity potential. The spatial distribution of capacity for the PCH and UHE power classes is presented on a national map, which also includes exclusion zones and the locations of existing hydroelectric plants. Results are presented comparing total capacity potential by state in which the total capacity is divided into power categories. These same data are also presented on a capacity per unit area basis to reveal relative power density. State comparisons are also presented limited to only available capacity both in terms of capacity and capacity per unit area by power class.

Assessment results are discussed in terms of four power categories:

- Total
- Developed
- Excluded
- Available

[2] Plants having installed capacities greater than 1 MW but less than or equal to 30 MW and inundation areas greater than 3 km^2 are considered by ANEEL to be UHE plants rather than PCH plants. The present study did not include an assessment of possible inundation.

and three power classes which are used to classify Brazilian hydroelectric plants:

- Usina hidrelectrica (UHE)
- Pequenas centrais hidrelectrica (PCH)
- Centrais geradora de energia (CGH).

The Total power category refers to resource total gross power capacity. The Developed power category refers to a total amount of existing installed capacity (nameplate). The Excluded power category refers to the total amount of gross capacity residing in areas where hydropower development is unlikely or would be particularly closely scrutinized. The Excluded power category has been subdivided into potential capacity located in aboriginal lands and conservation areas. In some states, segments of these lands overlap and therefore total excluded gross capacity may be less than the sum of that in the two subcategories. The Available power category refers to the total amount of gross capacity that has not been developed and is not located in exclusion zones. The term "Available" in this case only denotes that capacity has not been developed and is not located in an exclusion zone of the types previously described. Other land or water use restrictions not visible to the study may preempt hydropower development at various sites further reducing the amount of capacity available for development.

Power Category Distribution of Assessed Water Energy Resource Site Population

The water energy resource site population on which the assessment was performed included 818,546 sites (stream reaches) nationwide representing a total gross power potential of 734,638 MW. The distribution of gross power potential of these sites by power category and power class is shown in Table 1. The power potential values in this table are based on site-specific values some of which have significant uncertainties because of flow rate uncertainties, non-conflation of synthetic and actual hydrographies, and hydraulic head uncertainties particularly in heavily forested areas. However, they represent a more comprehensive set of estimates than has previously been achieved. Additional exclusions that were beyond the scope of the project to research would most certainly reduce the amount of available power potential. The number would no doubt be further significantly reduced based on engineering and economic feasibility assessments of specific sites, which were not performed.

Table 1. Summary of results of the hydropower resource assessment of Brazil.

Power Class	Total (MW)	Developed (MW)	Conservation Lands Excluded (MW)	Aboriginal Lands Excluded (MW)	Available (MW)
Total	**734,638**	**77,624**	**62,946**	**84,396**	**520,068**
UHE	400,839	72,743	31,692	36,813	262,379
PCH	237,870	4,822	22,274	33,692	182,817
CGH	95,928	58	8,980	13,890	74,872

The distribution of the total number of sites and power potential between developed, excluded, and available power categories is shown graphically in Figure 2. This figure shows that only about 10% of the total power potential has been developed. The power potential in exclusion zones is 20%, leaving 70% of Brazil's hydropower potential available for possible development.[3] The number of available sites is too high because a single project may capture the hydraulic head of multiple stream reaches upstream of the powerhouse location. This is particularly true of UHE projects and a significant number of PCH projects. Some PCH and most CGH projects typically capture the hydraulic head of a single stream reach.

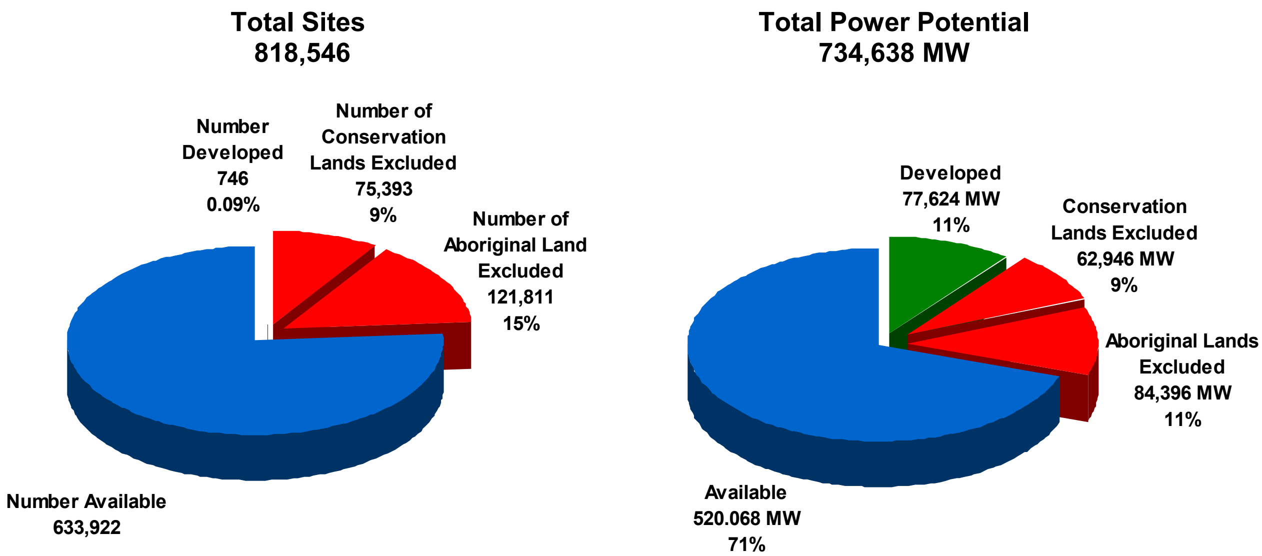

Figure 2. Power category distribution of potential hydropower sites and their associated total gross power potential.

The distribution of the total number of available sites and power potential by power class is shown graphically in Figure 3. As expected, there are a vast number of CGH sites (92 % of all sites) with roughly 48,000 PCH sites (8%) and 2,000 UHE sites (< 1%) making up the balance of the sites. However, from a capacity potential perspective, the UHE sites represent about half of the 520 GW of available power potential with the PCH sites providing 35% of this potential, and the CGH sites providing only 14% of the potential. Because of the inundation criteria, some of the PCH potential (if developed) may become UHE plants. Also, much of the UHE and PCH potential would actually encompass groups of the number of sites shown in the figure. It is noteworthy that a relatively small number of UHE sites have the potential to increase the hydropower installed capacity by over three times the present total installed capacity. The large number of potential CGH and PCH sites also collectively represent a total power of over three times the present total installed capacity, which also indicates significant opportunities for distributed generation.

[3] Some overlap of Conservation and Aboriginal lands causes Available potential in Table 1 to be higher than the total minus developed and two excluded potentials, and Figure 1 percentages to sum to slightly greater than 100%.

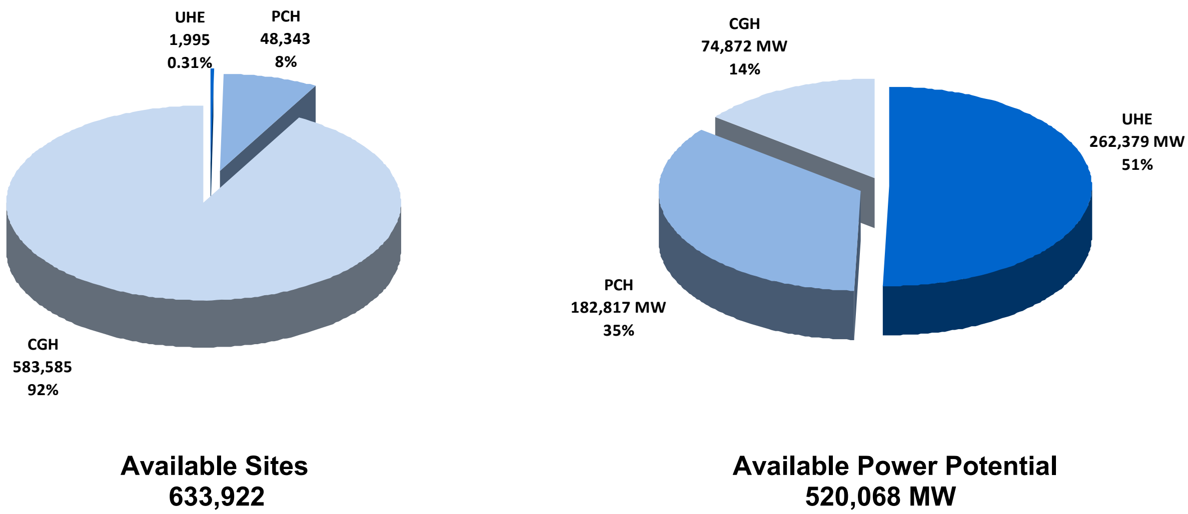

Figure 3. Number of available sites and power potential by power class.

The spatial distribution of UHE and PCH potential sites is shown in Figure 4. CGH sites are not shown because they are so numerous that they would blanket the map. The locations of existing hydroelectric plants and conservation areas and aboriginal lands are included to show both developed sites and exclusion areas were hydropower development is less likely. Existing hydroelectric plants are for the most part concentrated near the areas of highest population density. However, Figure 4 shows that opportunities for both UHE and PCH class plants are located throughout the country with opportunities for PCH plant development being densely distributed in all parts of the country except the northeast sector.

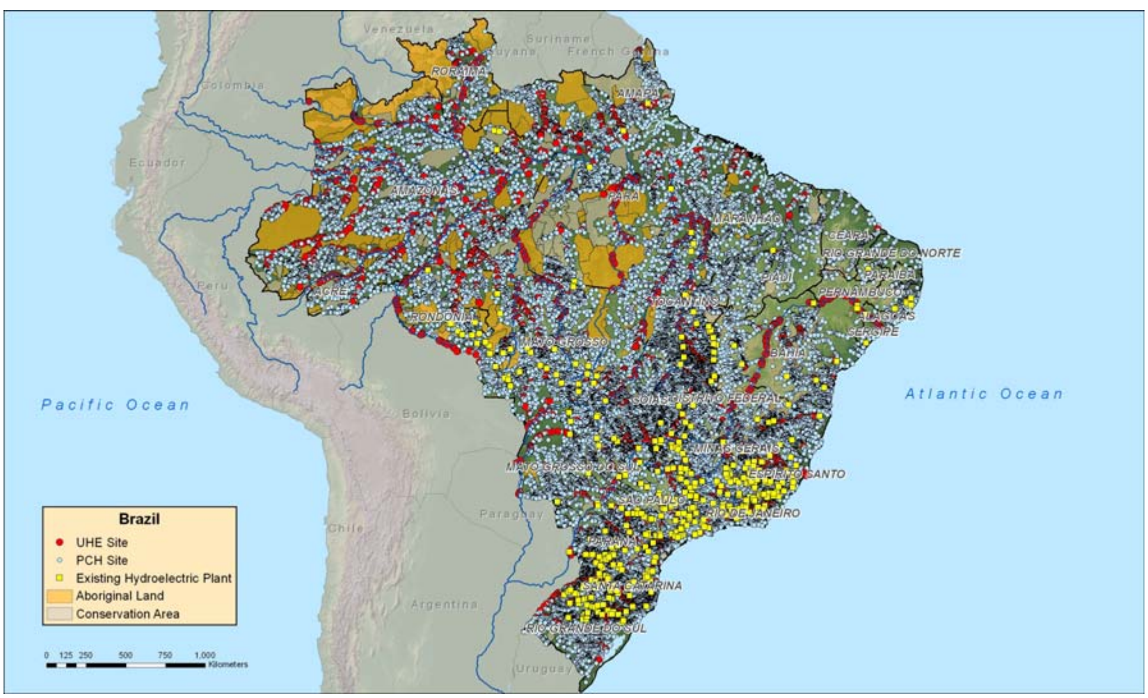

Figure 4. Spatial distribution of UHE and PCH potential hydropower project sites with locations of existing hydroelectric plants, conservation areas, and aboriginal lands.

Comparison of State Power Potentials

The total capacity potential of the 26 Brazilian states and the Federal District subdivided into developed, excluded, and available constituents are compared in Figure 5 by presenting them in ascending order of total power potential. Two states, Amazonas and Para have outstandingly higher total power potentials than the other 24 states with their potentials of approximately 170 GW and 126 GW, respectively. These two states are also outstanding with regard to the available and excluded power potential. With regard to developed potential they are outstanding with regard to how little potential has been developed. Amazonas in particular has only 280 MW of installed capacity; less than 1% of its total potential. In contrast, five states have the largest installed capacities ranging from about 8,000 to 15,000 MW. These are in increasing capacity order: Goiás (7,751 MW), Pará (8,213 MW), Minas Gerais (9,865), Paraná (13,980 MW), and São Paulo (15,235 MW).

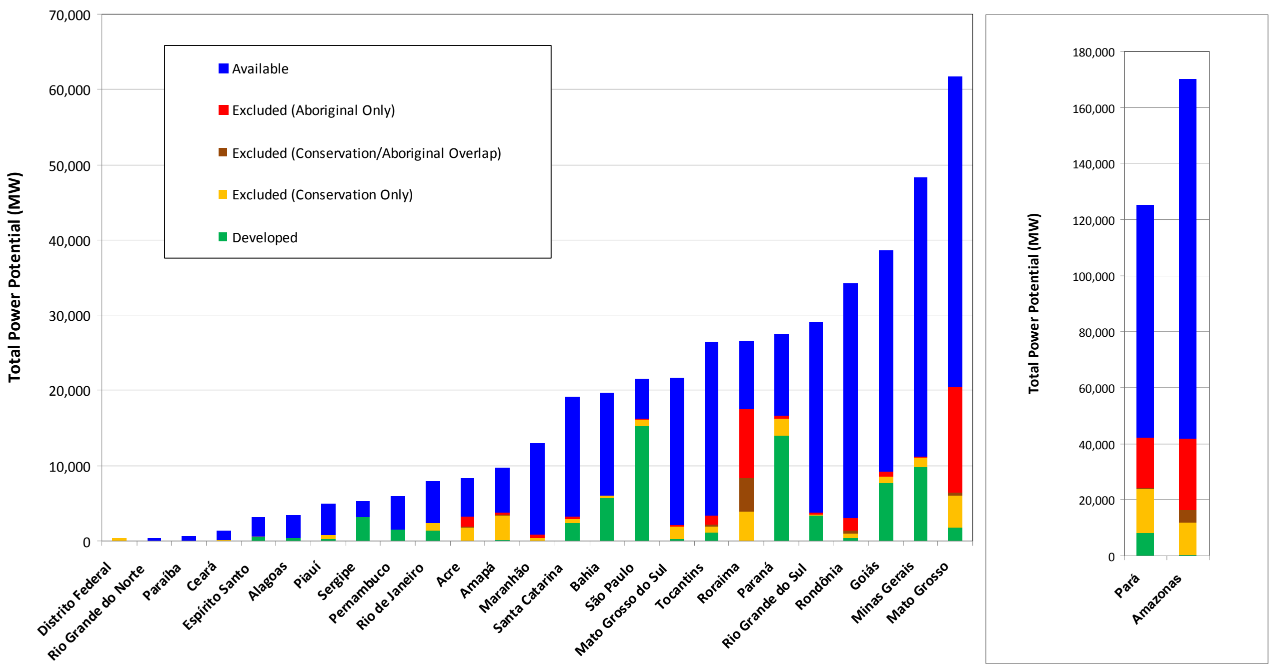

Figure 5. Total power potential of the hydropower resources in the 26 states of Brazil and the Federal District divided into available, excluded, and developed power categories.

With a total installed capacity of about 80 GW and a hydropower potential of about 735 GW, on a countrywide basis approximately 10% of the potential has been developed. The great majority of states have installed capacities corresponding to less than 20% of their total potential. Exceptions are: Bahia (29%), Parana (51%), Sergipe (59%), and São Paulo (71%). On the other hand, all but four states have greater than 60% of their total potential available for possible development. The percentages of available potential of these four states are: Sergipe (41%), Parana (40%), Roraima (34%), and São Paulo (25%).

The amounts of total power potential shown in Figure 5 are partially determined by the size of the state. Therefore, each power potential value was normalized by dividing it by the corresponding planimetric area of the state, which yielded power potential densities in units of kW/sq. km.[4] The resulting total power densities subdivided into developed, excluded, and available constituents are compared in Figure 6 by presenting them in ascending order. From this perspective, the distribution of power potential amongst the states is very different. The two states having the highest power potential, Amazonas and Para, are respectively 9th and 11th in the ranking by power density. Sergipe, Santa Catarina, and Rio de Janeiro stand out by having power potential densities averaging greater than 180 kW/sq km.

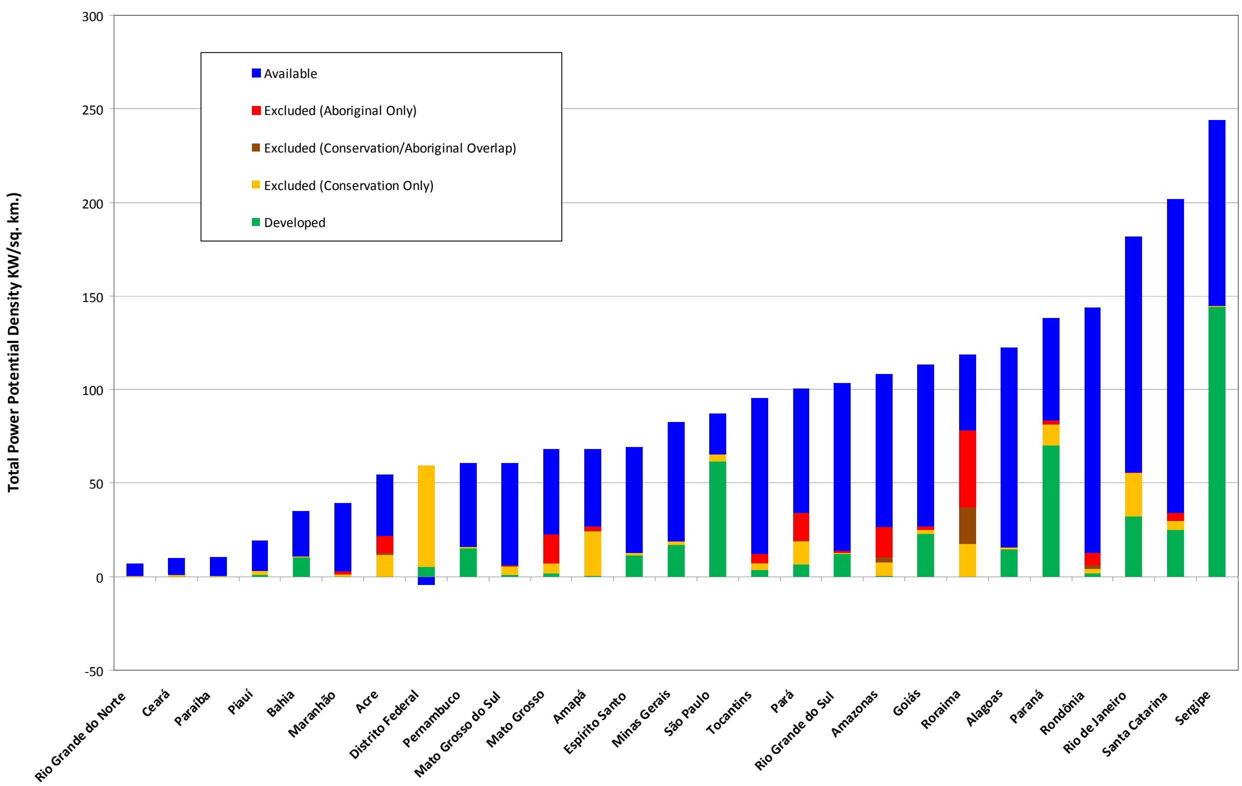

Figure 6. Total power potential density of hydropower resources in the 26 states of Brazil and the Federal District divided into available, excluded, and developed, constituents.

The negative available potential for the Federal District is the result of the fact that the entire district is designed as a conservation area. As such, all resources within the district are excluded from development according to the definition used in the assessment. The 30 MW Paranoá plant thus results in a negative available capacity potential (not visible in Figure 5 because of the power scale). The high density in Sergipe may partially explain why 60% of the state's hydropower potential has been developed. However, comparison of the density of developed hydropower represented by the green bar segments in Figure 6 shows that with the exception of Sergipe and perhaps Parana, hydropower development does not correlate directly with total power density.

The available capacity potentials of the states subdivided into the three power classes are shown in Figure 7. The states are presented in ascending order of available capacity potential. The two

[4] The power potential densities thus derived are average values and do not indicate the stated amount of power potential in every square kilometer.

states, Amazonas, and Para, having the largest total capacity potentials also have the highest available capacity potentials offering nearly 130,000 MW and slightly over 80,000 MW of available capacity, respectively. The states are nearly evenly split between those having the largest available capacity in either the UHE and PCH power classes.

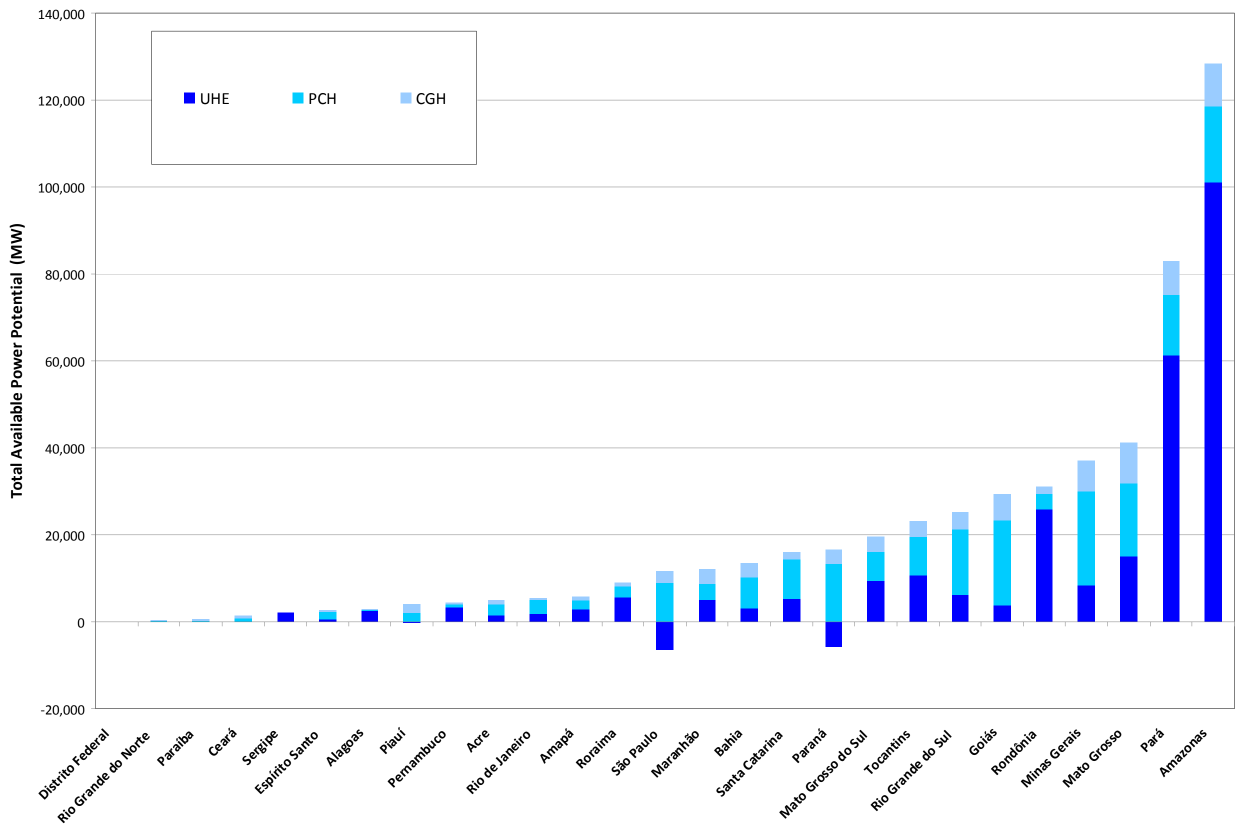

Figure 7. Total available power potential of the hydropower resources in the 26 states of Brazil and the Federal District by power class.

Negative UHE capacity potentials occurred for Paraná, São Paulo, and the Federal District. These occurred because more capacity in this power class has been developed than the total capacity less the capacity in exclusion zones would indicate should be available. In the case of São Paulo and Paraná, these anomalies are most likely the result of the inundation criteria that designates plants having installed capacities less than or equal to 30 MW being designated as UHE plants in the developed capacity, but not in the estimated total capacity potential. For both states, the sum of UHE and PCH available capacity is a positive number. In the case of the Federal District, the anomaly occurs because the entire district is a conservation area (exclusion zone) so that the developed capacity results in a negative available capacity potential.

The available capacity potentials shown in Figure 7 were area normalized to produce available capacity potential densities. The resulting available capacity densities subdivided into the three power classes are compared in Figure 8 by presenting them in ascending order. The ranking by power density is a better indicator of where available capacity potential can be found in close proximity. The states shown to have the higher available capacity densities in Figure 8 are not in the same states shown to have the highest total available capacity potentials in Figure 7. From this perspective, three states have outstanding available average capacity densities compared to the other states: Santa Catarina (167 kW/km^2), Rondônia (131 kW/km^2), and Rio de Janeiro (126 kW/km^2). An additional group of 11 states have average available capacity densities between 50 and 107 kW/km^2.

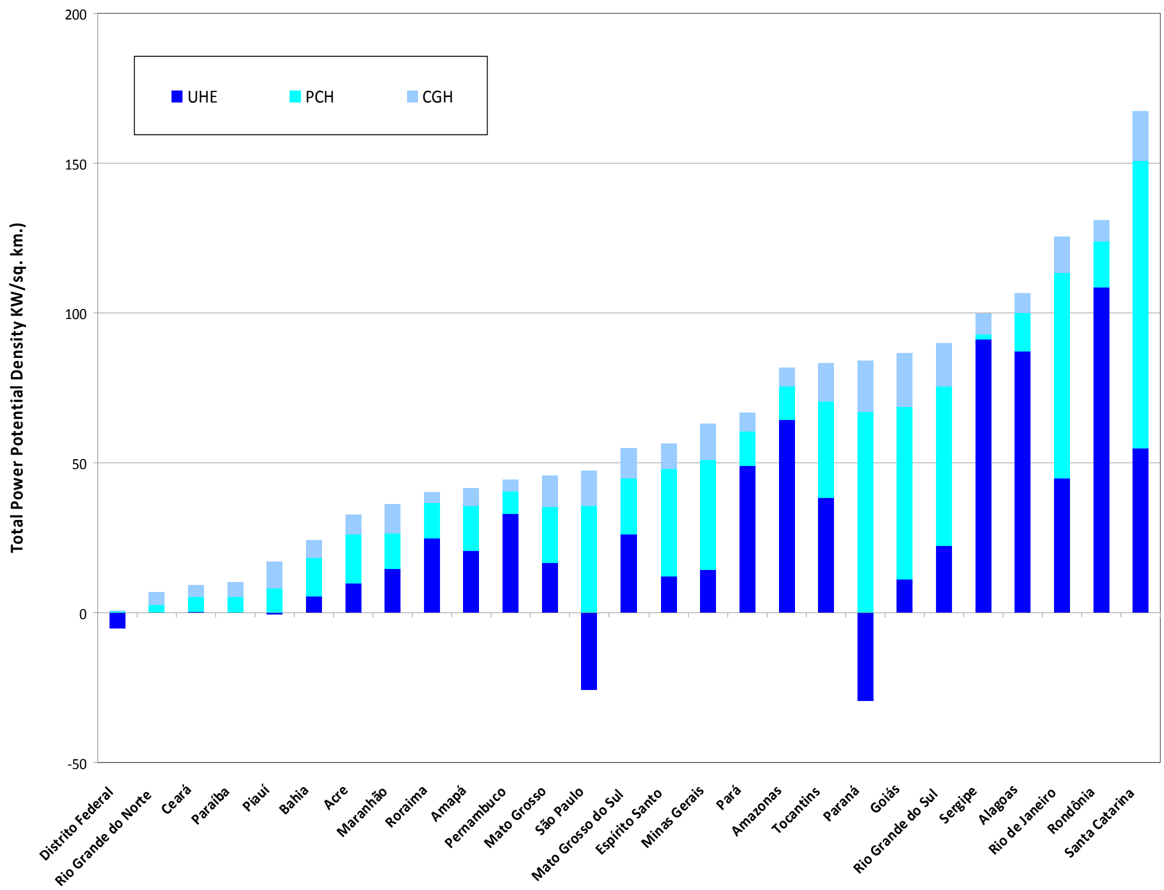

Figure 8. Total available power potential density of the hydropower resources in the 26 states of Brazil and the Federal District by power class.

Figures 7 and 8 provide a picture of the relative amounts of available capacity potential and the density of these resources amongst the states. A perspective of where development has taken place is provided by comparing available capacity potential to the installed capacity of hydroelectric plants in a state. Table 2 provides this comparison by presenting available capacity potential as a percentage of developed capacity. Four states (Acre, Ceará, Maranhão, and Rio Grande do Norte) do not have any installed capacity and thus all of their capacity potential is available. At the other end of the spectrum, three states (Paraná, Sergipe, São Paulo) and the Federal District have available capacity potentials less than the total installed capacity of existing hydroelectric plants. Between these two extremes, states have available capacity potentials ranging from 2 to 1800 times their total installed capacity.

Table 2. Available potential capacity as a percentage of current installed capacity by state in descending order.

State	Developed (MW)	Available (MW)	Potential Increase	State	Developed (MW)	Available (MW)	Potential Increase
Acre	0	4,991	∞	Rio Grande do Sul	3,434	25,311	737%
Ceará	0	1,356	∞	Alagoas	402	2,960	737%
Maranhão	0	12,086	∞	Santa Catarina	2,400	15,967	665%
Rio Grande do Norte	0	363	∞	Espírito Santo	514	2,605	507%
Roraima	5	9,040	180803%	Rio de Janeiro	1,414	5,490	388%
Amazonas	280	128,274	45842%	Minas Gerais	7,751	29,415	379%
Paraíba	4	580	16474%	Goiás	9,865	37,081	376%
Mato Grosso do Sul	215	19,622	9118%	Pernambuco	1,486	4,382	295%
Amapá	68	5,924	8714%	Bahia	5,711	13,610	238%
Rondônia	403	31,138	7723%	Paraná	13,980	10,882	78%
Mato Grosso	1,742	41,313	2372%	Sergipe	3,163	2,184	69%
Tocantins	1,072	23,103	2155%	São Paulo	15,235	5,333	35%
Piauí	237	4,101	1728%	Distrito Federal	30	-25	-85%
Pará	8,213	82,982	1010%				
				Brazil Total	**77,624**	**520,068**	**670%**

Another means of viewing available capacity is provided by Figure 9, which shows available capacity as a percentage of the total potentially developable capacity equal to capacity that has been developed plus that which is available for development (non-excluded potential). This figure shows that 14 states and the Federal District have more than 90% of their developable capacity potential remaining to be developed.[5] Twenty-three states and the Federal District have more than 70% of their developable capacity potential remaining to be developed. Only three states (Paraná, Sergipe, and São Paulo) have less than 50% of their developable potential left for development. From a national perspective, 87% of the developable capacity potential remains for possible development.

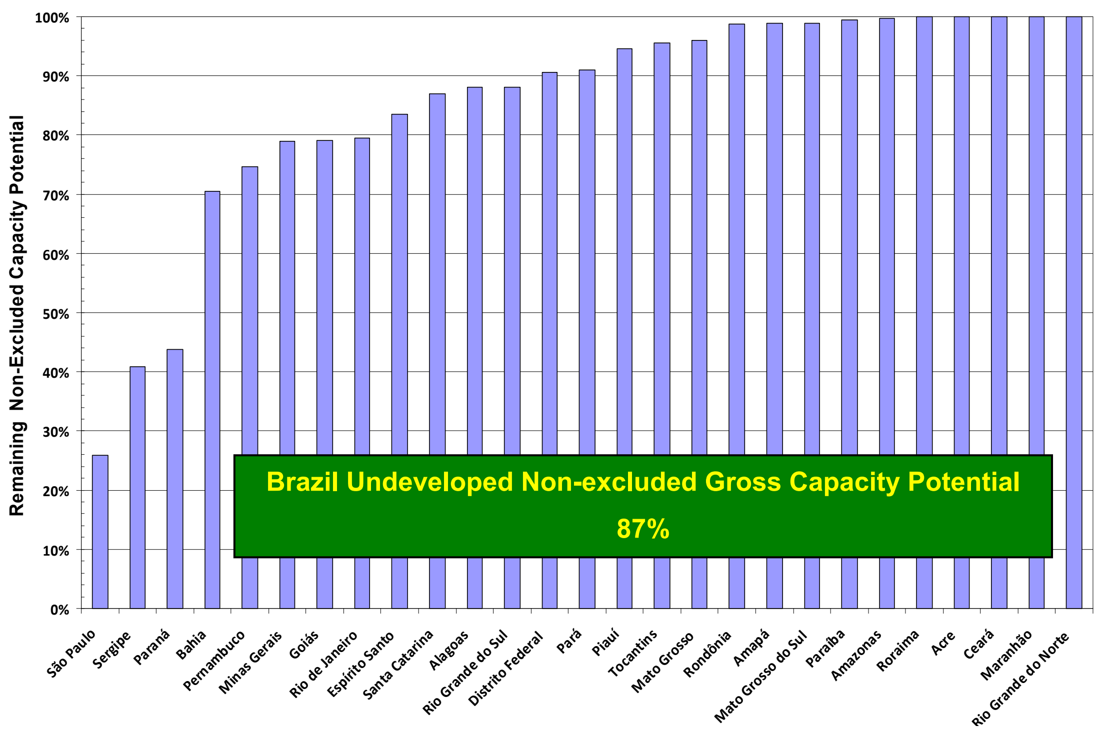

Figure 9. Percent of non-excluded capacity potential not developed by state.

[5] For this comparison, all of the Federal District potential has been considered to be non-excluded even though the entire district is a conservation area.

VIRTUAL HYDROPOWER PROSPECTOR do BRASIL

Site-specific information about the 818,546 stream reaches (potential hydropower sites) nationwide that were assessed in the study is provided by a GIS application on the Internet called the Virtual Hydropower Prospector do Brasil (VHP do Brasil) (VHP-B 2011). This application is similar to an application displaying United States hydropower resources called the Virtual Hydropower Prospector, which was initially launched in July 2005 and most recently upgraded and launched as Version 2.1 in June 2011 (VHP 2011).

The purpose of VHP do Brasil is to provide site-specific information about Brazilian potential hydropower sites in the context of features affecting hydropower development so that hydropower stakeholders can perform customized preliminary evaluations of potential development sites. Application display features, feature sets, and tools are described below.

Display Features

The desktop of the VHP do Brasil application is shown in Figure 10. The sectors of the desktop are:

- Legend containing feature sets that can be selected to populate the map (left side)
- Geographic coordinate readout (below Legend)
- Mapview which displays the full extent of Brazil or user selected regions of the country including geospatially located features selected by the user (center)
- Map navigation controls (center above Mapview)
- Background map selection buttons (right above Mapview)
- Feature selection tools with measure and marking tools (right side)
- Information window displaying the attributes of selected features (below Mapview – not shown in Figure 10)
- Link to source table, print tool, and link to related websites (right side above title banner).

The Legend is presented in a hierarchical set of folders, which is initially fully expanded to show groupings of feature sets, individual feature sets, and the symbology used to display features in a feature set. Checking a box next to the feature set activates display of features belonging to that set in the Mapview. The geographic coordinates of the cursor position in the Mapview is readout in dms units below the Legend.

The map navigation controls are fairly standard including: thumbnail map toggle, zoom in and out, pan, full extent, and forward and backward display of map views. The user can select from four background maps: color shaded relief (default), satellite imagery, topographic, and single color. Features selected for display or highlighted using the feature selection tools are maintained when a different background is selected.

Figure 10 Virtual Hydropower Prospector do Brasil desktop.

The feature selection tools and associated Information Window are discussed below. The application provides a measuring tool that reads out distances or areas corresponding to selected points on the map. It also provides an *Insert Pin* tool for marking features or locations with a variety of pin types.

The *Data Sources* button opens a table providing the organization from which data in the feature sets were obtained and the vintage of the data. The *Print* button creates images of the Mapview and a complete Legend, which can be saved or imported into a document. The *Web Links* button opens a table of websites at which information relating to hydropower potential in Brazil can be found.

Feature Sets

VHP do Brasil provides the following sets of features that a user can chose to display on the map in the Mapview:

- **Potential Hydropower Sites** – three feature sets including: CGH, PCH, and UHE potential sites
- **Power System** – five feature sets including: Hydro Plants, Thermoelectric Plants, Wind Plants, Transmission Lines, and Substations
- **Transportation** – four feature sets including: Major Roads, Minor Roads, Unpaved Roads, and Railroads

- **Hydrography** – ten feature sets including: Principal Rivers, Waterbodies, Streams, Detailed Streams, EDNA (synthetic hydrography), Waterfalls, Rapids, Isthmuses/Capes, Flood Areas, and Canals
- **Areas and Places** – nine feature sets including: Countries (national boundaries), States (Brazilian), Municipalities, Populated Places (urban areas), Federal and State Capitals, Municipality Capitals, District Capitals, Villages, and Settlements
- **Land Use** – two feature sets including: Conservation Areas and Aboriginal Lands.

The data in these feature sets were provided by multiple Brazilian organizations. Data source and vintage are listed in the data sources table provided by VHP do Brasil.

Tools

VHP do Brasil provides tools for selecting features of interest and displaying their attributes. All features have some attributes associated with them. The user interface for operating the tools presents the user with a step by step process for input of the necessary information to operate the tool. Input information can be one or several pieces of information. The tools and their functions are as follows:

- ***Find*** – selects features having a user supplied name and displays their attributes in the Information Window.
- ***Identify*** – displays the attributes of a feature or set of features in the Information Window selected by clicking on a feature or dragging a rectangle around a set of features in the Mapview and highlights the feature or features on the map.
- ***Distance*** – displays the attributes of a set of features in the Information Window within a user supplied search radius about a user selected point in the Mapview and highlights the features on the map.
- ***Buffer*** – displays the attributes of a set of features in the Information Window that are within a user supplied buffer distance of a user selected feature or features in the Mapview within an area of interest and highlights the features on the map.
- ***Feasibility*** – displays the attributes of a set of features in the Information Window that meet feasibility criteria specified by the user in terms of proximity to a road, railroad, power plant, transmission line, substation, or populated place and whether selected features can or can not be located in an exclusion zone and highlights the features on the map.
- ***Query*** – displays the attributes of a set of features in the Information Window that meet the conditions of a user constructed query statement (query statements can be multi-conditional) and highlights the features on the map.

An example of feature selection is shown in Figure 11; in this case, selecting PCH potential hydropower sites using the *Identify* tool within an area of interest. The selected features are highlighted in the Mapview. The attribute information of sites within the area of interest is displayed in the Information Window. The attributes for each site is preceded by four tools to:

- Display a list version of the attributes
- Zoom to the local area of the feature
- Clear the highlighting of the feature
- Insert a pin in the location of the feature (the pin can be cleared by selecting the tool again).

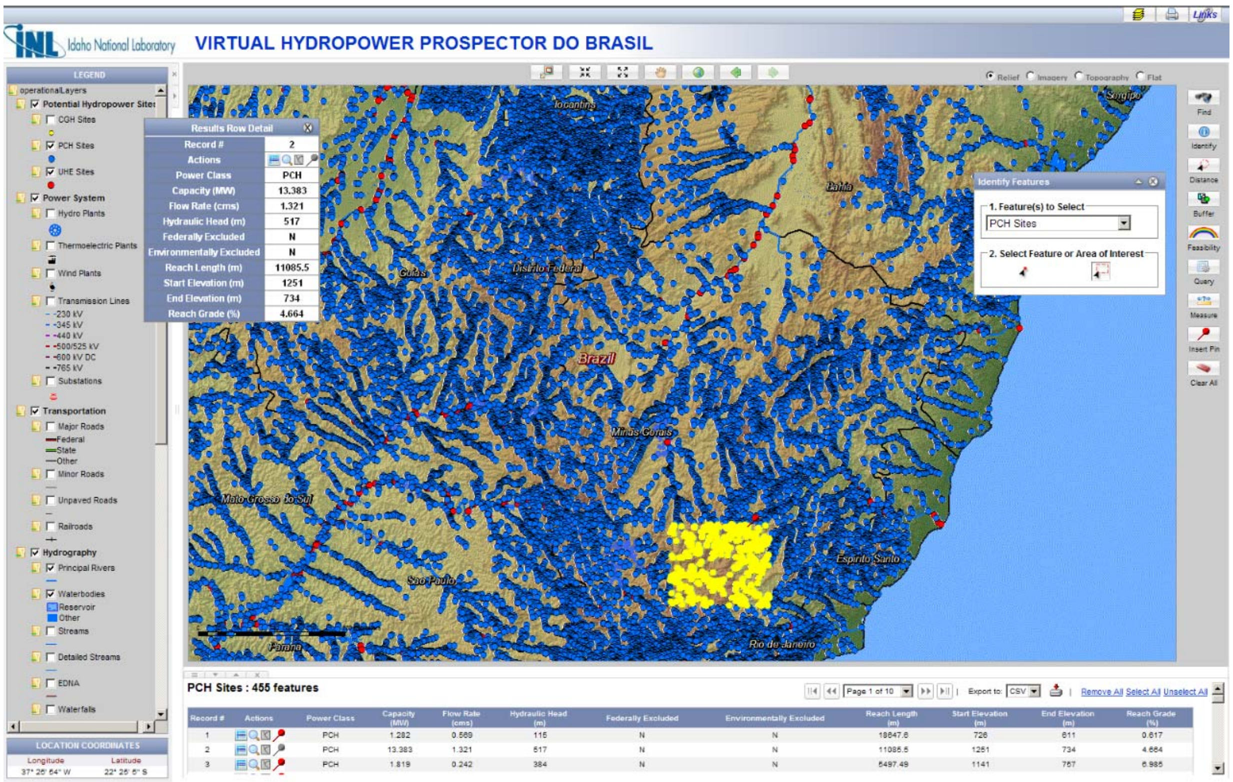

Figure 11. Virtual Hydropower Prospector do Brazil desktop illustrating results of selecting PCH potential hydropower sites using the *Identify* tool.

CONCLUSIONS

This study has shown that valuable insights into the magnitude and spatial distribution of Brazil's hydropower resources can be obtained using analytical methods to estimate stream reach hydraulic head and flow rate. The national, conventional hydropower, total gross capacity potential is estimated to be 735 GW. Of this total, slightly more than 125 GW are in located in conservation and aboriginal lands where hydropower development is unlikely or may require significantly more effort to obtain an operating license. With about 80 GW of installed capacity at Brazil's hydroelectric plants, 520 GW or 70% of the national total potential is estimated to be the maximum capacity available for development. This available potential corresponds to 50,000 PCH and UHE and over 580,000 CGH potential projects — all well distributed over the country.

From a state perspective, Amazonas and Para have outstandingly high available potentials. Fourteen states lead by Santa Catarina have available average potential power densities greater than 50 MW/km^2. Comparison of available capacity potential to existing installed capacity shows that 23 out of 26 states have the potential to increase installed capacity from two to more than 1800 times their currently installed capacity including four states that have no installed capacity. Considering installed capacity and available potential capacity as potentially developable capacity, these 23 states have 70% or more of their developable capacity that could potentially be developed with 14 states having more than 90% of their developable capacity remaining for possible development.

Brazil has abundant and widely distributed undeveloped hydropower resources in its natural streams that can be developed using conventional hydropower technology. Non-traditional water energy resources such as sites on major rivers with rapid currents, tidal estuaries, ocean currents, constructed waterways, and waves harnessed by emerging technologies make the production of electricity using non-emitting sources possible for much of Brazil's electrical consumption. It also offers the possibility of significant rural electrification, which can further protect the global environment and increase the quality of life in rural communities.

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Author

Douglas G. Hall is the Water Energy Technical Lead for the Idaho National Laboratory Wind and Water Power Program. He has led resource assessments of United States (U.S.) natural streams and studies of the ownership and cost of developing U.S. hydroelectric plants. He has also led the development of Prospector GIS applications for U.S. renewable energy resources, Brazil hydropower resources, and renewable energy resources of Malawi.