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Assessment of Natural Stream Sites for Hydroelectric Dams in the Pacific Northwest Region

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The term “candidate site” in this report is only used to refer to greenfield sites at which there is no existing dam and that are not located in a zone where hydropower development is unlikely. The term does not denote any knowledge of the feasibility of developing or of any resource owner or agency having jurisdiction over a site having an interest in developing or intent to develop any site for the purpose of hydroelectric generation. Actual feasibility of a site for development as a hydroelectric plant must be determined by a site specific, comprehensive evaluation performed by the perspective developer.

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ABSTRACT

This pilot study presents a methodology for modeling project characteristics using a development model of a stream obstructing dam. The model is applied to all individual stream reaches in Hydrologic Region 17, which encompasses nearly all of Idaho, Oregon, and Washington. Project site characteristics produced by the modeling technique include: capacity potential, principal dam dimensions, number of required auxiliary dams, total extent of the constructed impoundment boundary, and the surface area of the resulting reservoir. Aggregated capacity potential values for the region are presented in capacity categories including total capacity potential, that at existing dams, within federal and environmentally sensitive exclusion zones, and the balance which is considered available for greenfield development within the limits of the study. Distributions of site characteristics for small hydropower sites are presented and discussed. These sites are screened to identify candidate small hydropower sites and distributions of the site characteristics of this site population are presented and discussed. Recommendations are made for upgrading and extending the methodology, enhancing the assessment of Hydrologic Region 17, and extending the research to make the results more accessible and available on a larger scale.

SUMMARY

Resource assessments of United States natural streams to determine the magnitude of the resource and identify opportunities for conventional hydropower development have been conducted most recently over the past 20 years and were conducted even prior to this period. During the 1990's the Idaho National Laboratory (INL) conducted a nationwide assessment of hydropower development opportunities based primarily on sites for which a preliminary permit had been issued by the Federal Energy Regulatory Commission, but were undeveloped at the time of the assessment. During the first decade of the 21st century, INL conducted a comprehensive assessment of the gross power potential of all U.S. streams, and a subsequent assessment of feasible development sites and the developable power than could be produced at those sites assuming a damless small hydropower development model.

The more recent assessments have benefitted from several technological advancements:

- Digital elevation models with 30 m resolution provided by the National Elevation Dataset (NED)
- Derivatives of the NED, Elevation Derivatives for National Applications (EDNA) that produced three dimensional hydrography with associated stream reach catchments
- Hydrologic modeling that provides the means to estimate the annual average flow rate on any stream in the 50 states
- Geographic information systems (GIS) tools that provide the means to combine geospatial data to produce new attributes while retaining the attributes of the original data.
- Development of geographic coordinates for dams listed in the Army Corps of Engineer's National Inventory of Dams (NID) that placed each dam on its stream of residence in the high resolution hydrography provided by the U.S. Geological Survey's National Hydrography Dataset (NHD)
- Addition of flow rate estimates and other attributes to the medium resolution NHD hydrography issued as the National Hydrography Dataset Plus (NHD Plus).

While recent assessments have provided estimates of the gross power potential of all U.S. natural streams on a reach by reach basis, and even estimates of the developable power potential of feasibly developable reaches (development sites), they did not provide basic physical project characteristics that would be required and result if a greenfield site was developed using a conventional stream obstructing dam. The Bureau of Reclamation, Bureau of Land Management, and individual developers have taken site evaluation to this level for specific sites. The objective of the present study was to develop and demonstrate a methodology capable of comprehensively modeling sites in a large region using a stream obstructing dam development model that provides basic project characteristics including power potential, dimensions of the principal dam, the need for any auxiliary dams, the total length of the impoundment constructed boundary, and the size of the inundation area (reservoir).

The individual stream reaches in Hydrologic Region 17 as defined by the medium resolution NHD as provided by NHD Plus were used as the site population to be modeled. Hydrologic Region 17 encompasses most of Idaho, Oregon, and Washington. The power potential of each site was estimated by combining the elevation difference between the upstream and downstream end of the reach with the unit runoff model predicted flow rate provided by NHD Plus. To obtain project physical characteristics, the modeling approach identified all points in a raster digital elevation model (DEM) having the same elevation as the upstream end of a stream reach thus defining the inundation area (reservoir) that would result from placing a stream obstructing dam at the downstream end of the reach. The height of the dam was that necessary to impound water up to the upstream end of the reach and therefore was equal to the difference in elevation between the upstream and downstream ends of the reach plus an assumed freeboard percentage. The length of the dam was determined by where its ends encountered places on the catchment boundary where the topography is of sufficient elevation to complete the impoundment boundary. Gaps in the impoundment boundary where the elevation of the topography was insufficient to contain the water in the reservoir were considered places requiring an auxiliary dam. In this pilot study, the potential project site population was limited to single stream reaches. Sites where multiple reaches could be ganged together to form larger projects is the subject of a subsequent study.

Basic project characteristics were produced for the nearly 232,000 stream reaches in Hydrologic Region 17. As an illustration of how these data can be used to define a population of candidate sites having technically reasonable characteristics, the full population was decomposed into subsets having progressively greater value for further assessment. The datasets from the successive decompositions, the number of reaches (sites) and their total capacity potential in each are shown in the following table:

Dataset Hierarchy	Dataset	Number of Reaches	Total Capacity Potential (MW)
1	All Reaches	231,747	211,666
1.1	All with Capacity Potenital ≥ 1MW	29,580	185,485
1.1.1	Small Hydropower Reaches	24,489	73,934
1.1.1.1	Available Small Hydropower Reaches	15,676	42,835
1.1.1.1.1	Candidate Small Hydropower Sites	5,439	15,021

The first subset (1.1), which was limited to sites offering capacity potentials of 1 MW eliminated sites that were considered to be too small to be developed in most cases. The capacity potential of sites in this population was divided into capacity categories by identifying sites on which there is an existing dam and sites that are located in zones where federal land use and environmental sensitivities make development unlikely. These results were compared with those of the gross power potential assessment published by INL in 2004 and found to have varying levels of agreement depending on the capacity category.

It was found that sites in the 1.1 population included sites on large rivers that were very short reaches. While the project characteristics for these sites were correctly modeled, they were of no practical value thus leading to the production of a subset of small hydropower sites (1.1.1) using an upper capacity limit of 50 MW and upper limit on flow rate and lower limit on hydraulic head. This dataset was also divided into capacity categories with sites in the "available" category (not having an existing dam[a], and not in an "exclusion zone" forming the next population of interest (1.1.1.1). The distributions of capacity potential and project physical characteristics of this population are presented using exceedance plots to provide an overview of population. These distributions revealed that some of the sites had physical characteristics that are technically unreasonable compared to existing project norms. These sites were screened out of the population resulting in the final population of candidate sites (1.1.1.1.1) having project characteristic values making them worthy of assessment to determine whether they are technically feasible. Distributions of their project characteristics are presented. For this population, plots are also presented that show project physical characteristics versus capacity potential. Site plans are provided for sample sites and a map of region 17 show the locations of the candidate project sites.

It is concluded that the methodology developed for this study is capable of producing project site characteristics for single reach projects and could be extended to identify and model projects that would capture the hydraulic head of multiple successive reaches. The data produced by the modeling approach can be used to identify candidate small hydropower project sites and with closer examination could possibly identify candidate single reach projects offering capacities greater than 50 MW. The study has met the objective of demonstrating a methodology to model potential project sites and provide basic project characteristics, but the full value of the results should go beyond providing distribution data for site populations and provide site specific data including site plans and characteristic data via a publicly accessible GIS application like the Virtual Hydropower Prospector, which is served by INL.

Recommendations for upgrading and extending the methodology are made. An appendix discusses issues associated with using NHDPlus data for the type of modeling performed in this study. A second appendix in electronic form provides the project characteristic data and other attributes for all of the available small hydropower reaches and the candidate sites on a CD on the back cover of the report.

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a. Some sites with dams are the sites of existing hydroelectric plants. A study of the power potential of non-powered dams is the subject of another study.

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FIGURES

TABLES

ACRONYMS

ACE	Army Corps of Engineers
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
CAC	Coefficient of Aerial Correspondence
	CAC is computed for any two polygons as the area of intersection divided by the area of the union.
DOE	U.S. Department of Energy
EDNA	Elevation Derivatives for National Applications (http://edna.usgs.gov/)
	EDNA is a multi-layered database derived from the NED, which has been hydrologically conditioned for improved hydrologic flow representation (http://edna.usgs.gov)
FERC	Federal Energy Regulatory Commission
GIS	geographic information system
	An integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed.
INL	Idaho National Laboratory
NED	National Elevation Dataset (http://ned.usgs.gov/)
NHD	National Hydrography Dataset
	A comprehensive set of digital spatial data that contains information about surface water features such as lakes, ponds, streams, rivers, springs, and wells. (http://nhd.usgs.gov)
NHDPlus	National Hydrography Dataset Plus
	An integrated suite of application-ready geospatial data products, incorporating many of the best features of the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), and the National Watershed Boundary Dataset (WBD). NHDPlus includes a stream network based on the medium resolution NHD (1:100,000 scale), improved networking, feature naming, and "value-added attributes" (VAA). (http://www.horizon-systems.com/nhdplus/)
NID	National Inventory of Dams (http://geo.usace.army.mil/pgis/f?p=397:12:4908812188420972)
USGS	U.S. Geological Survey

NOMENCLATURE

Annual mean flow rate	The statistical mean of the flow rates occurring at a particular location during the course of one year. The annual mean flow rates used in this study provided by the National Hydrograpy Dataset Plus were estimated using unit runoff models based on gauged stream flow rates that occurred over a period of many years. The annual mean flow rate in any given year will usually differ from the value predicted by the models.
Annual mean power	The statistical mean of the rate at which energy is produced over the course of one year. When based on the predicted annual mean flow rate the predicted annual mean power is the mean of the annual mean powers occurring over a period of many years. Such power values are denoted by units of “kWa” or “MWa”. The actual annual mean power in a specific year will usually differ from the predicted value. A power rating of a hydroelectric plant based on electricity generation at this rate throughout the course of a year would produce the average annual electricity generation of the plant; sometimes referred to as average megawatt power rating denoted in some usages by “MWa.”
Attribute	Characteristic information about a feature such as name or owner, or data describing it such as length or voltage.
Capacity	Typically refers to the design power rating of a hydroelectric plant and is denoted by units of “MW”. Considering all U.S. hydroelectric plants, the average ratio of capacity to annual mean power is a factor of two.
Capacity factor	The ratio of actual amount of electricity produced in a year to the ideal amount of electricity that would be produced in a year if a power plant operated throughout the year at its maximum power rating (nameplate capacity). Subsequently, the ratio of annual mean power to nameplate capacity having a typical value of 0.5 for hydroelectric plants.
Capacity potential	The estimated power rating (nameplate capacity) if a hydroelectric plant were to be installed on a site based on estimates of flow rate and available hydraulic head and assuming a typical hydroelectric plant factor of 0.5 to convert from estimated annual mean power potential to estimated capacity potential.
Catchment	The local portion on a drainage basin supplying runoff to a particular stream reach.
Exceedance	The percentage of a population having the value of the independent variable or greater.
Exclusion zone	An area in which hydroelectric plant development is highly unlikely due to federal land use statutes or policies or environmental sensitivities.
Gross power potential	Ideal hydroelectric power based on an annual mean flow rate and an associated hydraulic head having units of MWa (average megawatts) in this report. The actual value in any given year will usually differ from the predicted value because of annual variations in annual mean flow rate.
Hydraulic head	In this study, the elevation difference between the upstream and downstream ends of a reach. For a dam, the difference between the elevation of the

	headwater upstream of a dam and the elevation of the tailwater downstream of the dam.
Raster data	A raster consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information, such as elevation, climatic data, or land use.
Reach	A stream segment delineated by two successive confluences.
Vector data	Data associated with points along a path. The path is typically defined by a physical phenomenon like part or all of a stream network.

Assessment of Natural Stream Sites for Hydroelectric Dams in the Pacific Northwest Region

1. INTRODUCTION

Fundamental information about an energy source for electricity production includes its magnitude and spatial extent. This information provides an indication of its potential for increasing the supply and what areas might most benefit from its development. Assessments of conventional stream based hydropower potential have been made over the past 30 years and earlier. Prior to the use of geographic information systems (GIS) tools, assessments were based on site surveys. Topographic maps containing mapped hydrography and measures of topographic relief can be used to identify sites of interest for hydropower development. However, without a means of estimating stream flow rates on ungaged stream reaches, either the site stream flow rate had to measured or roughly estimated.

During the 1990's the Idaho National Laboratory (INL) conducted a series state hydropower resource assessments. These assessments depended heavily on projects for which the Federal Energy Regulatory Commission (FERC) issued a preliminary permit, but which at the time had not been developed. For these assessments, information about the power potential of the permitted site came from the applicant developer presumably based on field reconnaissance. The combined results of these state assessments (Connor, Frankfort, and Rinehart, 1998) identified 5,677 sites having a total capacity potential of nearly 70 GW. Application of environmental, legal, and institution constraints led to an estimate of likely power development of 30 GW.

The assessment results published in 1998 were based on previously identified hydropower development opportunities, but did not represent a comprehensive assessment of the power potential of all U.S. natural streams. Research at the INL, which was originally focused on assessing low power resources (less than 1 MW), ultimately lead to an assessment of the gross power potential of all streams in the 50 states (Hall et al 2004). This assessment benefitted from several assets. One was the development of the Elevation Derivatives for National Applications (EDNA) by the U.S. Geological Survey (Verdin and Jenson 1996), which provided three dimensional representations of hydrography derived from digital elevation models. This "synthetic hydrography" provided the means to estimate the gross hydraulic head of individual stream reaches. Another asset was hydrologic modeling research, which provided a means to estimate flow rate on any stream reach in the country (Vogel, Wilson, and Daly 1999) (Parks and Madison 1985) (Yamanaga 1972). A third asset was the availability of GIS tools that provided the modeling framework to combine reach hydraulic head and flow rate to estimate gross power potential. The comprehensive assessment performed using these assets resulted in an estimate of gross power potential of U.S. streams of 300 GWa of annual average power corresponding to 600 GW of potential installed capacity assuming a typical hydropower capacity factor of 0.5.

INL subsequently conducted a feasibility assessment based on the work published in 2004 to determine which sites were feasible to develop and to estimate the amount of developable power at each feasible site (Hall et al 2006). Feasibility criteria included site accessibility, proximity to transmission and load, and location subject to federal or environmental development restrictions. The plant development model that was used was a damless small hydroelectric plant (less than 30 MWa or approximately 60 MW installed capacity). It was also assumed that only half the stream flow was available for power production and penstocks carrying water from the stream offtake to the powerhouse were of realistic lengths based on currently installed small hydropower plants in the region. These conservative assumptions resulted in an estimate of total developable power potential of 30 GWa of annual average power or an estimated installed capacity of 60 GW.

The objectives of the present study requested by the Department of Energy (DOE) Water Power Program were to obtain the total and site specific hydropower potential and information about the physical characteristics and impacts of using a stream obstructing dam as a hydroelectric plant development model at greenfield sites. For this study each stream reach was considered to be an individual, potential development site. Ganging adjacent reaches together to produce more extensive reservoirs will be addressed in a subsequent study.

A pilot study area was chosen to be Hydrologic Region 17, which covers most of Idaho, Oregon, and Washington. Principal site specific information of interest are the dimensions of the constructed impoundment boundary (dam or dams), the extent of the inundated area produced by the resulting reservoir, and the power potential. The U.S. Geological Survey (USGS), in collaboration INL, produced the site data of interest, which was subsequently analyzed by INL for this report.

The report is organized by describing the methodology by which the characteristics of potential sites were derived and the analysis methods used to identify subsets of the entire reach population dataset culminating in a set of candidate small hydropower sites worthy of further assessment. Assessment results are presented for a population of stream reaches offering potential capacities of 1 MW or greater, small hydropower reaches, small hydropower reaches that appear to be available for development, and finally a candidate set of available small hydropower reaches having technically reasonable project site characteristics. Based on this information, conclusions are drawn about the opportunities for hydropower development using stream obstructing dams in Hydrologic Region 17. Recommendations to upgrade and extend the assessment are made. Appendix A presents an illustrated discussion of issues found in attempting to use the NHDPlus (NHDPlus 2011) to determine inundation area. A CD is included on the back cover of the report as Appendix B. The CD contains datasets detailing the available small hydropower reaches and a subset of this dataset containing candidate small hydropower sites.

2. TECHNICAL APPROACH

An understanding of the hydropower resources of Hydrologic Region 17 at greenfield sites on natural streams requires estimates of the mean flow, hydraulic head (the change in elevation along the stream channel), and subsequently the potential hydropower capacity for each stream reach in the hydrologic region. Additionally, with the assumption of a stream obstructing dam development model, locations of the dams necessary to impound water thus capturing the full hydraulic heads of all reaches along with the resulting inundated areas are needed. In order to determine which potential sites are actually greenfield sites, reaches with existing civil structures have to be identified. The sources and production of these data are heavily reliant on GIS software and geospatial datasets.

2.1 DATA

Three essential datasets were used in conducting this assessment for Hydrologic Region 17:

1. National Hydrography Dataset (NHD)
2. National Hydrography Dataset Plus (NHDPlus)
3. Elevation Derivatives for National Applications (EDNA) digital elevation model (DEM) and flow direction grids
4. National Inventory of Dams (NID).

2.1.1 NHDPlus Data for Region17

Initially it was decided that NHDPlus (NHDPlus 2010) would provide the stream flow values and hydraulic heads, and be used to determine the required dam extents and inundated areas. However, issues were found with the NHDPlus raster layers which made the dataset unusable for determining the dam extents and inundated areas. Appendix A describes the problems encountered in trying to use the NHDPlus data for this type of raster analysis.

The NHDPlus "Value Added Attributes" were used in the analysis. The medium-resolution (1:100,000) hydrography that is distributed with the NHDPlus was used as the hydrographic framework for the analysis. The original data are distributed in a geographic coordinate system. These data were projected into the National Albers equal-area projection to match the raster layers contained in both the NHDPlus and the EDNA (Verdin and Greenlee 2003) datasets (see Table 1). The following projection parameters were used:

Table 1. Albers equal area projection parameters.

1st standard parallel	29 30 0
2nd standard parallel	45 30 0
central meridian	-96 0 0
latitude of origin	23 0 0
false easting	0
false northing	0

In Hydrologic Region 17, the medium-resolution hydrography from NHDPlus is comprised of 271,350 reaches. These reaches were filtered to exclude those with unknown flow direction (FlowDir = "Uninitialized") and those flagged as coastline (FTYPE = "Coastline"). This left 231,747 reaches for which power potential, and dam and inundated extents were evaluated. In order to subdivide the area into manageable pieces, all processing was done on a hydrologic subregion (4-digit) basis. All processing was done for each of the 12 subregions in Hydrologic Region 17 shown in Figure 1. The breakdown of the number of reaches by subregion is shown in Table 2.

2.1.2 Elevation Derivatives for National Applications (EDNA) Data

Since the NHDPlus raster layers were unusable in defining inundated extents, EDNA data were used. EDNA is a multi-layered database derived from a 30-meter resolution version of the National Elevation Dataset (NED) (Gesch et al 2002), which has been hydrologically conditioned for improved hydrologic flow representation. The seamless EDNA database provides 9 raster and 6 vector data layers including the critical layers used in this study, a hydrologically-conditioned DEM and the resulting flow direction grid.

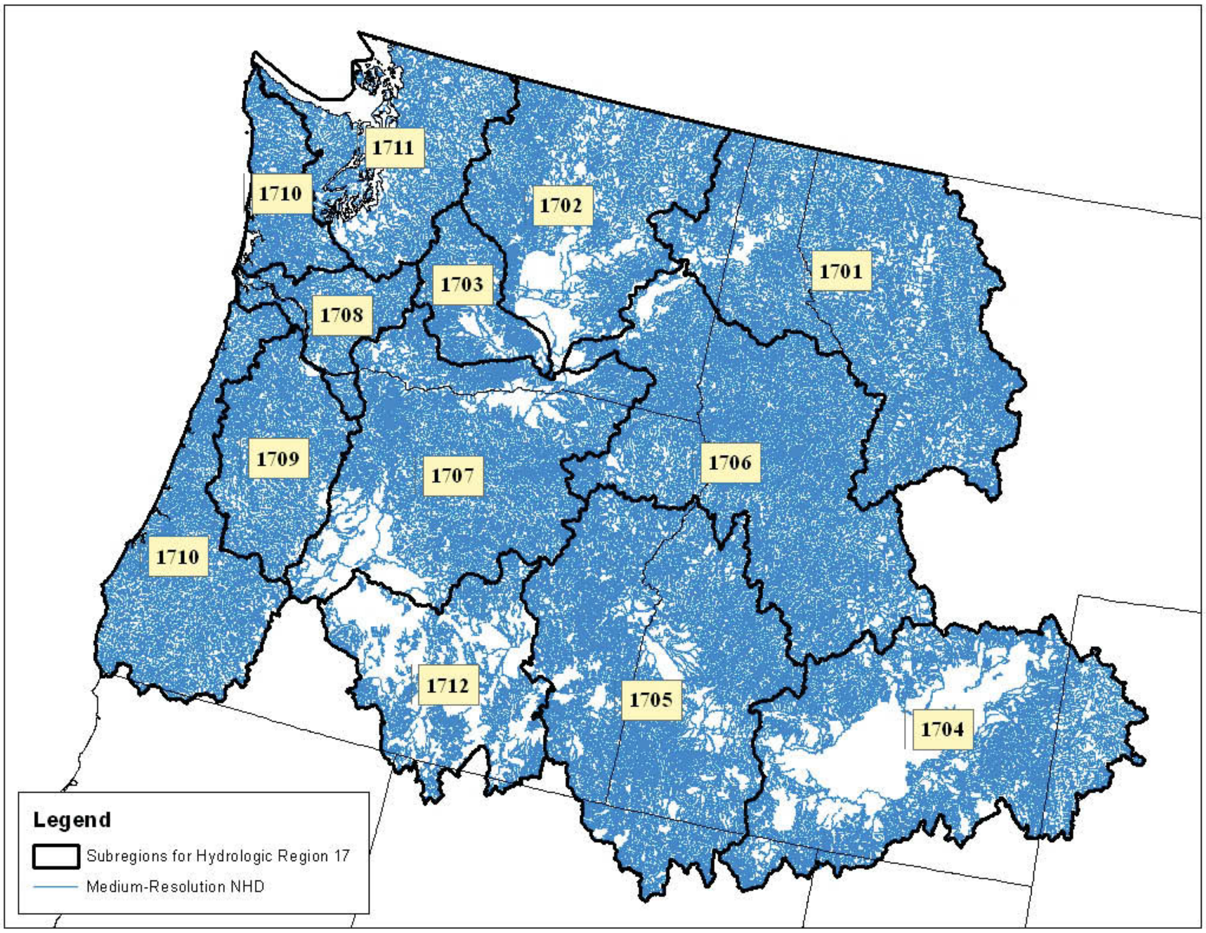


Figure 1. Subregions for Hydrologic Region 17.

Table 2. Distribution of medium-resolution NHD reaches in Hydrologic Region 17.

Subregion	Number of Reaches
1701	36,731
1702	16,648
1703	6,403
1704	27,617
1705	34,302
1706	35,670
1707	19,698
1708	6,245
1709	9,807
1710	18,121
1711	11,615
1712	8,890
TOTAL	**231,747**

In order to use the EDNA data in conjunction with the NHDPlus vector data, EDNA-based catchments were derived for each NHDPlus flowline. To develop the EDNA-based catchments, the NHDPlus flowlines were rasterized, and the ArcGIS (ESRI 2011) WATERSHED tool was used to derive a catchment. The flowline and the associated catchment were linked by a common identifier, COMID. The rasterized flowlines, the EDNA-derived catchments, and the EDNA DEM were used in subsequent analyses. Figure 2 shows the EDNA-derived catchments, rasterized NHDPlus flowlines and NHDPlus catchments for a small headwaters area.

A comparison of the EDNA-derived catchment with those distributed with the NHDPlus dataset was undertaken. For each flowline, the EDNA-derived catchment was compared with the analogous NHDPlus catchment and a Coefficient of Areal Correspondence (CAC) (Taylor, 1977) was calculated. The CAC is computed for any two polygons as the area of intersection divided by the area of the union. The values range from 0 (totally disjoint polygons) to 1 (polygons which share the same area and geospatial footprint). The CAC was attributed on the final flowline dataset to provide additional information regarding the consistency of the EDNA-derived catchment with those derived from the NHDPlus. In Figure 2, the catchment in the upper left portion of the figure (COMID = 23763181) has a high CAC (98.6%), since the EDNA-derived and NHDPlus-derived catchments have similar areas and overlay each other well. Other catchments do not agree as well, particularly in low-lying terrain.

2.1.3 National Inventory of Dams (NID) Data

The National Inventory of Dams (NID) (ACE 2010) data were used to identify streams which have an existing civil structure. The data for Hydrologic Region 17 were taken from the ***NHDPointEventFC*** feature class which is distributed with the high-resolution (1:24,000) NHD (NHD 2011). This feature class provides linkages between the NID and the high-resolution NHD. The NID data were geo-located on the medium-resolution NHDPlus hydrography using the techniques described below in the Methods section.

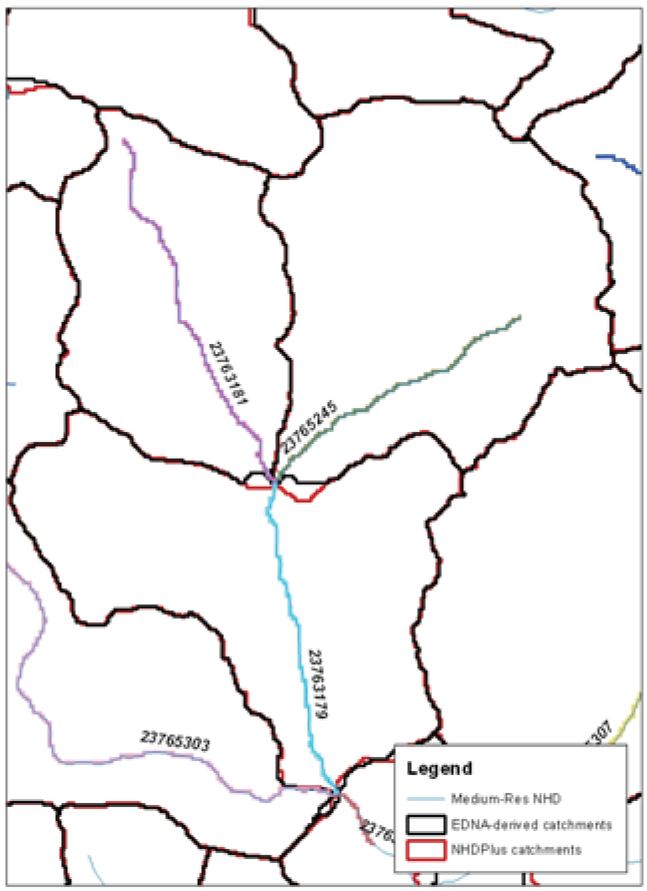


Figure 2. Comparison of EDNA-derived and NHDPlus catchments for small headwaters area.

2.2 Methods

In order to assess the total hydropower potential, and determine the footprint and dimensions of the dam or dams required to capture each reach's hydraulic head and the resulting inundated area, GIS processing was undertaken on the various datasets. In all, the following processes needed execution for each Hydrologic Region 17 reach in the medium-resolution NHDPlus:

1. Determine the stream flow for use in the power evaluation
2. Evaluate the hydraulic head of the reach
3. Determine the reach power potential
4. Model placement of a dam at the downstream end of the reach, capable of impounding water to capture the entire reach hydraulic head
5. Model the inundated area resulting from the dam
6. Evaluate which reaches have existing civil structures.

2.2.1 Streamflow Evaluation

The NHDPlus dataset provides two estimates of mean annual flow for each flowline: the Unit Runoff Method (UROM) (RTI 2001) and values derived from regional regression equations (Vogel, Wilson, and Daly 1999). The regression equation estimates are valid only within the ranges of the original data used for computing the regression. For this reason, not all NHDPlus flowlines were assigned a flow estimate using the Vogel technique. Therefore, for this study, the mean annual flow values) derived using the Unit Runoff Method were used in the analysis. The values were transferred from the Value Added Attribute tables included with the NHDPlus onto the flowline attribute table (MAFLOWU from the flowlineattributesflow.dbf table).

2.2.2 Hydraulic Head

The NHDPlus dataset provides values of up and downstream elevation for each stream reach. However, for this analysis, since these elevations are not derived directly from a hydrologically-conditioned DEM, they could not be used in modeling the dam extent and inundated area extent (see Appendix A). Therefore, to have a consistent analysis, the hydraulic head was derived from the EDNA DEM. The difference between the minimum and maximum elevation values along the rasterized NHDPlus flowlines were used to derive the hydraulic head for the reach. Each NHDPlus flowline was attributed with the upstream elevation and the hydraulic head.

2.2.3 Potential Power

The potential power for each NHDPlus flowline was calculated using:

$$P = \kappa * H * Q$$

where P = Power in kilowatts
κ = 1/11.8 having the units kW·s/ft^4
H = hydraulic head in feet
Q = flow in cfs

2.2.4 Dam Placement and Inundated Area

Attempts were made to use the NHDPlus dataset to model placement of the necessary dams and resulting inundated areas. However, the DEM which is distributed with the NHDPlus dataset was not hydrologically conditioned. For this reason, they could not be used in modeling the dam extent and inundated area extent (see Appendix A). Therefore, determination of the required position, width, and height of the dam necessary to capture the entire hydraulic head of each NHDPlus reach and the resulting inundated area was made using the EDNA-derived catchments and DEM. Since each flowline had an upstream elevation attribute, the inundated area within each EDNA catchment could be determined through a simple map algebra query; selecting only those pixels, within the reach's corresponding EDNA-derived catchment, with elevations equal to or less than the upstream elevation of the reach. This resulted in a raster dataset of the inundated area which would result from placement of a dam at the lower end of the reach. This raster dataset was then converted to a polygon dataset.

Initial attempts at determining the footprint and dimensions of the dam necessary to capture the hydraulic head focused on placing a dam at the lower end of the reach, perpendicular to the flowline. This technique yielded peculiar results and did not optimize the placement of the dam. For single reach project sites a dam at the lower end of the reach should, ideally, only impound water within the drainage area to that reach. For this reason, use of the EDNA-derived catchments helped to optimize the placement of the dams. Through a series of dissolve, densification, and intersection commands in the ArcGIS environment, the necessary location of the dam required to capture the hydraulic head was determined as that portion of the inundated area boundary that shared exact segments with the EDNA-derived catchment. Figure 3 depicts the relevant datasets necessary to derive the dam footprint. The inundated area, shown in blue, is derived through querying the EDNA DEM for all pixels less than or equal to the upstream elevation. The EDNA-derived catchment, shown in black, was derived from the EDNA flow direction grid using the rasterized NHDPlus flowlines as seeds. The footprint of the modeled principal dam, shown in red, was defined by coincident segments of the inundated area and catchment boundaries. Coincident segments, which are not contiguous with the principal dam for some reaches constitute auxiliary dams that are part of the total constructed impoundment boundary. The rest or other parts of the inundated area are the shoreline of the reservoir that would be created. The height of the primary dam is equal to the reach hydraulic head increased by 15% to provide free board. Each NHD flowline, associated dam segments, and inundated area share the same COMID identifier.

2.2.5 Indexing National Inventory of Dams to Medium-Res NHD

The National Inventory of Dams (NID) dataset was used to identify which Hydrologic Region 17 stream reaches have existing civil structures. This dataset has been referenced to the high-resolution NHD hydrography, but not to the medium-resolution NHDPlus hydrography. The geolocation of the NID dams on the high-resolution NHD, along with several auxiliary attribute tables distributed with the high-resolution NHD, the EDNA catchments, and the medium-resolution flowlines, were used to identify which medium-resolution reaches have existing civil structures

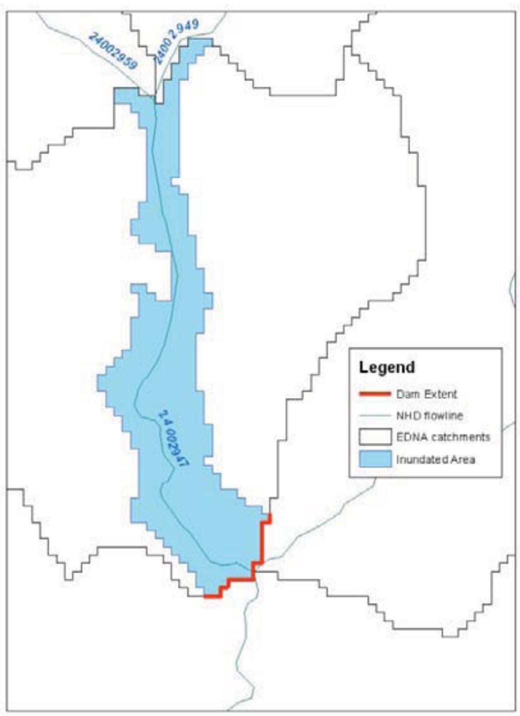


Figure 3. Technique to model placement of the dam using the EDNA-derived inundation patterns and catchments.

The NID dam locations are distributed as point events in the high-resolution NHD distribution package. Each NID dam point event holds a "***REACHCODE***" attribute which refers to the high-resolution NHD hydrography. Unfortunately, the ***Reachcode*** attribute is not necessarily consistent between the medium-resolution NHDPlus and high-resolution NHD hydrographies.

The identification of which medium-resolution flow lines have existing civil structures was done in a multi-step process. The following datasets were used in the process:

- Medium-resolution NHDPlus (***med_res_NHD+***)
- High-resolution NHD (***high_res_NHD***)
- National Inventory of Dams (***NID***) linked to the ***high_res_NHD*** through the NIDID index
- ***NHDReachCrossReference.dbf***
- EDNA-derived catchments.

An attribute was added to the ***med_res_NHD+*** to hold the name of any dam that might be located on the reach ("***DamID***") as identified by one of the following process steps:

1. Many features in the ***med_res_NHD+*** still shared a common "***Reachcode***" with the ***high_res_NHD***. For these, a simple join of the ***high_res_NHD*** and ***med_res_NHD+*** attribute tables was performed. With the NIDID index to the ***NID*** in the ***high_res_NHD***, the "***DamID***" field in the ***med res NHD+*** was simply populated.
2. The ***NHDReachCrossReference.dbf*** holds information regarding the change in "***Reachcode***" values between the ***high_res_NHD*** and the ***med_res_NHD+***. Since the ***NID*** is indexed to the ***high_res_NHD***, which might have a newer "***Reachcode***", the ***NHDReachCrossReference.dbf*** was used to provide a cross-walk between the two datasets. Once the cross-walk was built, simple joins between the "***NewReachCode***" in the ***high res NHD*** and the ***Reachcode*** in the ***med res NHD+*** allowed additional "***DamID***" fields to be populated.

These procedures resulted in many of the dams being located (For Subregion 1701, for example, 113 out of 195 dams were located using simple table manipulations). The dams that were not located using table manipulations were geolocated by using the EDNA catchments and the ***med_res_NHD+***.

The dams which were not associated with a ***med_res_NHD+*** flowline in the previous steps were investigated as follows:

1. The dams (point events in the ***high_res_NHD***) were attributed with the "***COMID"*** of the EDNA derived catchment in which they lie through a spatial join ("***COMID-1"***).
2. These same dams were attributed with the "***COMID"*** of the nearest ***med_res_NHD*** reach using the ArcGIS Near function with a search tolerance of 1 km ("***COMID-2***").
3. Dams for which "***COMID-1"*** = "***COMID-2"*** were assumed to be located on the corresponding ***med_res_NHD*** reach. The corresponding reaches were attributed with the "***DamID***". For subregion 1701, an additional 51 dams were located this way.

The remaining dams were not automatically located on NHD reaches. For Subregion 1701, 31 dams were not geolocated automatically. A simple script was developed to loop through these dams to ensure that they were, in fact, located on reaches that were only present in the ***high_res_NHD***. For Subregion 1701, only 2 of these remaining dams should have been located on an appropriate ***med_res_NHD+*** reach. The other 29 were dams that were located on reaches which only appear in the ***high_res_NHD*** and therefore are most likely very small dams. The ***NID*** indexing summary for Region 17 is detailed in Table 3.

Table 3. Summary of National Inventory of Dams geolocation onto medium-resolution NHDPlus reaches for Hydrologic Region 17.[b]

Subregion	Number of Reaches	Number of Dams (NID)	Number of Reaches with Existing Dam
1701	36,731	195	981
1702	16,648	103	484
1703	6,403	16	129
1704	27,617	113	672
1705	34,302	248	1,144
1706	35,670	56	290
1707	19,698	95	322
1708	6,245	37	144
1709	9,807	94	337
1710	18,121	111	170
1711	11,615	130	283
1712	8,890	51	76
Total	**231,747**	**1,249**	**5,032**

Removal of the 5,032 reaches associated with an existing dam left a population of 226,715 stream reaches as potential greenfield hydropower development sites. This population was further reduced to a population of 29,580 sites of interest by applying a minimum power potential threshold of 500 kWa (1MW capacity potential) or greater.

2.2.6 Population Reductions to Obtain Populations of Particular Interest

The methodology described above provided an estimate of the gross power potential of the individual natural stream reaches in Hydrologic Region 17 assuming that a stream obstructing dam was placed at the downstream end of the reach and thus collectively the power potential of all the reaches in the region. In addition, it provided information about the constructed inundation boundary and resulting inundation area associated with damming the reach, but only to the extent that the hydraulic head of the reach was captured. This pilot approach did not consider ganged reaches and thus did not provide the characteristics of the inundation boundary (e.g., maximum height and extent) and the inundated area that would result from building a dam that would take advantage of the local topography as the head walls of a dam that would capture the hydraulic head of multiple upstream reaches.

The reach population of Hydrologic Region 17 numbers 231,747. It was assumed that reaches offering less than 1 MW of capacity potential are not realistic sites for development using a stream obstructing dam. Therefore, the first dataset of interest for analysis was comprised of 29,580 reaches offering 1 MW or greater of capacity potential. This dataset was analyzed to segregate reaches on which there was an existing dam and those located in a so called “exclusion zone” based on federal land use designations and environmental sensitivities as defined by the Conservation Biology Institute (CBI 2003). Reaches in exclusion zones were determined using GIS tools by intersecting the reach population with exclusion areas. Grouping reaches into categories of developed and excluded allowed a population of greenfield sites to be identified that are available for development, but only to the extent that they do not currently include a dam and are not in one of the exclusions zones used for the study.

Review of the over 18,000 “available” sites revealed that some had characteristics that made them unsuitable for further consideration as realistic single reach development sites. In this pilot study, reach lengths and associated hydraulic heads were dictated by the NHDPlus hydrology which formed a basis for the study. As a result, there are reaches in the population of short extent offering little hydraulic head but that are part of a large river having a high flow rate. To illustrate this point, consider a 50 ft long reach on a river whose annual average flow rate is 20,000 cfs and over which there is a 10 ft change in elevation. The assessment methodology correctly calculated the constructed inundation boundary maximum height and total extent and the inundation area, but only for a reservoir occurring over the 50 ft of the stream and capturing the 10 ft of hydraulic head. While results in such cases were usable to estimate total capacity potential of the region, they had no value in providing insights as to the characteristics of the inundation boundary or the resulting inundation area for a realistic installation of a hydroelectric dam.

b. The number of reaches is greater than the number of dams because all the reaches overlaid by a reservoir associated with a dam are attributed with the dam ID.

Alternately, inundation boundary and area for small hydropower plants determined by using the methodology have practical value in describing the extent of the required inundation boundary and the area of the resulting reservoir (inundation area). The population of stream reaches having power potentials of 500 kWa (1 MW capacity potential) or greater was filtered to segregate small hydro reaches using the following criteria:

- Capacity potential ≤ 50 MW
- Hydraulic head ≥ 5 ft
- Flow rate ≤ 1,000 cfs.

The capacity potential limit is a convenient round number for what is generally considered the upper limit for small hydro plants. The hydraulic head limit is based on the operating envelopes of turbines from several manufactures. The flow rate limit was chosen to ensure that large rivers were not included in the population, since capacity potential alone did not eliminate large rivers with high flow rates and low hydraulic heads.

The dataset of small hydropower reaches numbering 24,489 reaches produced by applying the above filter criteria was segregated into the developed and excluded categories as was done for the parent dataset resulting in the identification of a population of available, small hydropower, greenfield sites. The distributions of characteristics of this population were examined using exceedance plots. These plots revealed that some of the 15,676 available sites had characteristics that made them unsuitable for further consideration as realistic development sites. This included characteristics such as dams having extremely large dimensions, the need for a realistic number of auxiliary dams, and total impoundment constructed boundaries that were extremely long.

Further screening was performed to limit the site characteristics to corresponding to norms for existing hydroelectric plants. This resulted in a dataset of 5,439 greenfield sites having individual characteristics within the prescribed limits. Exceedance plots were used to examine the distribution of site characteristics of this population of sites. Site characteristics in the form of physical dimensions were also plotted against site capacity potential. As will be discussed in the next section, even this highly filtered subset of the full population of stream reaches contained sites whose characteristics when considered as a whole make them most likely not suitable for further consideration as realistic development sites.

A summary of the decomposition of the Hydrologic Region 17 reach dataset to arrive at a dataset of small hydropower greenfield sites many of which are candidates for evaluation as technically feasible is provided by Table 4.

Table 4. Stream reach (site) populations of interest defined by successive decomposition of datasets.

Dataset Hierarchy	Dataset	Number of Reaches	Total Capacity Potential (MW)
1	All Reaches	231,747	211,666
1.1	All with Capacity Potenital ≥ 1MW	29,580	185,485
1.1.1	Small Hydropower Reaches	24,489	73,934
1.1.1.1	Available Small Hydropower Reaches	15,676	42,835
1.1.1.1.1	Candidate Small Hydropower Sites	5,439	15,021

3. RESULTS

The basic characteristics of the stream reach population of Hydrologic Region 17 are:

- Number of reaches: 231,747
- Total capacity potential: 211,666 MW
- Reach length: 2 ft to 42 mi
- Hydraulic head: 0 to 5,491 ft
- Flow rate: 0 to 295,688 cfs
- Reach capacity potential: 0 to 4,145 MW

The average reach length is approximately a mile (6,485 ft).

This population was reduced to one containing reaches that offered capacity potentials of 1 MW or greater, which were of primary interest from a power development perspective. This subset of the total population was divided into power categories, which were subdivided by power class. While of interest from a capacity potential perspective, many of the stream reaches in this subset were too short or of too low a hydraulic head to be of interest in terms of practical dam extents and inundation areas. A further subset of small hydropower reaches was thus selected, analyzed, and further decomposed to define a candidate site dataset.

3.1 Reach Population Offering Capacity Potentials of 1 MW or More

A subset of the total population of reaches composed of reaches having power potentials of 500 kWa (capacity potential of 1 MW) or greater resulted in a population with the following basic characteristics:

- Number of reaches: 29,580
- Total capacity potential: 185,485 MW
- Reach length: 43 ft to 42 mi
- Hydraulic head: .03 to 5,491 ft
- Flow rate: 1 to 291,929 cfs
- Reach capacity potential: 1 to 4,145 MW.

The capacity potential breakdown of this population of reaches is shown in Table 5. The capacity categories used in this breakdown are:

- Total – includes all reaches
- Existing dam – reaches on which there is an existing dam
- Federal Exclusion – reaches that intersect with areas in which hydropower development is excluded or is highly unlikely because of federal land use designations
- Environmental Exclusion – reaches that intersect with environmentally sensitive areas in which hydropower development is unlikely or may require more extensive study
- Available[c] – reaches that are greenfield sites not located in federal or environmental exclusion zones.

The power categories used in this breakdown are:

- Large Hydro – reaches offering more than 30 MWa of annual average power potential (60 MW of capacity potential)
- Small Hydro – reaches offering a least 1 MWa and less than or equal to 30 MWa of annual average power potential (2 to 60 MW of capacity potential)
- Low Power – reaches offering less than 1 MWa but more than or equal to 500 kWa of average annual power potential (1 to 2 MW of capacity potential).

These capacity classes were chosen to facilitate comparison with the results of a previous gross power potential assessment (Hall et al 2004).

c. Available in this usage only denotes reaches on which there are no dams and have not been determined to be in federal or environmental exclusion zones with the visibility provided by the zonal data used in the assessment. Additional land use restrictions and environmental sensitivities may apply.

Table 5. Capacity potential breakdown by power category and power class.

Potential Installed Capacity (MW)	Total	Existing Dam	Federal Exclusion	Environmental Exclusion	Available
	Capacity Potential (MW)	Capacity Potential (MW)	Capacity Potential (MW)	Capacity Potential (MW)	Capacity Potential (MW)
Total Power	**185,485**	**34,261**	**56,265**	**11,557**	**83,402**
Large Hydro	70,260	32,282	15,930	2,945	19,103
Small Hydro	96,210	1,905	35,671	7,355	51,280
Low Power	19,014	74	4,664	1,256	13,020

A comparison with the results of the previous assessment is shown in Table 6. The two assessments used different hydrographies and different methods for estimating reach flow rates. The prior study used EDNA synthetic hydrography derived from 30 m DEMs from the National Elevation Dataset (NED) that was verified by comparing it to NHD high resolution mapped hydrography compared to NHDPlus medium resolution mapped hydrography that was used in the present study. It also used flow rates derived from regional regression equations compared to those from unit runoff models used in the present study. The methodology of combining estimated flow rate with a hydraulic head equal to the change in elevation from one end of the reach to the other to calculate power potential was basically the same as where the exclusion areas in the two studies. The results from the prior study were converted from annual average power potential values to capacity potential values using the same assumed capacity factor of 0.5.

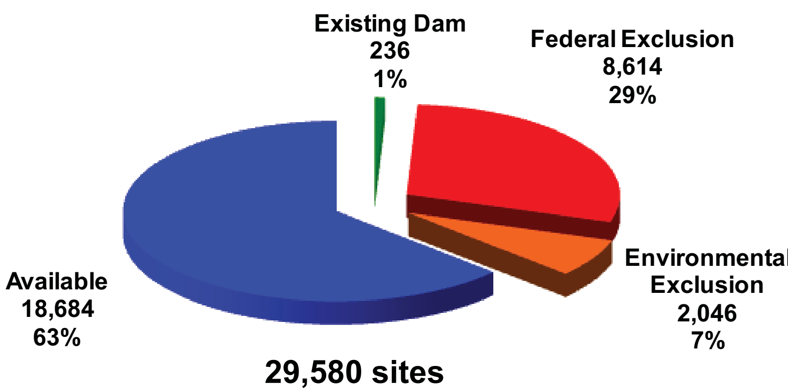
Table 6 shows that the present study resulted in a total capacity potential 33 GW higher than the prior study – an increase of 21 %. Most of this difference is associated with reaches in exclusion zones. The capacity potential associated with reaches on which there is dam from the two

Table 6. Comparison of resource assessment results from the current study and 2004 results.

Potential Installed Capacity (MW)	Total	Existing Dam	Excluded	Available
Total Power	Capacity Potential (MW)	Capacity Potential (MW)	Capacity Potential (MW)	Capacity Potential (MW)
Current Study	**185,485**	**34,261**	**67,821**	**83,402**
Hall et al 2004	**152,880**	**33,288**	**40,018**	**79,574**
Difference	32,605	973	27,803	3,828
Percent Difference	21%	3%	69%	5%

studies agreed within 3%. Likewise and most significantly, the "available" capacity potential estimates from the two studies agreed within 5% - 83 GW in the present study compared to 80 GW in the prior study. This agreement is particularly good considering the uncertainties in the data from both studies.

A power category distribution of the total reach population and its capacity potential is shown in Figure 4. The distribution by number of potential sites shows that only 1% have a resident dam with significantly more than half the potential sites in the region being located outside zones where hydropower development is precluded or is highly unlikely. These sites numbering more than 18,000 represent a large number of opportunities for adding to the existing hydropower capacity in the region. From a power perspective, nearly 20% of the capacity potential is located on reaches containing a dam with most sites having the largest potential being hydroelectric dams. There remains 45% of the capacity potential outside of zones where hydropower development is precluded or is highly unlikely. This percentage is quite similar to the figure of 52% in the prior study.



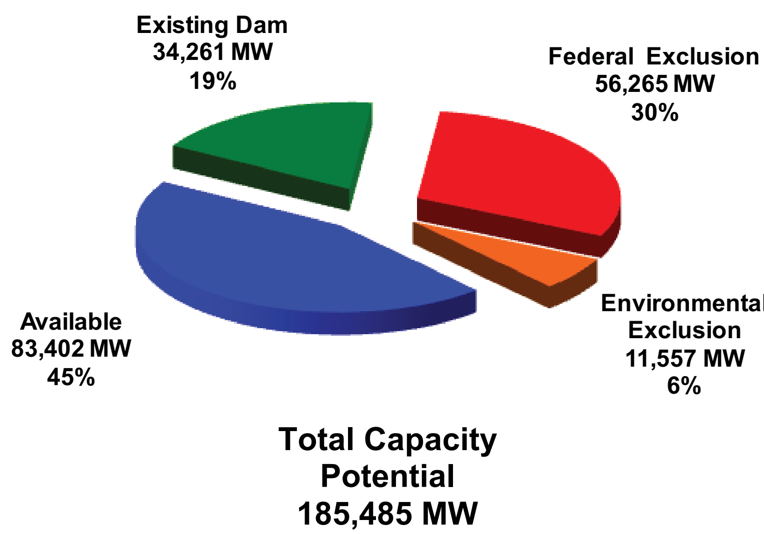


Figure 4. Power category breakdown of the total number of reaches in Hydrologic Region 17 having capacity potentials greater that 1 MW and their associated capacity potential.

3.2 Small Hydropower Reach Population

The small hydropower reach population offered capacity potentials between 1 and 50 MW. In order for the project site characteristics to have practical value, the small hydropower reach population was also limited to reaches offering 5 ft or more of hydraulic head, and having of annual average flow rates of 1,000 cfs or less. The basic characteristics of this population are:

- Number of reaches: 24,489
- Reach length: 69 ft to 19 mi
- Total capacity potential: 73,934 MW
- Reach capacity potential: 1 to 50 MW
- Hydraulic head: 6 to 5,491 ft
- Flow rate: 1 to 1,000 cfs.

This population is discussed both in terms of its capacity potential and it terms of impoundment constructed boundary and inundation area that would result from capturing the capacity potential by installing a stream obstructing dam at the downstream end of the reach.

3.2.1 Small Hydropower Capacity Potential

The capacity potential breakdown of this population of reaches is shown in Table 7 and the power category distribution of the small hydropower reach population and its capacity potential is shown in Figure 5. By comparison to the population discussed in the prior section, this population contains in the low 80 percentiles of the numbers of reaches in the total, federal exclusion, environmental exclusion, and available power categories, but only 40% of the reaches on which there is an existing dam. From a capacity potential perspective, the small hydropower reaches in aggregate have associated capacity potentials between 40 and 50% in the total, federal exclusion, environmental exclusion, and available power categories compared to the parent population, but only 1% of the capacity potential of reaches on which there is an existing dam. As with the parent reach population, about 60% of the small hydropower reaches are available for development, but they represent 58% of the total small hydropower capacity potential compared to 45% of the total capacity potential of the parent reach population. Considering that the available small hydropower reaches in Hydrologic Region 17 represent nearly 43 GW of capacity potential, they appear to offer significant opportunities for small hydropower development.

3.2.2 Available Small Hydropower Site Characteristics

In this pilot study, stream reaches as defined by the NHDPlus medium resolution hydrography were individually considered to be project sites for the installation of a stream obstructing dam. Reaches were not ganged together to define a project site.

The discussion of site characteristics is limited to project sites on the small hydropower reaches that were found to possibly be available for development. The project site associated with each reach consists of the principal dam, the impoundment constructed boundary containing auxiliary dams, if needed, and the inundation area defined by the impoundment boundary.

Table 7. Capacity potential breakdown of small hydro reaches by power category.

Potential Installed Capacity (MW)	Total	Existing Dam	Federal Exclusion	Environmental Exclusion	Available
	Capacity Potential (MW)	Capacity Potential (MW)	Capacity Potential (MW)	Capacity Potential (MW)	Capacity Potential (MW)
Total Power	**73,934**	**370**	**25,864**	**4,865**	**42,835**

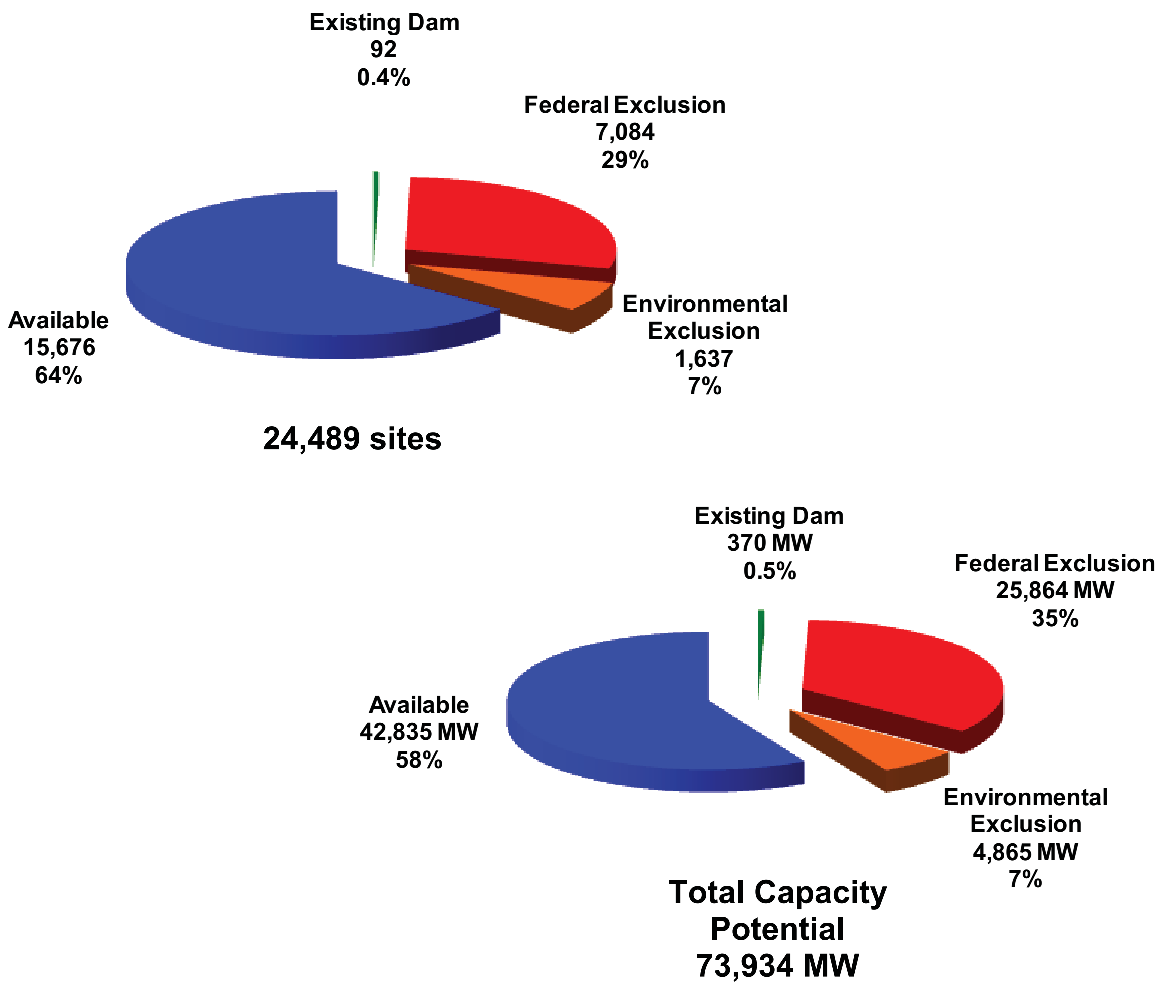


Figure 5. Power category breakdown of the small hydropower reaches in Hydrologic Region 17 and their associated capacity potential.

The purpose of the dam installed at the downstream end of reach is to create an impoundment that would capture the hydraulic head of the reach thus resulting in a reservoir covering part of all of the catchment extending to the upstream end of the reach. Ideally, the reservoir boundary is mostly provided by topography except for the dam at the lower end. Depending on the topography at the site, the civil works may not a single dam, but rather a principal dam at the downstream end of the reach with multiple lower auxiliary dams needed to complete the impoundment boundary, where the topography does not provide the necessary elevation. The choice in modeling the site development, was either to restrict the height of the dam and thus the captured hydraulic head to what could obtained using a single continuous civil structure, or model capture of the entire reach hydraulic head and observe the number of auxiliary dams that would be needed. For this pilot study, the latter approach was taken.

A full appreciation of the potential small hydropower sites and subsequent selection of candidate sites requires viewing them graphically in the context of surrounding topography, existing infrastructure, population, and land use. Since it is not feasible to provide graphic images of all the sites, ranges and distributions of the site attributes are provided. The ranges of the characteristics of the available small hydropower reach population are:

Power Characteristics

- Site population: 15,676 reaches
- Available capacity potential: 42,835 MW
- Capacity potential: 1 to 49 MW
- Flow rate: 2 to 1,000 cfs
- Hydraulic head: 6 to 4,569 ft

Site Characteristics

- Reach length: 70 ft to 19 mi
- Principal dam maximum height: 7 to 5,255 ft
- Principal dam length: 98 ft to 33 mi
- Total impoundment constructed boundary extent: 197 ft to 42 mi
- Principal dam length percentage of total constructed impoundment boundary: 21 to 100%
- Number of impoundment constructed boundary segments: 1 to 56
- Reservoir area: .2 to 61,068 acres.

As with any modeling that does not capture a complete set of limitations for technical reasonableness, some of the sites in the available small hydropower reach population are clearly not technically reasonable; for example, reaches requiring extremely high or long principal dams and impoundment constructed boundaries that are extremely long or require a large number of auxiliary dams.

The distributions of basic project characteristics in the form of exceedance[d] curves are presented in Figures 6 through 14 provide insights into the percentage of the 15,676 potential sites in the available small hydropower reach population that are technically reasonable development sites using a stream obstructing dam. Figure 6 shows that while some of the sites offer capacity potentials up to 49 MW, 98% offer capacity potentials of 10 MW or less. Reach lengths of the population are as high as 19 miles, but Figure 7 shows that 92% are less than 4 miles with the average length being 2 miles. About 70% of the sites have flow rates of 100 cfs or less as shown in Figure 8. The distributions of reach length and flow rate are understandable given the dendritic nature of stream networks.

The perspective of reasonableness of development begins to be clear from the distribution of principal dam maximum heights in Figure 9. The largest maximum dam height required at any of the available small hydropower site is 5,255 ft, which while accurate as modeled, makes the site unreasonable to develop using a stream obstructing dam. Depending on the site characteristics, it is possible that sites requiring unreasonably high dams may be candidates for being developed as conduit projects. A third of the population would require dams having maximum heights of 1000 ft or more while 40% of the sites would require dams having maximum heights of 250 ft or less.

The distribution of the length of the principal dam shown in Figure 10 is particularly informative. While the longest extent of a principal dam in the population was found to be 33 miles, 40% of the sites require a principal dam that is less than a mile in length. About 18% of the sites require a principal dam that is less than 2,000 ft long; the shortest length being 98 ft.

The constructed impoundment boundary is made up of the principal dam and auxiliary dams needed to contain the reservoir. The sum of the lengths of these dams is the total length of the constructed impoundment boundary. The distribution of these total lengths is shown in Figure 11. The maximum value of this parameter is an unreasonable 42 mi. Half of the population would require total constructed impoundment boundaries of 1.6 mi.

The distribution of the number of constructed impoundments (principal plus auxiliary dams) in Figure 12 indicates that 1.5% would require more

d. Note that while the exceedance distributions are for the same population of reaches (sites), they are independent of one another. The value of a parameter at a given exceedance value in one figure generally does not correspond to a value for the same reach (site) at the same exceedance value in another figure.

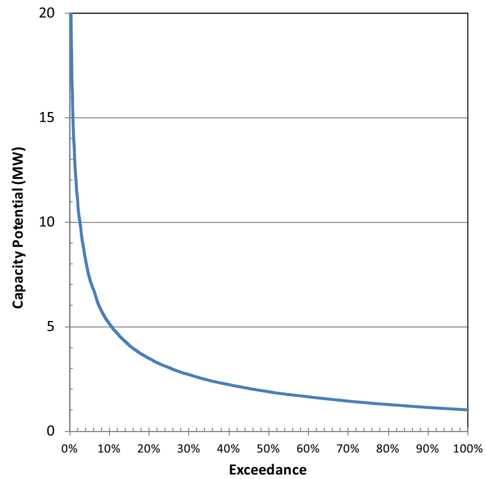


Figure 6. Distribution of capacity potential of available small hydropower reaches.

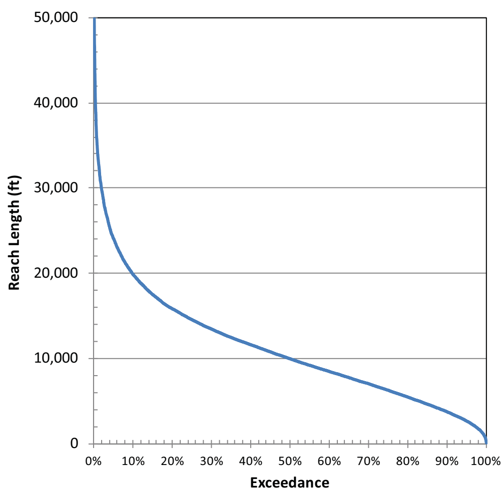


Figure 7. Distribution of lengths of available small hydropower reaches.

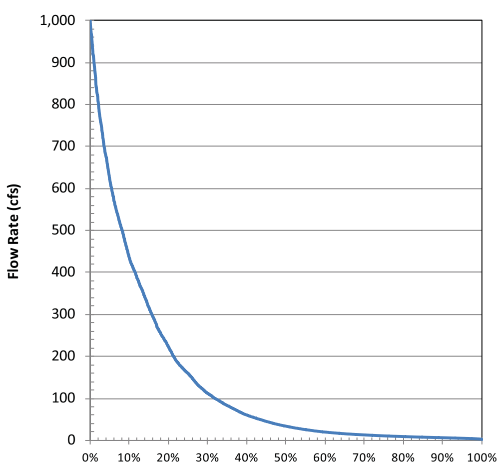


Figure 8. Distribution of flow rates of available small hydropower reaches.

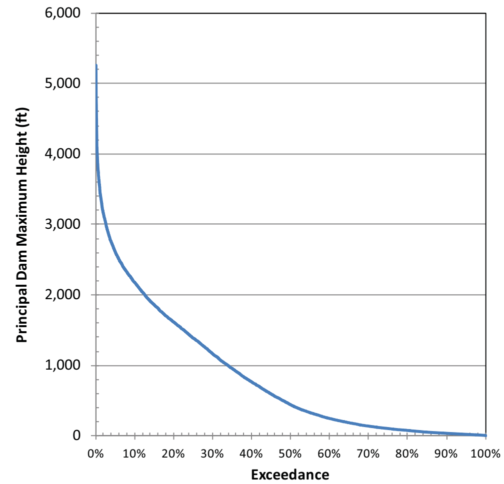


Figure 9. Distribution of principal dam maximum height on available small hydropower reaches.

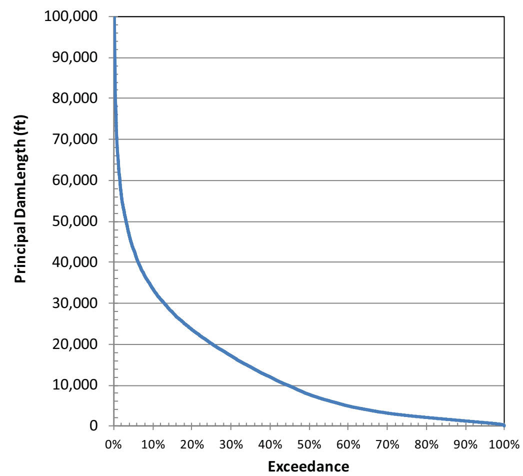


Figure 10. Distribution of the principal dam length on available small hydropower reaches.

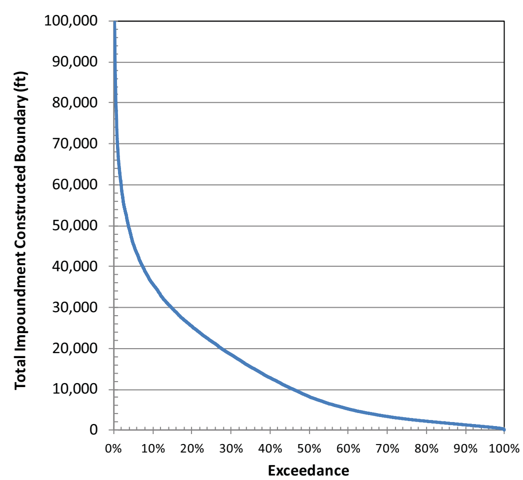


Figure 11. Distribution of total impoundment constructed boundary on available small hydropower reaches.

than five dam segments. A majority of the sites (90%) would require only the principal dam and at most one auxiliary dam. The distribution of the ratio of the principal dam length to the length of the total impoundment constructed boundary in Figure 13 illustrates that 79% of the population require only a principal dam, while the remaining sites require principal dams varying from slightly less than 100% to 21% of the total impoundment constructed boundary length.

Figure 14 presents the distribution of inundated area (reservoir surface area) at the sites. Ninety-nine percent of the sites have associated inundation areas less than 4,200 acres and 75% sites have inundation areas less than 1,000 acres.

3.3 Selection of Candidate Development Sites

As an illustration of how the modeling results of the assessment can be used to identify candidate project sites that are technically reasonable[e], the following screening criteria were applied to the population of available small hydropower sites:

- Dam height ≤ 500 ft
- Dam length ≤ 4500 ft
- Total impoundment constructed boundary ≤ 10,000 ft
- Number of dams at site: 5 or less.

These criteria are in addition to those used to define the available small hydropower population:

- Capacity ≥ 1 MW and ≤ 50 MW
- Flow rate ≤1000 cfs
- Head ≥5 ft
- Available
  - No existing dam
  - Not federally excluded
  - Not environmentally excluded.

e. "Technically reasonable" sites have site characteristics that are within the norms for existing hydroelectric plant sites making them candidates for evaluation as technically feasible.

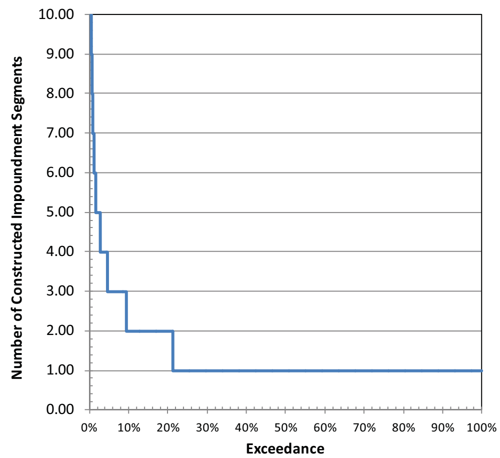


Figure 12. Distribution of number of constructed impoundment segments on available small hydropower reaches.

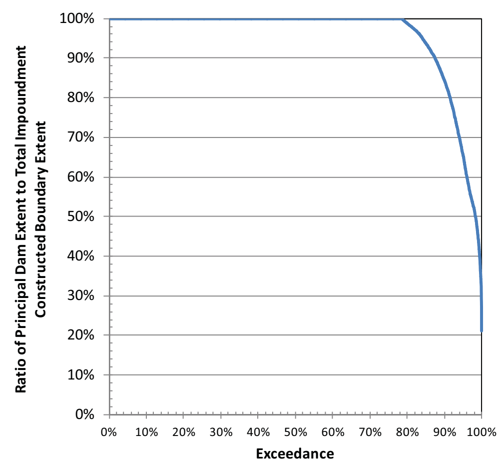


Figure 13. Distribution of principal dam length as a percentage of total impoundment boundary extent on available small hydropower reaches.

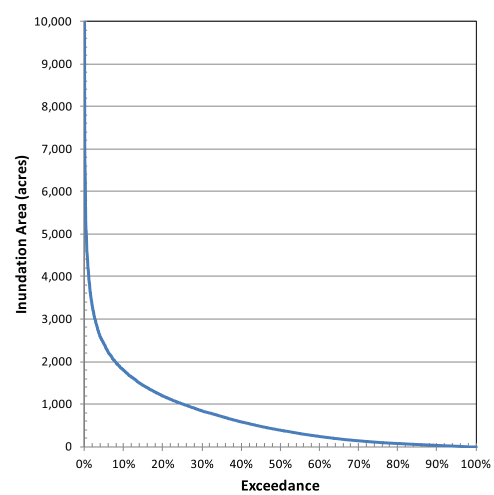


Figure 14. Distribution of inundated area on available small hydropower reaches.

The basic characteristics of the resulting population of potential sites are:

Power Characteristics

- Site population: 5,456 reaches
- Available capacity potential: 15,140 MW
- Capacity potential: 1 to 49 MW
- Flow rate: 14 to 1,000 cfs
- Hydraulic head: 6 to 435 ft

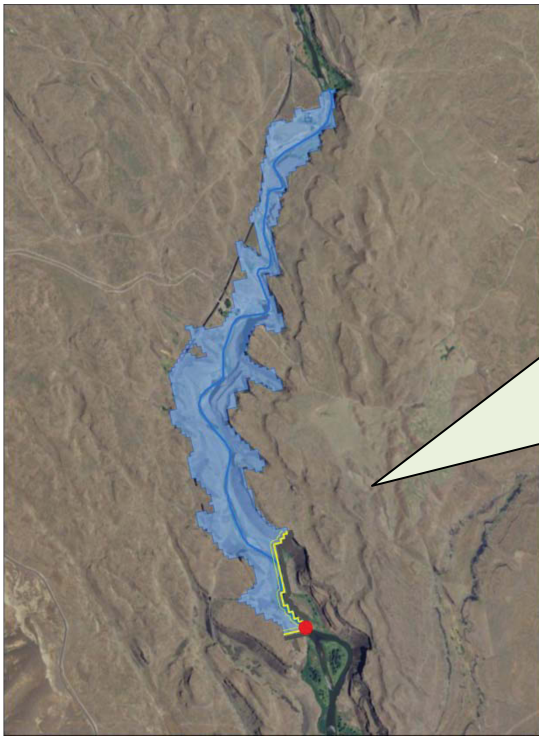
Site Characteristics

- Reach length: 69 ft to 7 mi
- Principal dam maximum height: 7 to 500 ft
- Principal dam length: 98 to 4,429 ft
- Total impoundment constructed boundary: 98 to 9,055 ft
- Principal dam length percentage of total constructed impoundment boundary: 29 to 100%
- Number of impoundment boundary segments: 1 to 5
- Reservoir area: .2 to 22,782 acres.

Site plans for two candidate sites are shown in Figures 15 and 16. The images in these figures are not "artist conceptions". They are dam (shown in brown-yellow) and reservoir (shown in blue) GIS features generated by the assessment model and overlaid on satellite imagery. These sites on the Palouse and Hood Rivers offering 41 and 10 MW of capacity potential would have to be evaluated further to determine whether they are technically feasible. The figures illustrate the value of site plan images to identify potential issues with a prospective hydropower project. Installation of a stream obstructing dam on Hood River site appears to result in inundation of farm land, which is most likely privately owned. This example also illustrates a case in which an auxiliary dam would be needed, which is just visible at the upstream end of the site. In all cases, since the dam footprint was positioned and its extent was analytically derived based on reach characteristics and local topography, an actual physical dam at the site would most likely be located at different position on the reach and its footprint would be more economical to construct.

The distributions of basic characteristics of the candidate potential project sites are shown in Figures 17 through 25. The capacity potential distribution in Figure 17 shows that while this population of over 5,000 sites offers capacity potentials up to 49 MW, only 3% of the sites (178 sites) offer capacity potentials of 10 MW or greater. This is nearly the same percentage of the greater available small hydropower population discussed in the previous section. Figure 18 shows that 85% of the reaches on which the potential project sites are located are less than 2 miles long. Higher flow rates occur at a disproportionate number of sites with flow rates equal to or greater than half the range occurring at about 18% of the sites as shown in Figure 19.

The distribution of the maximum heights of principal dams in Figure 20 shows that as with the flow rates, the higher dam heights occur for a small percentage of the sites with heights of 250 ft (half the range) or greater occurring at only 17% of the sites. Principal dam lengths are more uniformly distributed over most of the population having values from 500 to 4,400 ft as shown in Figure 21. For 90% of the sites, this character is also true of the distribution of the total impoundment constructed boundary shown in Figure 22. Only 1% of the sites require constructed boundaries that are more than a mile in total length. With regard to the need for auxiliary dams to complete the impoundment constructed boundary, the distribution of the number of constructed impoundment segments in Figure 23 shows that 91% of the sites would only require a principal dam , with only 3% requiring at most one auxiliary dam. For the sites requiring one or more auxiliary dams, Figure 24 shows that the ratio of the principal dam length to the total length of the impoundment constructed boundary varies from just than 100% to 29%. The distribution of inundation area or surface area of the reservoir shown in Figure 25 indicates surface areas of less than 500 acres for 92% of the sites, but is over 22,000 acres for a single site thereafter dropping to less than 7,000 acres for all the sites but this one.



Palouse River

Power Characteristics
- Capacity potential: 41 MW
- Flow rate average: 967 cfs
- Hydraulic head: 251 ft

Site Characteristics
- Reach length: 3.3 mi
- Principal dam maximum height: 289 ft
- Principal dam length: 4,134 ft
- Number of impoundment boundary segments: 1
- Reservoir area: 401 acres

Figure 15. Candidate site on the Palouse River, Washington.

Hood River

Power Characteristics
- Capacity potential: 10 MW
- Flow rate average: 459 cfs
- Hydraulic head: 122 ft

Site Characteristics
- Reach length: 1.6 mi
- Principal dam maximum height: 141 ft
- Principal dam length: 2,461 ft
- Number of impoundment boundary segments: 2
- Impoundment constructed boundary length:
- 2,756 ft
- Reservoir area: 191 acres

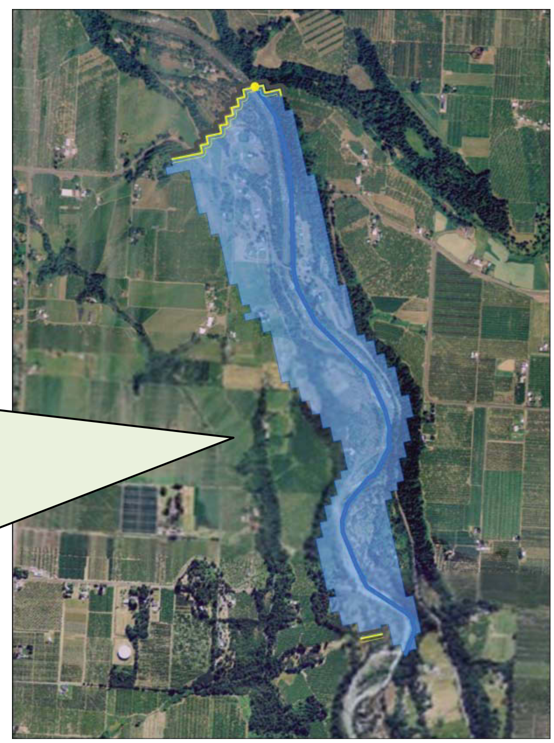


Figure 16. Candidate site on the Hood River, Oregon.

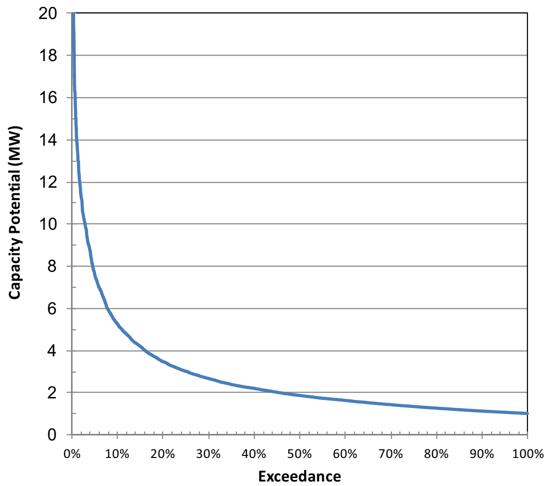


Figure 17. Distribution of capacity potential of candidate small hydropower sites.

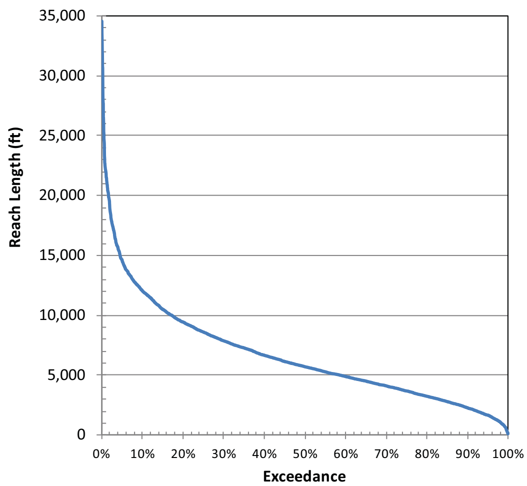


Figure 18. Distribution of reach lengths of candidate small hydropower sites.

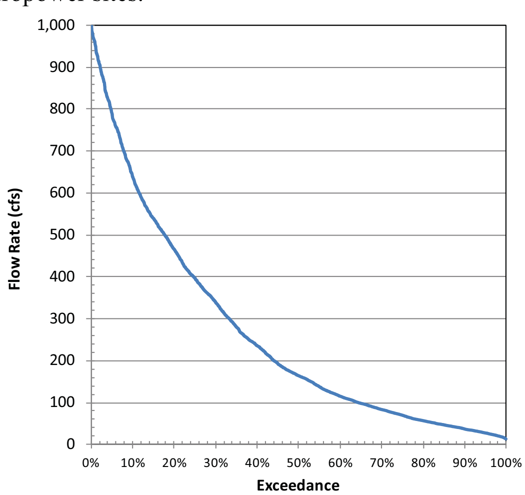


Figure 19. Distribution of flow rates at candidate small hydropower sites.

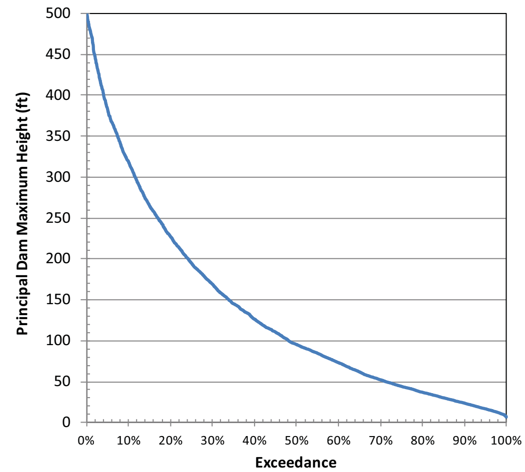


Figure 20. Distribution of principal dam maximum height at candidate small hydropower sites.

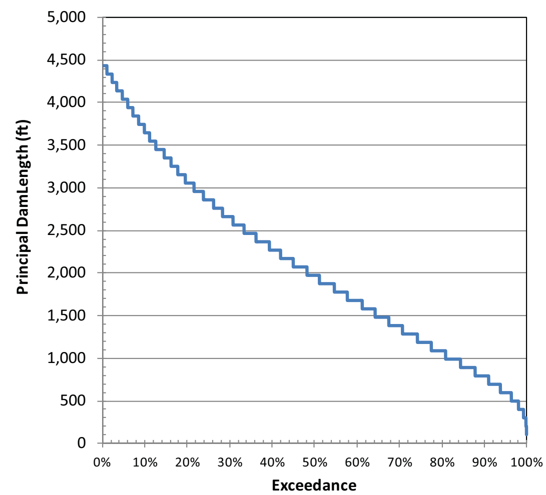


Figure 21. Distribution of the principal dam length on candidate small hydropower sites.

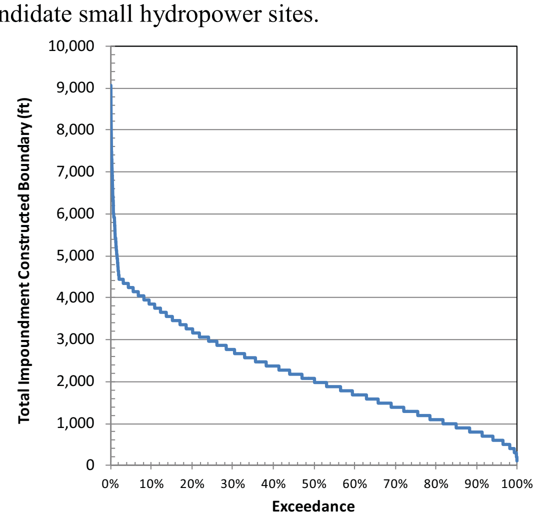


Figure 22. Distribution of total impoundment constructed boundary at candidate small hydropower sites.

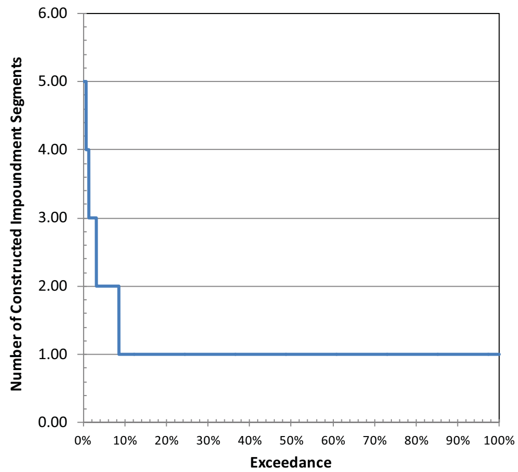


Figure 23. Distribution of number of constructed impoundment segments at candidate small hydropower sites.

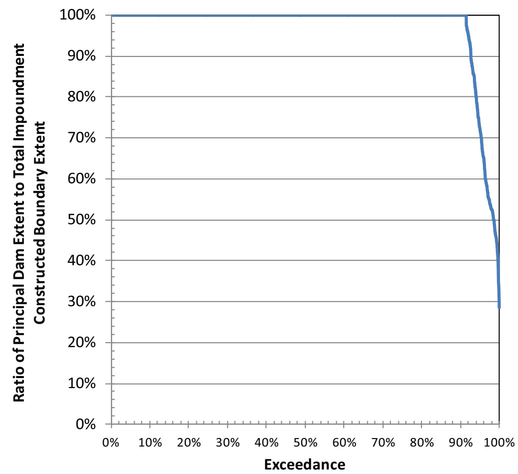


Figure 24. Distribution of principal dam length as a percentage of total impoundment boundary extent at candidate small hydropower sites.

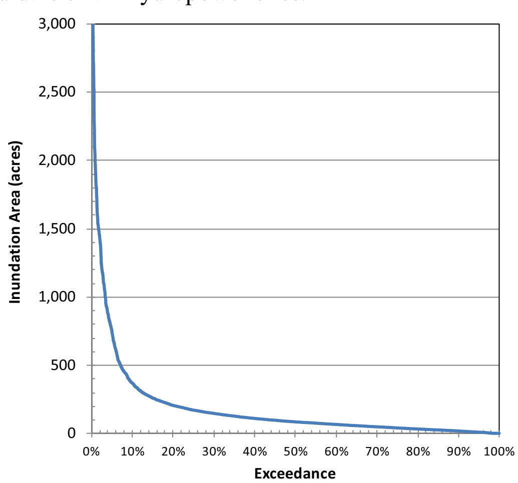


Figure 25. Distribution of reservoir area at candidate small hydropower sites.

An additional perspective of the capacity potential and site characteristics of the 5,456 candidate small hydropower sites is provided by Figures 26 through 31. The combinations of hydraulic head and flow rate at the sites are shown in the context of capacity power curves in Figure 26. As indicated by the capacity distribution in Figure 17, the vast majority of capacity potentials offered by the sites are 1 MW or greater but less than 10 MW. The distribution of points in Figure 26 shows a bias to flow rate being the larger factor in determining capacity potential, but there are also sites with lower flow rates and higher hydraulic heads at the same power value.

Site characteristics: reach length, principal dam height and length, total impoundment constructed boundary, and reservoir area are plotted versus the corresponding site capacity potential in Figures 27 through 31. The lengths of the reaches constituting the candidate sites vary widely even for the majority of sites having capacity potentials less than 10 MW. The reach lengths vary over the full range from 69 ft to 6 mi. Figure 27 shows that most lengths of the reaches on which most of the candidate sites are located are less than 15,000 ft or about 3mi long. This feature of having site characteristics spanning the full range even at sites having lower capacity potentials is also exhibited by the plots of the other site characteristics. Principal dam heights and lengths[f], and impoundment constructed boundary shown in Figures 28 through 30 span the full range of lengths even at sites offering as little as 1 MW of capacity potential. These figures also show that the higher capacity potentials do not require civil works having the maximum dimensions. The sharp cutoff of principal dam heights at the lower end of the distribution in Figure 28 is due to the restriction of the flow rate to 1,000 cfs and capacity potential to 1 MW or greater. Sites offering capacity potentials of 10 MW or greater do not require total impoundment constructed boundaries longer than 1 mi as shown in Figure 30. The distribution of reservoir surface area shown by the distribution in Figure 25 is illustrated in Figure 31, which shows that higher

f. The length incrementing shown in Figure 29 stems from the fact that a 30 m DEM was used in the study resulting in boundaries composed of 30 m segments.

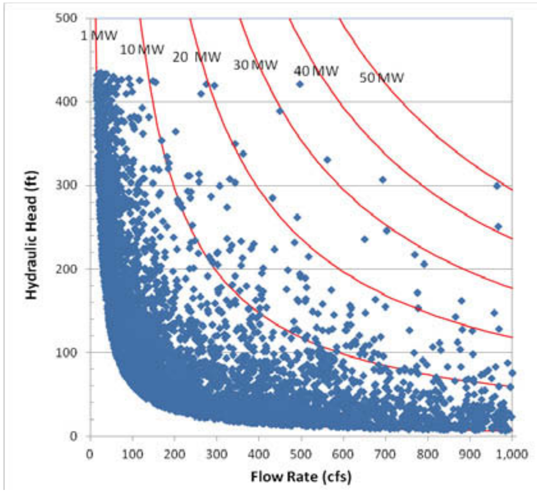


Figure 26. Hydraulic head versus flow rate at candidate small hydropower sites.

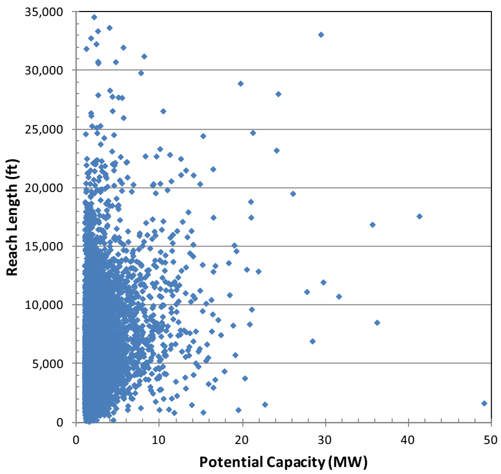


Figure 27. Reach length versus potential capacity for candidate small hydropower sites.

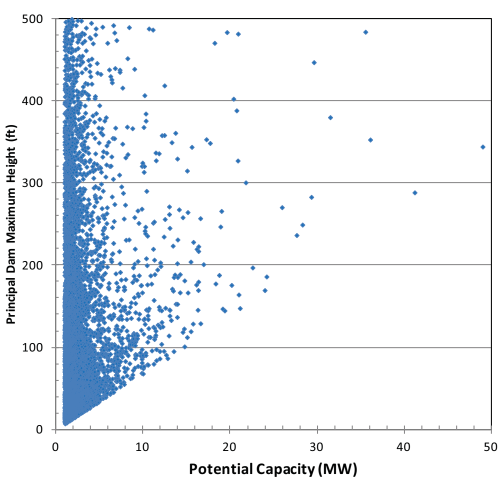


Figure 28. Principal dam maximum height versus potential capacity for candidate small hydropower sites.

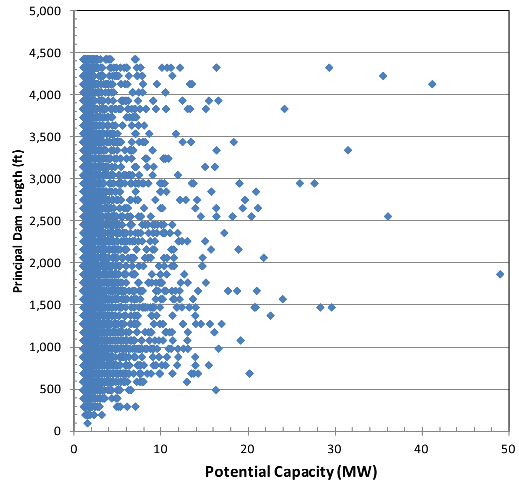


Figure 29. Principal dam length versus potential capacity for candidate small hydropower sites.

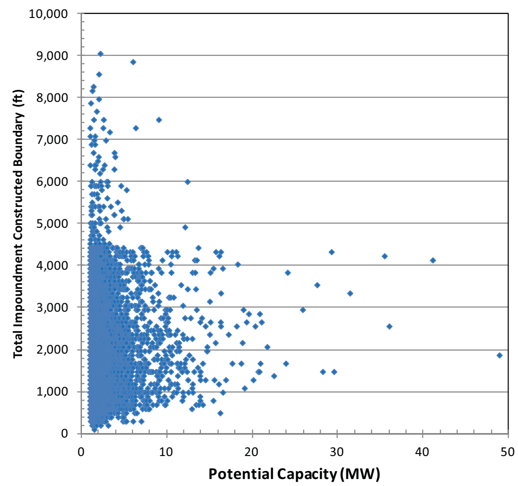


Figure 30. Total impoundment constructed boundary versus potential capacity for candidate small hydropower sites.

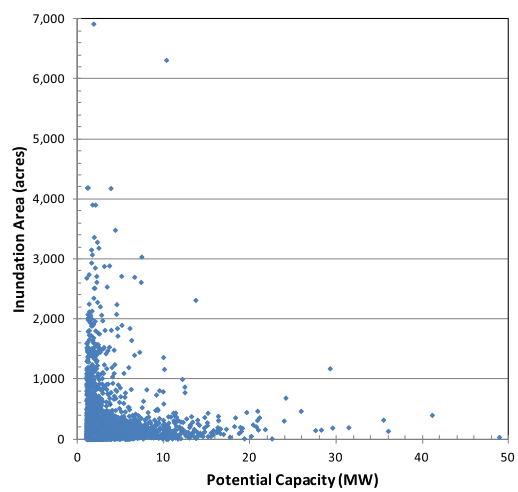


Figure 31. Inundation area versus potential capacity for candidate small hydropower sites.

capacity potential does not require a large reservoir.

The distributions of civil works dimensions in Figures 28 through 30 illustrate that while the candidate sites were selected based on parametric limits that were reasonable, when considered together at a specific site, the dimensions may not be reasonable. Obviously, sites offering 1 MW of capacity potential requiring 500 ft high dams or dams 4,500 ft long are not reasonable. The data produced by the assessment does allow for refined selection of reasonable sites as candidates for further assessment, but additional screening criteria are needed based on the characteristics of existing plants and expert judgment.

A map of Hydrologic Region 17 showing the locations of candidate sites is presented in Figure 32. Most of the sites are located in Idaho mountain ranges, and the Cascade and Pacific Coast Ranges in Oregon and Washington. Sites offering higher capacity potentials in the range from 10 to 50 MW are generally individual sites. Sites offering capacity potentials in the range from 5 to 10 MW exhibit instances of closely located or successive reaches on the same stream being candidate sites. This clustering of sites is even more pronounced for sites offering capacity potentials in the range from 1 to 5 MW. These clustered sites may represent opportunities for ganged reach project sites where a dam at the most downstream reach can capture the hydraulic head of multiple upstream reaches. Whether these are reasonable projects depends on greatly on the number of auxiliary dams that will be required and the total length of the impoundment constructed boundary relative to the project capacity potential.

The available small hydropower and candidate site datasets are available in Appendix B to assist the interested reader in further research of these sites.

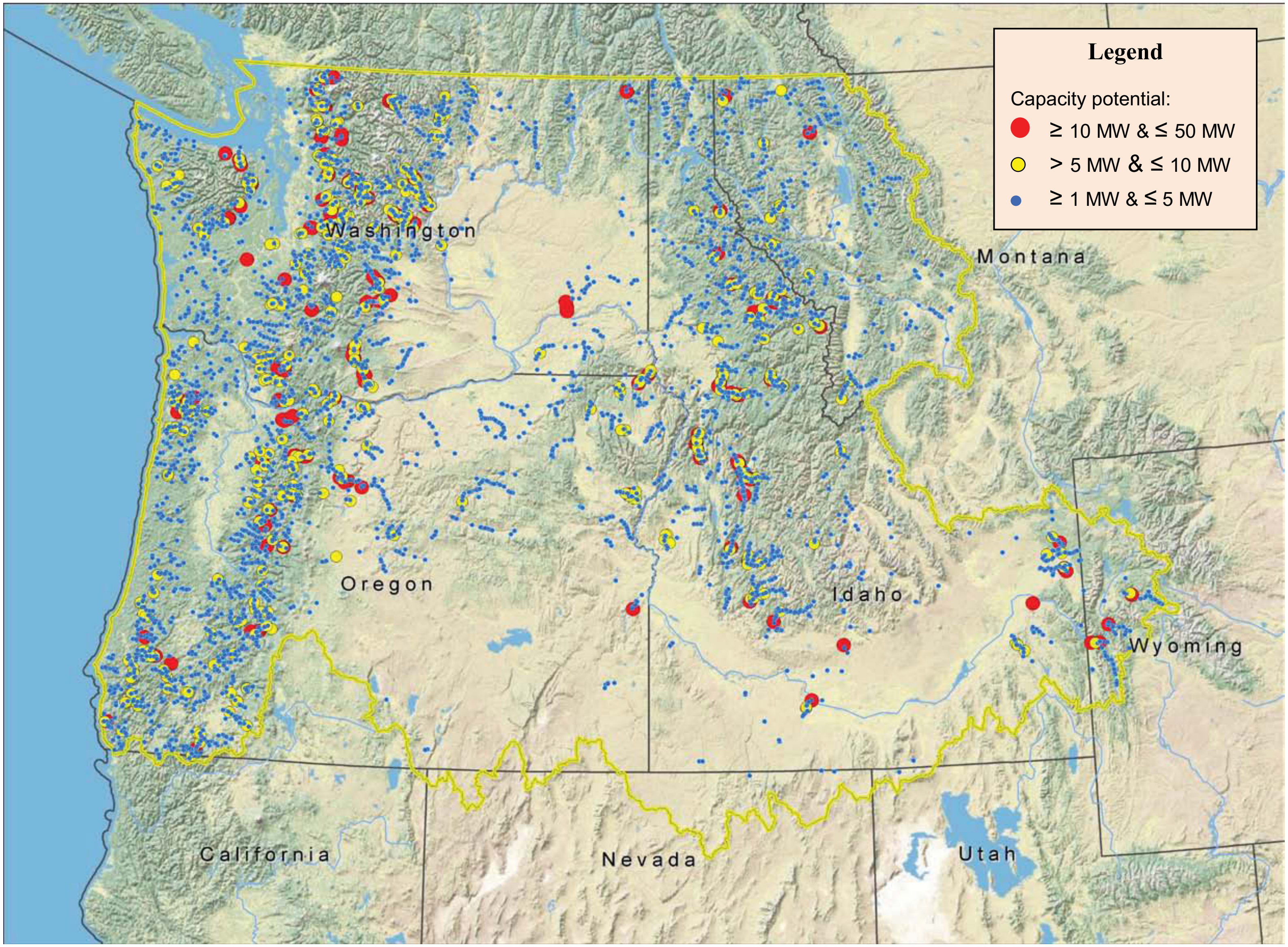


Figure 32. Locations of candidate small hydropower sites in Hydrologic Region 17.

4. CONCLUSIONS

The pilot assessment, which included modeling of project characteristics resulting from the placement of a stream obstructing dam on stream reaches in Hydrologic Region 17, met the objective of demonstrating that the assessment methodology is capable of assessing the capacity potential of a large region by aggregating the power potential of individual stream reaches and providing project site characteristic information for single reach project sites. The modeling technique provided the basic power related characteristics of hydraulic head, annual average flow rate, and capacity potential, and site characteristics including stream reach length, principal dam dimensions, the number of auxiliary dams needed to complete the impoundment boundary, the total length of the impoundment constructed boundary, and the size of the resulting reservoir.

The assessment produced a total regional capacity potential estimate that was 21% higher than a prior regional assessment conducted using different hydrographic and flow rate estimating models. This difference is most likely within the combined uncertainties of the two modeling techniques. It is noteworthy that the two studies resulted in capacity potentials in the existing dam and available power categories that agreed within 5% or less. Explanation of fact that the current methodology resulted in a capacity potential in exclusion zones that is nearly 70% higher than in the previous study would require further study.

The assessment based on stream reaches defined by the medium resolution hydrography provided by NHDPlus yields good estimates of reach capacity potential, but does not provide useful site characteristics for all reaches particularly those on large rivers that of short extent. The assessment methodology does provide useful site characteristics for reaches that realistically could be developed as stand-alone project sites. The methodology could be modified to provide site characteristics for large projects in which reaches are ganged together. However, this type of assessment requires defining or determining the extent of reaches to be included in the project and may benefit from identifying locations where the topography can provide the necessary headwalls for a dam capable of capturing the hydraulic head of multiple upstream reaches.

The decomposition of the full population of the stream reaches in Hydrologic Region 17 (231,747 reaches) to those offering at least 1 MW of capacity potential (29,580 reaches); to small hydropower reaches based on flow rate, capacity potential, and hydraulic head (24,489 reaches); to available small hydropower reaches (15,676 reaches); and ultimately to candidate reaches not located in exclusion zones and possessing site characteristics within reasonable limits (5,429 reaches) demonstrates that the assessment methodology provides the necessary characteristics to identify development sites worthy of further assessment. However, what are "technically reasonable site characteristics" taken one at a time for the purpose of screening a population of potential project sites may not be technically reasonable for a particular project site when considered collectively. Technically reasonable site characteristics and further, technical feasibility would require more detailed assessment of individual sites. An assessment of economic feasibility introduces a host of additional factors.

The data produced by the assessment is of sufficient value that site specific data should be provided to hydropower stakeholders. The electronic appendix to this report does this in database form. However, it is difficult to fully understand the results of the site modeling without seeing the graphical project site layout. Full value from the assessment in facilitating informed project site evaluation and selection can only be achieved by providing site layouts and attribute data with accompanying context features in a geographic information systems (GIS) format such as that provided by the Virtual Hydropower Prospector (VHP 2011) and similar applications.

5. RECOMMENDATIONS

Based on the assessment that has been performed, the follow recommendations are made to upgrade and extend the modeling of potential hydropower projects using a stream obstructing dam:

1. This pilot assessment identified “candidate” sites for additional assessment. The results clearly show that additional screening criteria need to be applied to ensure that sites are technically reasonable based on their complete set of site characteristics rather than their characteristics being screened individually.
2. The modeling methodology demonstrated in the present assessment has provided useful project characteristic information for Hydrologic Region 17 and therefore should be extended to the remaining 19 U.S. hydrologic regions with the upgrades that follow.
3. The assessment results as presented in this report provide a general view of the potential and characteristics of hydropower development on greenfield sites, but other than informing of the possibilities, does little to actually facilitate adding additional hydropower capacity. Such facilitation necessitates access to site-specific information in the context of features affecting project development. Full value of the assessment results should be obtained by including these data in the Virtual Hydropower Prospector GIS application and made available via any other appropriate graphical or database source.
4. The methodology employed in the present assessment identified parts of the impoundment boundary that would require the installation of civil works; generally a principal dam and perhaps one or more auxiliary dams. The remainder of the impoundment boundary is provided by the topography. The site characteristics would be upgraded by ensuring that an adequate amount of freeboard exists at all points on the impoundment boundary where civil works are not indicated to be needed.
5. As an extension of Recommendation #3, it would be useful to know how much hydraulic head would be lost at sites by lowering the principal dam height to provide a specified amount of freeboard at parts of the impoundment boundary that are not indicated to require civil works and to perhaps eliminate the need for any auxiliary dams.
6. The assessment provided the surface area of the reservoir at the project site, but did not evaluate the volume (e.g., in acre-ft) of the reservoir or address the amount of potential energy storage at the site, which could be an adjunct topic to evaluating the volume of the reservoir.
7. While the assessment addressed all the reaches in Hydrologic Region 17, it focused on small hydropower projects as a means to eliminate unrealistic project sites on small reaches that were part of a large river. The 5,000 reaches that were eliminated by focusing on small hydropower sites should be further assessed, because some may be candidate, greenfield, single reach project sites.
8. The methodology used in the assessment with some modifications is applicable to modeling larger projects capturing the hydraulic head of multiple successively stream reaches. Where the single reach assessment comprehensively modeled every reach in the region based on reaches as defined by the NHD Plus medium resolution hydrography, the streamwise extent of multi-reach project sites would have to be defined by appropriate criteria before they are modeled. While the definition of such criteria for site selection may be possible, an alternate approach is to identify topography that could provide dam abutments and define the project extent based on characteristics of the dam site and upstream topography.

9. The National Hydrography Dataset Plus (NHDPlus) has provided essential data for this and other hydropower resource assessments because of providing mapped hydrography accompanied by annual average flow rates from two hydrologic models. Two upgrades to the data would enhance its usefulness for hydropower resources assessments and other studies:

   a. As discussed in Appendix A, the DEM that is provided with NHD Plus is not fully hydrographically conditioned; thus, points along its stream reaches do not change elevation monotonically resulting in non-physical elevation representations of reaches.

   b. The National Hydrography Dataset (NHD) provides the locations of dams listed in the National Inventory of Dams (NID) that have been adjusted to ensure that they are located on reaches in the NHD high resolution hydrography. NHD also provides a reference index to the NID so that extensive dam attributes are available. NHDPlus does not provide a reliable cross reference from its medium resolution stream reaches to corresponding stream reaches in NHD. Such a complete cross reference would allow the benefits provided by NHD Plus to be complemented by those provided by the NHD.

6. REFERENCES

ACE, 2010, *National Inventory of Dams*, U.S. Army Corps of Engineers, 2010 (accessible at: http://nid.usace.army.mil).

Connor, Frankfort, and Rinehart, 1998, A. M. Connor, J. E. Frankfort, and B. N. Rinehart, 1998, *U.S. Hydropower Resource Assessment Final Report*, DOE/ID-10430.2, December 1998 (available at: http://hydropower.inl.gov/resourceassessment/index.shtml).

CBI, 2003, Conservation Biology Institute, 2003 (accessible at: http://www.consbio.org/).

Gesch et al, 2002, D. B. Gesch, M. Oimoen, S. Greenlee, C. Nelson, M. Steuck, and D. Tyler, "The National Elevation Dataset", *Photogrammetric Engineering & Remote Sensing,* Vol. 68, No.1, pp. 5–11, 2002.

ESRI, 2011, ArcGIS, Environmental Systems Research Institute (ESRI), Redlands, CA, 2011 (see http://www.esri.com/products/index.html).

Hall et al, 2004, D. G. Hall, S. J. Cherry, K. S. Reeves, R. D. Lee, G. R. Carroll, G. L. Sommers, and K. L. Verdin, 2004, *Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources*, DOE/ID-11111, April 2004 (available at: http://hydropower.inl.gov/resourceassessment/index.shtml).

Hall et al, 2006, D. G. Hall, K. S. Reeves, J. A. Brizzee, R. D. Lee, G. R. Carroll, and G.L. Sommers, *Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants*, DOE-ID-11263, January 2006 (available at: http://hydropower.inl.gov/resourceassessment/index.shtml.

Parks and Madison, 1985, B. Parks, and R.J. Madison, 1985, *Estimation of Selected Flow and Water-quality Characteristics of Alaska Streams*, Water-Resources Investigations Report 84-4247, 1985 (available at http://ak.water.usgs.gov/Publications/pdf.reps/wrir84.4247.pdf).

NDH, 2011, *National Hydrography Dataset*, U.S. Geological Survey, 2011 (accessible at: http://nhd.usgs.gov/).

NHDPlus, 2010, *National Hydrography Dataset Plus*, Horizon Systems Corporation, 2010 (accessible at: http://www.horizon-systems.com/nhdplus/).

RTI, 2001, *The National Water Pollution Control Assessment Model(NWPCAM) Version 2*, Research Triangle Institute, Research Triangle Park, NC, draft report prepared for the U.S. Environmental Protection Agency,2001.

Taylor, 1977, P.J. Taylor, *Quantitative Methods in Geography: An Introduction to Spatial Analysis*, Chapter 5: Areal Association, Houghton Mifflin, Boston, 1977, 396pp.

Verdin and Greenlee, 2003, K. L. Verdin, and S. K. Greenlee, "Continuous Basin Characterization using EDNA, In: Proceedings", 23rd Annual ESRI Users Conference, San Diego, California, July 2003.

Verdin and Jenson, 1996, K. L. Verdin, and S. Jenson, "Development of Continental Scale DEMs and Extraction of Hydrographic Features", *Proceedings of the Third International Conference/Workshop on Integrating GIS and Environmental Modeling*, Santa Fe, New Mexico, January 21–26, 1996. (CD-ROM available from National Center for Geographic Information and Analysis, Santa Barbara, California, 93106, USA).

VHP,2011, *Virtual Hydropower Prospector*, Idaho National Laboratory, 2011 (accessible at: http://hydropower.inl.gov/prospector/index.shtml).

Vogel, Wilson, and Daly, 1999, R.M. Vogel, I.W. Wilson, and C. Daly, "Regional Regression Models of Annual Streamflow for the United States," *Journal of Irrigation and Drainage Engineering*, Vol. 125, No. 3, pp. 148-157, 1999.

Yamanaga, 1972, G. Yamanaga, *Evaluation of the Streamflow Data Program in Hawaii*, U.S. Geological Survey Open-File Report, 1972.

Appendix A

Issues With using NHDPlus to Define Inundated Extent

Appendix A

Issues With using NHDPlus to Define Inundated Extent

The NHDPlus was developed for various purposes, one of which was the derivation of catchments (drainage areas) for the National Hydrography Dataset. In order to maximize the spatial agreement between the NHD, the Watershed Boundary Dataset (WBD) (USGS, 2011) and the derived catchments, the DEM used in the NHDPlus development was “burned” using the NHD and “walled” using the WBD. During the processing, the stream channel was “burned” 5000 meters and trenched 160 meters on either side of each reach. This processing significantly modified the elevation values along the streamlines, the area most likely to be inundated. The extent to which the DEM was modified in this process renders the burned DEM not useful for inundation mapping. Regardless, this burned DEM was not saved by the developers and, therefore, was not distributed as part of the NHDPlus dataset. The DEM delivered with the NHDPlus data set is simply a snapshot of NED. It has not been hydrologically conditioned and does not “agree” with the streamlines, catchments, flow directions, etc.

Since the NHDPlus DEM had not been hydrologically conditioned, the DEM still contained many sinks and the elevations along the NHDPlus flow lines were not monotonically decreasing. Since the DEM still contained sinks, most attempts at trying to model the inundated extent resulted in disconnected pockets of inundation. This is due to the unconditioned DEM, as well as the fact that the elevations assigned to the upstream and downstream end of the reach were not derived directly from a hydrologically conditioned DEM, but obtained through a smoothing technique. An example of the type of disconnected inundated patterns is shown in Figure A-1.

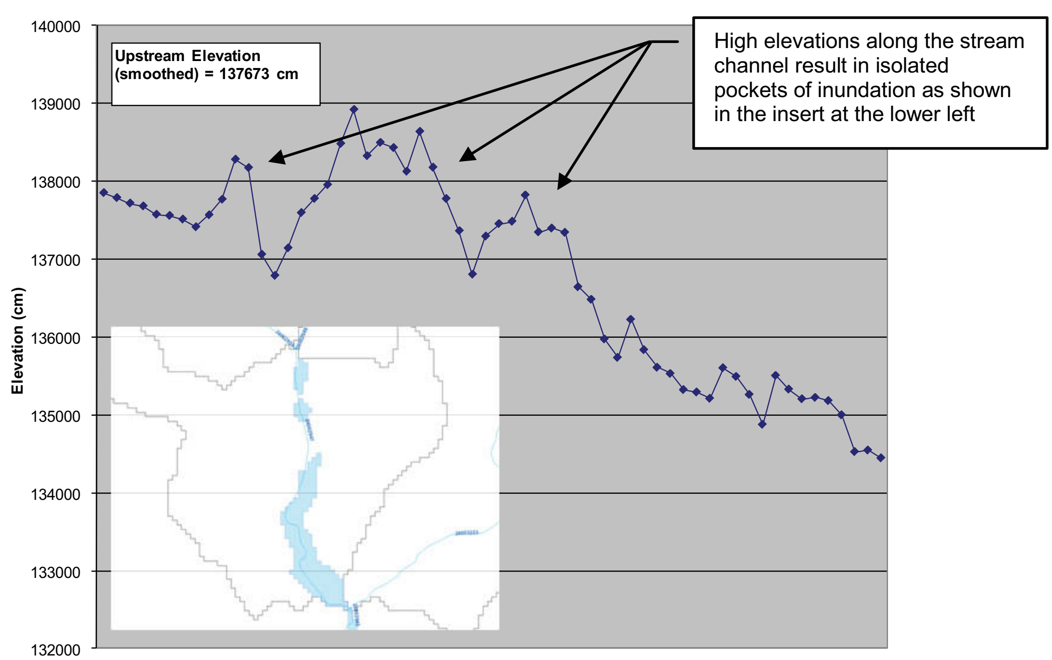


Figure A-1. Profile along NHD reach (COMID 24002947) using the NHDPlus DEM.

The upstream elevation from the NHDPlus attribute tables for this reach was 137673 cm. Shown in Figure A-1 is the profile along the NHD flowline from upstream to downstream using the NHDPlus DEM to derive elevations. The fact that the elevations were not monotonically decreasing from upstream to downstream resulted in the disconnected pockets of inundation as shown in the graphic at the lower left of the figure.

Use of the EDNA hydrologically conditioned DEM produced more reasonable patterns of inundation. A comparison between NHDPlus and EDNA-derived inundation patterns is shown in Figure A-2. The left-hand side of the graphic shows the inundation pattern resulting from the NHDPlus for the reach with COMID = 24007052, assuming a dam is built to inundate the entire head of the reach. The inundation is sporadic and does not reach the upstream end of the reach. The areas shown in color are those pixels with elevation at or below the elevation of the upstream end of the reach. Since the inundation does not extend to the upstream end of the reach, the actual elevation of the upstream end of the reach (as derived from the DEM) is higher than that assigned in the NHDPlus processing. On the right-hand side of Figure 5, the inundation pattern derived from the EDNA is shown. A similar pattern is shown Figure A-3 for the reach with COMID = 24007058.

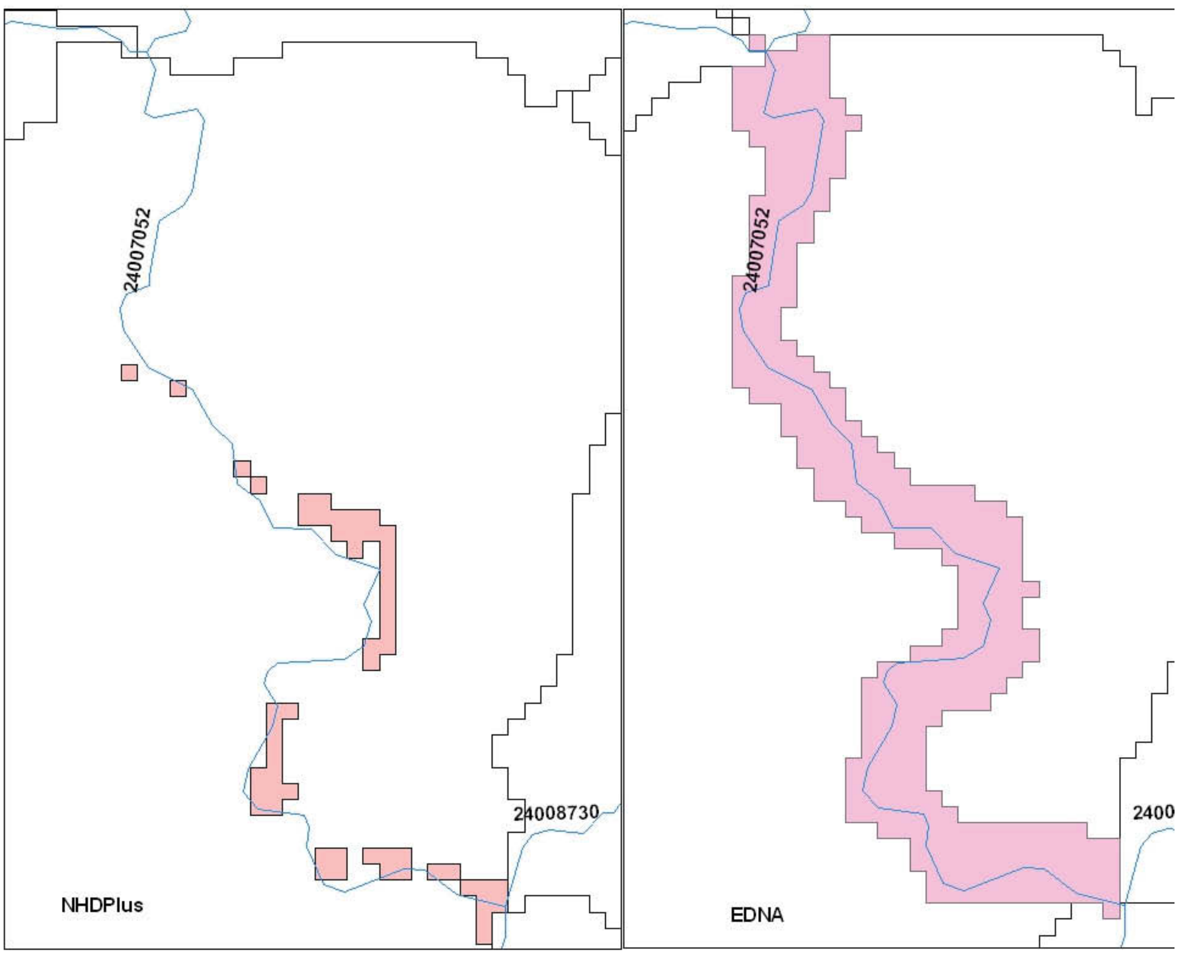


Figure A-2. Comparison of NHDPlus and EDNA-derived inundation patterns for NHD reach COMID 24007052.

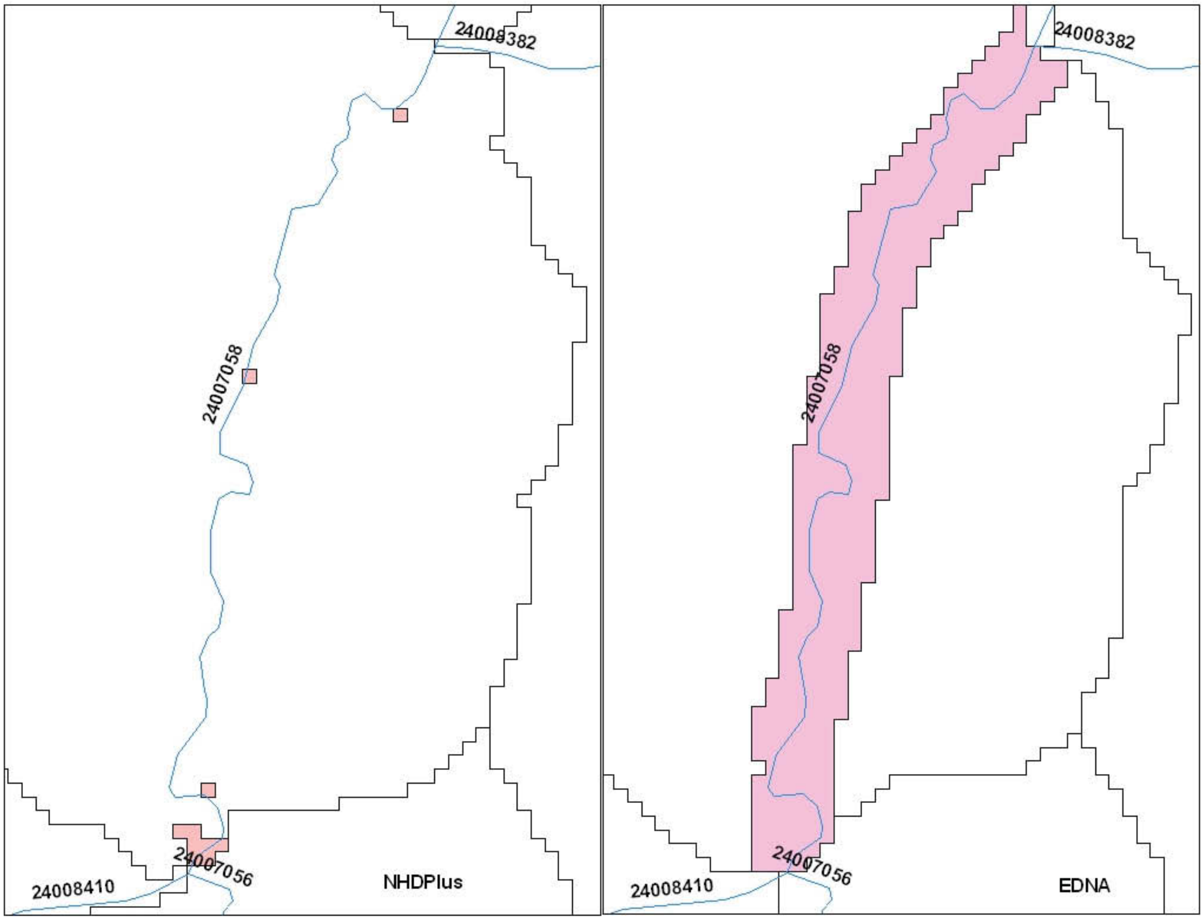


Figure A-3. Comparison of NHDPlus and EDNA-derived inundation patterns for NHD reach COMID 24007058.

Appendix B

Region 17 Greenfield Sites Datasets

Appendix B

Region 17 Greenfield Sites Datasets

This appendix is contained on the compact disk on the back cover of the report. It includes two datasets in Excel format that are discussed in the body of the report. The datasets are each composed of a population of stream reaches for which attribute information is provided including derived power and site characteristics. The datasets are:

- Available small hydropower reaches
- Candidate small hydropower sites.