Fall 2012

Assessing the feasibility of small hydropower in Northern California

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Recommended Citation

Peterson, Andrea, "Assessing the feasibility of small hydropower in Northern California" (2012). *Masters Theses*. 289.
https://commons.lib.jmu.edu/master201019/289

Assessing the Feasibility of Small Hydropower in Northern California

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A Dissertation submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

Partial Fulfillment of the Requirements

for the degree of

Master of Science

Integrated Science and Technology

December 2012

Acknowledgements

Thank you:

Dr. James Wilson

Dr. Jonathan Miles

Dr. Charles Galdies

Dr. Maria Papadakis

Larry and Terry Peterson

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Abstract

Small hydropower is an underutilized form of clean energy generation. In order for any potential for small hydropower to be developed or utilized, the amount of potential power needs to be estimated accurately. A number of studies have been conducted, though none of these studies have taken local climate into account, which affects the accuracy of their results. A number of places in Northern California have potential that has not yet been utilized, but a more accurate assessment of that potential is called for. Although studies can be conducted through a number of different methodologies, most use GIS technology to analyze the data. Laying out the exact methodology allows for the results to be verified, and for additional, refining studies to be conducted. The important piece of the methodology is the equation that is used to determine the potential power at any point. The methodology established here shows that there is unutilized small hydropower potential in the Northern California region. Comparison with the results of previous studies leads to surprising results, as the results of these studies vary in unexpected ways. A simple comparison of input data, rather than the final results of the studies, shows ways in which these previous studies are inaccurate. Starting with measured data, not unexplained models, makes this study more accurate than the previous studies. Also, presenting the process in a way that is transparent with results that are more accessible and understandable should allow for replication and make the findings available to the general public.

Introduction

Clean energy is increasingly being demanded by the world's concerned citizens. Clean energy is not generated through the combustion of fossil fuels, and can come in a number of forms and from a variety of sources, such as solar, wind, and water. Wind and solar power can be utilized in any area which has sufficient wind or sunlight, though neither wind nor sunlight is constant, from which it follows that their power generation is intermittent. Water, on the other hand, is constantly flowing, in year-round rivers and streams, which makes a water-generated power supply constant. Hydroelectric power tends to be associated with the construction and utilization of dams, which are built for a number of reasons in addition to power generation. This can be problematic though, since dams are environmentally damaging, creating a number of undesirable results. The construction of new dams, for whatever reason, is not commonly approved by the regulating agencies, especially in areas where other solutions accomplish the same goals, such as power generation and water storage. There are other ways besides the use of large dams to generate power from water without causing such ecological damage. These generally fall into the category known as small hydropower.

This study is designed to locate areas of unutilized small hydropower potential in the Northern portion of California. Small hydropower technologies divert a portion of the water from a river or stream through the use of a pipeline, called a penstock or conveyance, from which the water is then run through a turbine to generate hydroelectric power, also called hydropower. The diverted water is then returned to the river farther downstream through a tailrace (Figure 1). The amount of power that can be generated using small hydropower technologies depends on the flow rate of the river and the elevation change that

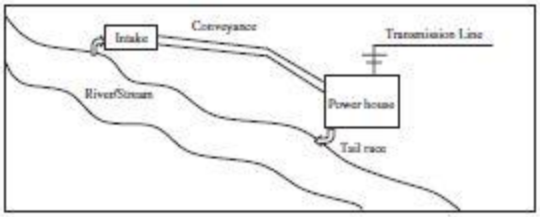


Figure 1 Diagram of a Small Hydropower Installation (Kosnik, 2010).

occurs in the area of the small hydropower installation. Generating power using water could lessen dependence on the use of fossil based fuels as a source of power. In order to make use of any potential power, the areas which have potential must first be located.

Various studies have explored various methods to locate sites for which there may exist the potential for the generation of hydroelectric power. Studies usually focus on certain areas of the world, and a number of different tools are used by each of the studies. These studies depend on the data that is publicly available, which can be a limiting factor in the study. There is also the possibility for errors to be made in any study, and this can cause problems for any future development that is initially based on the results of these studies. In order to improve on these studies and reduce the margin of error, it is first necessary to identify the shortcomings of these studies, and to find a way to work around these issues. After any deficiencies are identified, it is necessary to determine a methodology that will identify potential sites while introducing as little uncertainty as possible. Uncertainty cannot be completely eliminated from any broad study, and is inherent when working with data that may not be ideal.

California provides a good example of an area in which previous studies may not have been accurate in estimating the available potential for small hydropower development. California has a large variety of terrains and an extremely uneven population density. The majority of the people in California live in the metropolitan areas, with a smaller number of people living in the mountainous and forested areas. California is home to both large cities and large expanses of farm land, plus a significant number of rivers and streams. Most of the naturally occurring waterways are found in the Northern portion of the state, while the Southern portion of the state is fairly dry. Most of the water used in the South is imported, by way of artificial canals, from the north and east, where water more is plentiful. Therefore, the geographic area for this study includes only the northern section of the state. The climate of the Northern area is also considered, as the climate and precipitation rates affect the amount of water that is available in any area, and should be included in any study that looks at the amount of water available in the area. Rainfall is rarely constant throughout an average year in any part of the world and is affected by the terrain of the area in question. California, specifically, only gets a significant amount of precipitation during a portion of the year, so the amount of water in the rivers and streams has a profound but predictable seasonal variation (Figure 2). These precipitation graphs represent the annual average rainfall for different areas in Northern California: Eureka in the North, Sacramento in the Central Valley, Rohnert Park in the Coastal region, and Truckee in the Sierra Nevada Mountains.

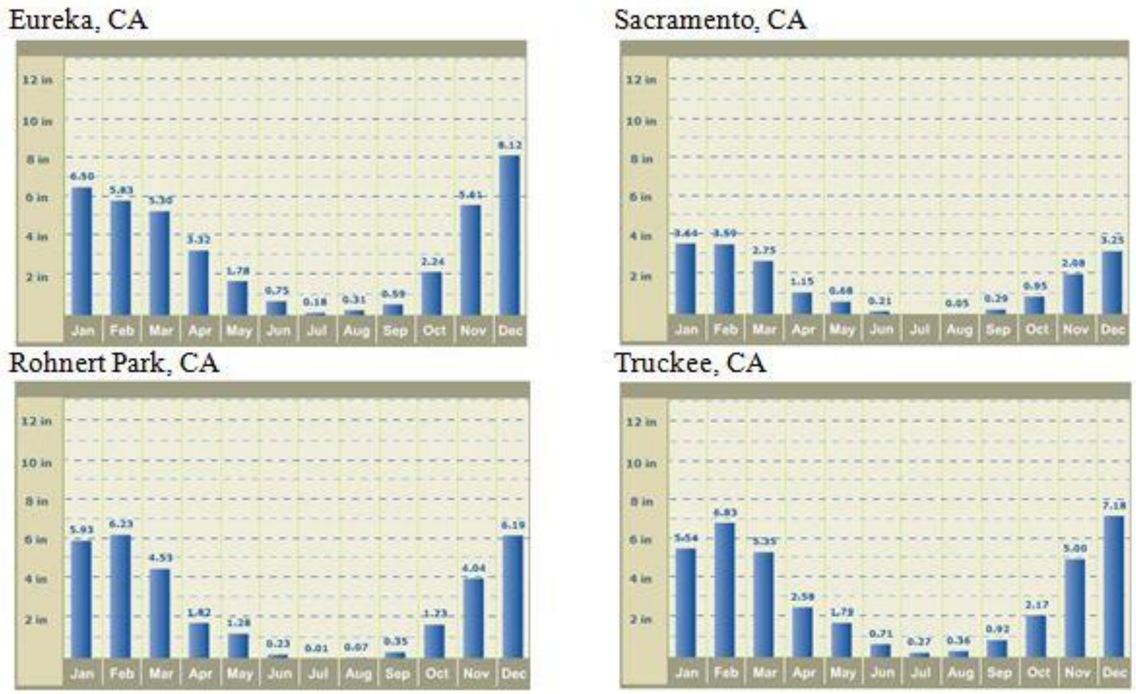


Figure 2: Monthly precipitation averages in four cities around Northern California (Weather Channel, 2012).

The areas considered to be Northern California for this study include all of the counties that fall along or north of a line drawn from the mouth of the San Francisco Bay to the point where the state border with Nevada forms an angle (Figure 3).

Figure 3: Area of interest, all counties on or North of the line between the mouth of the San Francisco Bay and the point where the border with Nevada makes an angle.

There are twenty six counties in this area. As Figure 4 demonstrates, it contains a number of different features, including mountain and extensive valley areas, which should allow for a wide range of differing power generation capabilities available for small hydropower development.

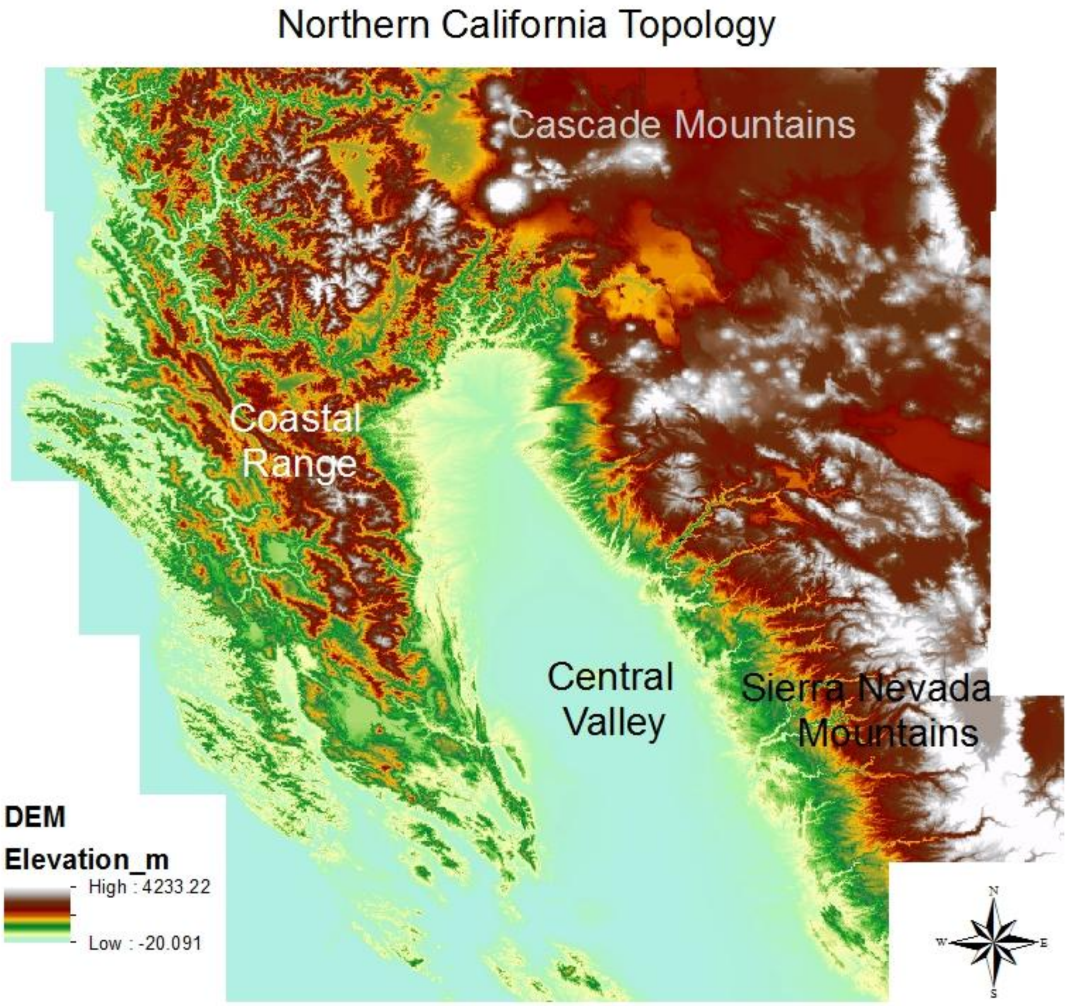


Figure 4: Digital Elevation Model showing the mountainous and valley areas of Northern California.

Many studies designed to ascertain the small hydropower potential utilize a variety of computer programs, which work with the geographical data that is most crucial in such a study. This data includes elevation, river flow, and, in some cases where such flow data is not readily available, watershed and climate data. Unfortunately, researchers are not always the people who are best able to make use of the data obtained, which makes it important that their information be understandable to end users, such as developers. Various government agencies, both at a federal and state level, have sponsored studies, but these agencies have no interest in developing the potential themselves. This results in data that is ideal for reports, but not as useful to the people most likely to develop it. If a fairly simple method can be found to conduct a study such as this, there is a greater possibility that a study could be accessible to, and even conducted by, the people who are most likely to make use of the results. While this study may not be ideal for end users, laying out the procedure and the equation should make the process more accessible to them for their own situations. In the United States, both flow data and elevation data are publicly available. This study, like many others, uses ESRI's ArcGIS 10 (2011), which is a mapping software package that can compare data geographically. Geographic comparisons are useful when considering the relative locations of rivers and the various areas in which hydropower could best be utilized. Proximity is easily determined through geographical relationships, and is much more difficult to determine through other methods.

Small hydropower can be used for a number of different purposes, from powering a single home or a small community, to using an installation to generate additional power for export to the power grid. Because of the number of options available, a number of factors need to be taken into account when considering the areas where potential for development may exist. Limiting the stretches of river to the areas where development is feasible prevents any study from locating potential which is irrelevant. Applying limits on which areas of rivers to study allows the study to concentrate on locating the areas whose potential is most likely to be realized. Though it may not allow for the locating of all of the potential, it does allow for the locating of the most practical sites. Once the locations with small hydropower potential have been determined, then the development can occur. However any specific undertaking is dependent on local laws, regulations, and site specific engineering studies, which are not considered in this study.

There are a number of implications to the availability of small hydropower potential. California's state government knows of the available potential, as it has sponsored studies, including Kane's study in 2005. Information about the existing small hydropower potential needs to be made generally available to the people who are best able to make use of the information, and who are most likely to develop the potential. Government awareness does not guarantee that any of this potential will be developed or even seriously considered for development. Public awareness of the options in local, clean power generation increases the probability that the potential will be realized, which is most likely to occur when the potential is considered by those who live in the area. This makes the needs of the local people extremely important, as it is their needs that will affect development. This also makes it important that any methodology that is found and developed, as well as the data that it is relied upon to be accessible and understandable to the general population.

This study is designed to find areas where hydropower potential exists within Northern California, some of which may be ideal for development. The potential found by this study will undoubtedly differ significantly from the potential found by previous studies, due to the differences in the data that is used and to practical limits on which sites to consider. The expectation is that these differences will result in a smaller amount of potential power generation capability being found by this study, but that the potential which is found will be more useful, relative to the results of previous studies.

There are a number of topics that are not covered by this study that would merit further study. The tidal power potential, for example, was not considered in this study, because the tidal technologies are new and not yet in widespread use. Other studies could be done to determine more definitively the potential small hydropower locations that are best for development, and for the use of the people who could best make use of the small hydropower generation capabilities. Site-specific studies, for example, would be most useful in determining the exact placement of potential penstocks for either maximum generation or the needs of the area under consideration. This is likely to be determined on a case by case basis, though it will require additional study. The specific needs of any area are beyond the generalizations of a broad study, and so can only be determined at the area around each site. Further study could also eliminate some of the uncertainty that is present in this study, and could allow for the location of additional areas with small hydropower potential that were not included in this study.

Literature Review

Pollution, resource depletion, and climate concerns have led to a push for renewable energy generation. The primary sources are sunlight (solar), wind, and water. Power from water is further divided into traditional hydropower, whether through the use of dams or any of the small hydropower technologies available, and the tidal or wave power technologies. The advantage of hydropower over solar and wind power is that the flow of water in a river and the changing of the tides are nearly constant, which makes the power supply constant, in contrast to the intermittent nature of wind and solar power. Since tidal and wave power technology are still in the experimental stages and not yet in widespread use, they will not be considered in this study. A number of factors need to be taken into account when considering any of these technologies. Climate, for instance, needs to be taken into consideration when evaluating the potential for small hydropower in any river, as it affects the pattern of water availability. While the flow of a river is not affected by every change in the weather the way that sunlight and wind are, the general climate does influence the flow, and therefore merits consideration in a study of small hydropower potential.

To maximize the realization of hydropower's potential, generating facilities should be placed appropriately. A number of studies have provided insights into the different methods that have been used to find the locations that would optimize power generation. These studies vary by geography and method, but they all accomplish the same goal, that is to find the unused potential that is available for development. Each study strives to achieve more accuracy than previous studies, while still maintaining some of the elements of previous studies, though the site specific details needed for development are not generally a part of this process.

Hydropower

Hydropower has a long history, and has gone through a number of changes since its inception. Hydropower is usually considered to be synonymous with dams. Although dams make up most large hydropower installations, they have negative impacts on the environment, and have become unpopular as a result. Small hydropower facilities are now preferable to the traditional large hydropower dams, as they are considered to have no adverse environmental impacts (Papadakis, 2010).

The use of water to generate electrical power in the United States has been common practice since the late nineteenth century. In 1882, the Fox River hydroelectric plant came online, the first hydropower installation in the country (Atkins, 2003). The same year, Niagara Falls was first used to generate electrical power, which, with one turbine, powered sixteen street lamps (PBS, 2006). By 1920, forty percent of the electrical power in the United States was generated by hydropower (Atkins). However, the growing environmental concern about dams has led to a decrease in the number of new hydropower installations (Hirji and Davis, 2009), and led to the trend of small hydropower installations, which power small communities (Atkins).

Rivers are an important part of any ecosystem. Both humans and the natural world are dependent on water, which makes rivers important for survival. Rafik Hirji and Richard Davis (2009) compiled a report for the World Bank on the importance of rivers and the factors that should be considered when evaluating potential sites for dams. Water is an important part of survival on this planet, and as such any changes that are made to the waterways, such as dams, should be carefully considered. Rivers provide ecosystem services which are important for survival, even if people do not understand these services completely. The most apparent of the ecosystem services provided by rivers is the food and water that rivers provide for humans, animals, and the plants that grow along the river banks, known as the riparian corridor. But supplying water is not the only ecological service provided by rivers. They also help to regulate temperature and, with the help of plants, filter pollutants out of both air and water. Because of the many services that rivers supply to both humankind and the natural environment, any changes to the river need to be considered very carefully. Dams are very disruptive to the environment, both because of the creation of a new water body, the reservoir behind the dam, and because of the interruption of the flow of the river downstream. Creating a new body of water, where there was not one previously, floods the area behind the dam, affecting the local ecosystem. With the dam blocking the flow of water, the quantity and quality of the water that flows downstream is negatively impacted, which also disrupts the ecosystem. The plants, animals, and humans who are dependent on the downstream flow would be directly impacted by the building of a dam. Their needs should be considered as well as the needs of the ecosystem and the people who would be affected in the reservoir area above the potential dam site. These negative impacts have greatly reduced the number of dams that are being funded by the World Bank. Those that are to be funded must first ensure that the benefits outweigh the drawbacks of any potential project (Hirji and Davis). Despite the benefits associated with hydropower, the negatives often outweigh the positives in new projects.

Other ways to generate power from water do not involve damming the river, or otherwise interrupting the flow of the river. Niagara Falls is used to generate large quantities of power, supplying large portions of both Ontario Province, in Canada, and New York State, in The United States, through power plants in both countries. In order to produce this power, water is diverted from the 212,000 cubic feet per second (cfs, 6003.2 cubic meters per second, cms) that flow down Niagara River toward the falls. Only 100,000 cfs (2831.7 cms) actually flow over the falls during the day in tourist season, with approximately half that at night and during the winter months (Cole, 2002). The water which is diverted is run through generators, and then returned to the river farther downstream. This dam-free practice is being emulated on a smaller scale, known as small hydropower or run-of-river systems (Papadakis, 2010), and is one of the leading forms of hydroelectric development at the present.

Although Niagara Falls provides a good explanation of how small hydropower works, it is by no means small. The definition of small hydropower varies by location, with upper limits ranging from 10MW (Papadakis, 2010) to 30MW (Kane, 2005). The State of California defines small hydropower as having a generating capacity of less than or equal to 30 MW (Kane). Because these installations divert a portion of the water from the stream or river, and return the water to the stream at a point downstream, they are considered to have negligible environmental impact (Papadakis). This makes small hydropower, run-of-river systems preferable to the traditional dams.

Studies of Small Hydropower Potential

A number of studies have been conducted to determine the potential for small hydropower in various locations around the world. These studies utilize different methodologies, which are dependent on the location under question. There are many techniques that have been used, as well as a number of software programs that have been developed to aid in the determination of the hydropower potential. Many of these programs can be used in determining the cost of the anticipated project. However, they are dependent on the exact location of the potential hydropower site (Punys *et al*, 2011). The potential site needs to be determined before the cost can be considered, which means that the location of hydropower potential needs to come before any other considerations. All of the methodologies and software need to start with several pieces of information. The elevation changes are generally determined using a digital elevation model (DEM), which makes the elevation changes fairly easy to determine within the river network. This is especially true when the DEM is used in conjunction with geographical information systems (GIS), such as ESRI's ArcGIS platform (2011). The flow rate of the rivers and streams in the network are also necessary for the determination of the power potential. The flow rate can be determined using mathematical of statistical modeling techniques, or through physical measurement (Punys *et al*). Because of these two pieces of required information, the elevation change and the flow rate, there are commonalities in all of the studies.

One similar trait in the studies done in recent years, such as Hall *et al* (2005) and Cyr *et al* (2011), is the method for determining the elevation change along a river. Another similarity these studies share is that they fail to lay out their specific methodology. Although the mathematical equations are usually laid out and explained, it is rarely clear how either of these studies arrived at any specific values. Their methodologies are spelled out in general terms, which is useful for decision makers, but much less useful to anyone who is trying to replicate the study for a specific use.

Many of the recent studies on small hydropower potential have cited the study done by the Idaho National Laboratory in 2006 (Hall *et al*) as one of the studies that has formed a baseline for all the studies done since then. The Idaho National Laboratory study looked at the potential for small hydropower development in the United States, and was sponsored by the United States Department of Energy. Perhaps because of the large area that was being studied, the entirety of the United States, there was very little differentiation made to the differing locales and the differing climates of these locations. The main differentiation that was made to location was in the maximum length of the penstocks that were being used to determine the locations of potential small hydropower sites. The Idaho National Laboratory study utilized the annual averages of the flow rates for each of the collection points as a basis for the flow rates that were determined through the use of regional regression equations. The elevation difference was determined using the digital elevation model developed by the USGS, which has a one arcsecond or thirty meter resolution. Also, in this study, no more than half of the flow rate of a river was used to calculate the power potential along any given stretch of river. This ensured that not all of the water in the river would be required to fulfill the calculated potential. Another assumption was that new development should take place within one mile (1.6 km) of existing infrastructure, such as roads, buildings, and existing transmission lines. This restriction decreases the amount of work necessary to distribute the power to the grid. Close proximity to existing infrastructure also reduces the cost of development, an important consideration for any construction project. Stretches of rivers within federal or Indian lands, or in areas which are protected for environmental reasons should be eliminated, as development is not allowed in these areas. Some of the studies did eliminate these areas, while some only made note of the status of the area. The Idaho National Laboratory study was conducted using GIS software to determine the proximity of the potential sites to infrastructure, and to eliminate areas in the exclusion zone.

Similar studies have been conducted in other parts of the world. One such study was conducted in New Brunswick, Canada. The authors discuss some of the options available for determining the flow rates of rivers, especially in the areas where flow data is not readily available. Cyr *et al* (2011) also points out that the flow data used in the Idaho National Laboratory study has brought about uncertainties in the findings of the potential power generation capabilities of the various sites that were identified, due to the method in which the flow rates for the ungauged streams are calculated. However, Cyr *et al* points out that there is some error built into the process. Flow data is not available for the rivers in New Brunswick, and thus the flow rates were estimated in a reliable manner. This study used a series of mathematical equations in order to estimate the flow rates for these rivers. Such estimates can be made if information about the local climate is available, such as the precipitation levels and the temperatures year round. They also used a digital elevation model to determine the elevation changes along the path of the rivers, as well as to accurately model the rivers' flow.

Lea Kosnik (2010) approached the issue of potential development from an economic perspective with a study that looked at a number of models for economic feasibility. Kosnik found that most (seventy five percent) of the small hydropower costs are site-specific, and differ on a number of variables. These variables include construction costs and equipment costs, which vary by site. Penstock length and transmission line lengths also factor into the overall cost of a small hydropower installation. This gives weight to the limiting of the length of a penstock, as well as limiting the distance from the existing infrastructure. Kosnik found that head height, or elevation change, is one of the most important factors in determining the cost effectiveness of a new small hydropower development. It was found that a site with a high head height (and, thus a larger amount of potential power) is almost always cost effective.

Many elements should be taken into account when considering potential small hydropower sites. Many studies address the engineering and economic criteria, such as the studies discussed above. Other aspects that should be considered are the environmental and social impacts of the proposed project. Rojanamon *et al* (2009) propose considering all four facets for any potential site. They used GIS to evaluate the engineering potential, or the feasibility of the locations under consideration, for sites along the Nan River Basin in Thailand. The economic cost and the environmental impacts of each potential were ranked according to a set list of criteria. They also spoke to the local people around the proposed sites to determine their perspectives about the project, in order to determine what the social impart of any project would be. The environmental and social impacts of any project cannot be ignored. Environmental impacts need to be considered because of the potential disruption of stream flow and damage to the banks from the construction of any small hydropower installation. The social impacts of small hydropower are also important, perhaps less in the developed world than in Thailand where the study was conducted. In Thailand the construction of a small hydropower plant would improve the standard of living, through the increased availability of electricity, for the local population (Rojanamon *et al)*. In the developed world public opinion can also have a great impact on whether a project goes through. In developed nations the public needs to know that the benefits outweigh the risks, as do people in the developing nations. Rojanamon *et al* recommend looking at all of these factors because they are important to the success of any potential project.

California and Small Hydropower

For the purpose of this study, only the energy potential of small hydropower locations will be considered, as all of the other factors are site-specific, requiring that the project being considered for construction is evaluated on a case by case basis. Feasibility for power generation depends on the locations while the feasibility for development is dependent on the other four factors. This study will look at identifying the potential sites for small hydropower in the Northern portion of California, where most of the State's water resources are located (Mount, 1995). For the purposes of this study, Northern California is defined as being the twenty six counties that fall along or north of a line drawn between the mouth of the San Francisco Bay and the point where the border with Nevada changes angles (figure 3). This covers a number of differing terrains, though there is similarity in the climate across the whole region.

Northern California has a Mediterranean climate, with a wide variation in precipitation across the state. The majority of the rainfall, and the resulting water resources, occur in the Northern portion of the state. The rainfall is not constant, nor does it occur evenly throughout the year. The rainfall in California occurs mainly in the winter months (Mount, 1995). This means that there is less water available during the summer months, which in turn affects the flow rate of the rivers, causing the flow rate to be lower in the summer than in the winter and spring.

There is also a lack of available data on the small hydropower potential in the state of California. The previous studies have looked, primarily, at the potential for hydropower development in the man-made waterways, such as canals, and at the potential for wave-powered generation. This has resulted in a lack of information about the potential for small hydropower development in the natural waterways in California. The data that is cited in the studies, such as Kane's (2005) study, funded by the state is from a national study, one that was a precursor to the most recent study from Idaho National Laboratory (Hall *et al*, 2006), which was reported on briefly in the report put together by Kane (2006) for the state of California. The data from this earlier study was evaluated to determine the undeveloped potential that fell into the small hydropower category, which is those small hydropower installations of 30MW or less, as defined by the state of California.

Methodology

Establishing the equation which determines potential power generating capacity of a small hydropower installation must be the starting point. Once the equation for the potential energy is known, the necessary information can be gathered. This information includes the flow rates of the rivers, the elevation changes at points along the river, and the best locations for penstocks, based on the elevation changes along the river. A number of steps need to be undertaken in order to ascertain the energy generation potential:

- Obtain flow data for the rivers and determine the lowest monthly flow rate, which will be used for each monitoring site, then convert the acquired flow data from cubic feet per second (cfs or ft^3/s) to cubic meters per second (cms or m^3/s).
- Obtain GIS data for surface water.
- Reduce the GIS data to only those rivers and streams for which there is flow data. Eliminate stretches within protected federal lands, and ensure that points to be evaluated are within one mile of a road.
- Merge DEM into one raster file; extract the elevation data from the raster to the river points.
- Convert the river layers from line segments into point data, in order to facilitate the extraction of data from the elevation data.
- Extend flow data to points along the rivers, within a certain distance to flow monitoring sites, in order to determine the potential energy.
- Generate Near Table in ArcGIS to locate potential penstocks. Then add joins or relates to tie back to the original points data layers.
- Evaluate small hydropower potential.

In order to ascertain how much energy is potentially available, several details need to be known or determined. There is an equation that has been used in multiple studies to estimate the potential power of a stream. This equation has been used in studies in Canada (Cry *et al,* 2011) and in the US (Kosnik, 2010):

$$\boldsymbol{P = \eta\rho g H Q}$$

In this equation, P stands for the power potential, η is the efficiency of the turbine, ρ is the density of water, g is the acceleration due to gravity, H is the head height, or elevation change, and Q is the working flow rate. Both the density and the acceleration due to gravity are known constants. The density of water actually varies with temperature, but it will be treated as a constant, as this is the accepted scientific practice. The generally accepted value for the density of water is 1000 kg/m^3, which is the value at 4°C, and will be used for the purposes of this study. While density does vary slightly with temperature, that effect will be disregarded, as the water temperature is changing constantly, and the density only varies by a small amount with changes in temperature. The acceleration due to gravity is known to be 9.81m/s^2. The efficiency of the turbine being used varies depending on the technology being used, which in turn is dependent on the head height. The turbines commonly used in California and the efficiencies of these turbines are noted in a study done for the State of California (Kane, 2005).

Table 1: Turbine Technology vs. Head Range, Source: Navigant Consulting, Inc.

Head Range	Rating (kW)	Head (ft)	Head (m)	Turbine Efficiency	Available Technologies	Best Fit Technologies
Very Low	100	7	2.136	68.3	Propeller, Cross-flow, Kaplan	Propeller, Kaplan
	1500	13	3.962	85.2		
	1000	19	5.791	88.3		
Low	100	20	6.096	86.5	Propeller, Cross-flow, Kaplan, Francis	Propeller, Kaplan
	1070	32	9.754	91.1		
	1000	44	13.411	91.7		
Medium	100	45	13.716	70.8	Cross-flow, Kaplan, Francis, Turgo	Francis
	1070	72	21.946	84.3		
	1000	100	30.48	87.6		
High	100	100+	30.48+	84.9	Cross-flow, Francis, Turgo, Pelton	Francis/Pelton
	300	100+	30.48+	68.4		
	1000	100+	30.48+	87.7		

Conversions were necessary in order to make use of this table, as the elevation data that is most easily available is in meters. Conversion is also necessary for the available flow rates, as they are available from the USGS in ft^3/s, which will need to be converted to m^3/s. Flow rate and elevation are the last two pieces of information that are necessary in order to compute the potential power of a stream or river. These are somewhat more complicated and need to be determined for each site.

The USGS has collected water data from around the nation. This data comes from sites that are maintained by locals, groups, or the USGS. All of the data that has been collected can be accessed and downloaded from the USGS website (2012). It consists of both current data and historical data, which can all be used for the purposes of this study, though the age of specific data should be taken into consideration, as historic data may not be accurate. In the area defined here as Northern California, there are nine hundred seventeen monitoring sites with monthly flow data, both current and historical. Of those, only about eight hundred have data that is useful for the purpose of this study. The data that will be used consists of monthly averages, which allows for the seasonal variations in precipitation, which is necessary in California where most of the rainfall occurs in the winter months. This means that while there may be a very high flow rate in the winter and spring months, there may be very little to no flow in the summer and early autumn. Annual averages have been used in the past, most notably in the Idaho National Laboratory study of 2006 (Hall *et al)*. This may work in parts of the country where precipitation is fairly consistent year round. Annual averages obscure the fact that there can be a small amount of water flow during the summer months. August and September usually have the lowest flow rates, according to the monthly averages obtained from the river flow data. The Noyo River near Fort Bragg, for example, has an annual average flow rate of 208.8 cfs, (5.91 cms), and a lowest monthly average of 6.2 cfs, (0.45 cms), in September. This is a very large difference, and indicates that the amount of potential power generation, based on the flow rate, during the summer is a very different than during the winter and spring months. This should be taken into account when estimating the available potential. The data that is not being used for the purpose of this study are those data sets that do not cover at least a full year, and those sets which are consistently missing months, regardless of the number of years spanned. These sets were left out of the analysis as they do not give a picture of the behavior of the river over the span of seasons, which is necessary for understanding the patterns of the river or stream. Otherwise there would be a larger amount of uncertainty in the potential power estimates. It should also be noted that not all of the data is current, and as such, other considerations should be made, as the flow rate may have changed. While this data will still be used, the resulting estimates should be investigated further before they are made use of in a practical manner, such as for development. Any estimates that are a result of outdated data will be noted as such.

Data Sources

There are multiple options for downloading surface water data that is made for use with GIS software, specifically ESRI's ArcGIS 10 (2011), which will be used for this study. Good data layers are available from both the USGS, as a portion of the National Hydrography Dataset (NHD), and from the California Atlas, which is supported by the state government. The California Atlas data is made up of line segments, called polylines, which give the path of rivers and streams, as well as the outlines of other bodies of water, such as lakes and bays, throughout the state.   This data includes the names of the water bodies. The USGS has several different layers relating to the hydrology of the nation, the NHD, which can be downloaded for the state of California. One set is made up of line segments, like the California Atlas set, and contains more water bodies than the California Atlas, including a larger number of the rivers for which flow data is available. The other set of surface water data is in a layer made up of polygons, which covers many of the water bodies in California, including some that are different from the other two layers. For the purpose of this study only the NHD layer will be used as it covers more of the rivers for which there is flow data, making it more compatible with the rest of the data (figure 5).

Another layer of data available from the USGS contains all of the monitoring sites in the United States (figure 5). Each of these layers needs to be reduced to the areas for which there is flow data. The flow data from the USGS can be added to the layer containing the monitoring sites, which still needs to be reduced to only those points for which there is adequate data for the flow rate of the river that is being monitored. This is done by editing data table for this layer to include the flow rates and the time frame over which they were collected. Rivers with no flow data or no flow during the summer months should also be eliminated, as these rivers do not have year round power generation capabilities. All of these layers have a scale of 1:24,000, and should all be clipped to the area of California in question, rather than looking at the whole state. The layers containing water features should also be reduced as not all of the water bodies are appropriate for generating power. Lakes and bays should certainly be eliminated from the data. Rivers for which flow data is not available should not be considered, as this study has no way to estimate the potential power of those rivers and streams. Stretches of streams or rivers that fall within federally managed or protected land should also be eliminated, as those areas are not open for development. Rivers which fall in this category have been labeled as scenic, wild, or recreational rivers, and have been protected to ensure that they remain as natural as possible, as well as maintaining access to these rivers to the public.

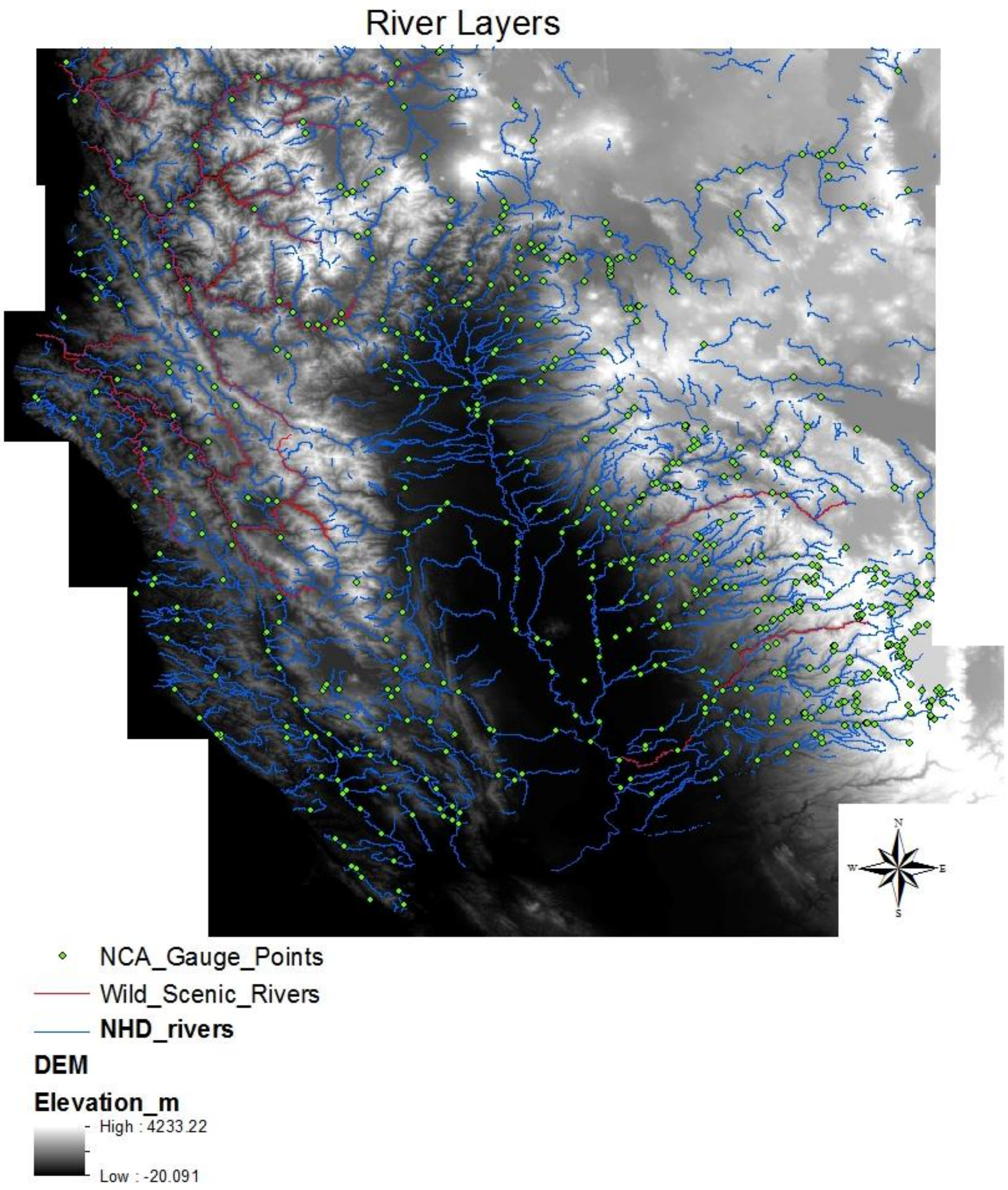


Figure 5: NHD river layer with only the rivers for which there is flow data available, with the Wild and Scenic Rivers and the USGS Gauge Sites.

In order to eliminate the areas where the potential power is unlikely to be realized, such as the areas that are protected, or areas that are difficult to access, these areas need to be identified. A GIS layer containing the rivers that are protected is available from the National

Wild and Scenic Rivers System (figure 5). Compiled with help from the USGS, this layer has a 1:2,000,000 scale, which is very different from the 1:24,000 scale of the rest of the river layers. This means that the layers will not match up exactly, with the National Wild and Scenic River System layer falling along slightly different paths from the NHD layer. However, this can still be used to eliminate points that fall within the protected stretches of these rivers by using the proximity of the protected rivers to the NHD rivers layer in order to eliminate the areas that cannot be developed due to their protected status. A list of these rivers is also available from the state government, as a part of the Public Resources Code, section 5093.50-5093.70 (California State). Additionally, it is necessary to eliminate any areas which fall too far from roads, which provide access points to rivers. A layer of roads, the Tiger road map, which was compiled by the US Census Bureau as a part of the 2000 census, last updated in 2007, is available from the California Atlas. Points that are more than one mile from any of these roads will be eliminated, as any development would be difficult in areas that are not currently accessible. Eliminating points that are protected and points that are not in proximity to a road limits this study to concentrating only on areas which are more likely to be developable.

Data Processing

Elevation data is readily available from the USGS (Gresh, 2007 & Gresh *et al*, 2002), with the National Elevation Data available for download as a set of raster files, which can be pieced together in order to create a Digital Elevation Model. Two resolutions, 1 arcsecond (30 meters) and 1/3 arcsecond (10 meters), are available for Northern California. Both have a scale of 1:24,000, which is the same scale as the river layers from the NHD. The layer with the 1/3 arcsecond resolution will be used for this study (figure 2). The elevation data is downloaded as a series of raster files, which need to be combined into a single file to facilitate working with the DEM. This can be done by creating a mosaic dataset, for which the statistics must also be calculated. Calculating the statistics is a step in the creation of a mosaic dataset, which incorporates the elevation values into the mosaic allowing for both the visualization of the elevation layer and extraction of the elevation data to other datasets. In order to determine the potential power it is essential to know the elevation change, which requires that this data be extracted from the DEM (Digital Elevation Model). The best way to extract data from raster files is to extract by points. This requires that a layer of points exists into which this data will be extracted. Extracting elevation data to the monitoring sites is fairly straight-forward, as it is already in point format. The river layers, on the other hand, are polylines which need to be converted into point format to allow for the extraction of elevation data from the DEM. The best way to do this is to create points in as many places as possible, using the "vertices to points" tool. This tool creates points at each line's endpoints and midpoints in a separate layer. While this does not allow for the extraction of raster values at all points along a river, it does allow for elevation data at points along rivers, all of which are within 10,000 feet (3 km) of the next point on the river. 10,000 feet is the maximum penstock length, as determined by the Idaho National Laboratory study (Hall *et al*, 2006). Once points are determined, and in a layer, elevation data can be added to each of the points in the layer.

This elevation data can be extracted to the layer containing points using the extract to points tool, which adds a field called raster value to the attribute table containing the elevation at each point. There are two different ways to calculate this value. One way is by taking the center value of the cell containing the point. The other way is through interpolation, which uses the values of the neighboring cells, and interpolates the value for each point based on its location in the cell. For this study, interpolation will be used as there may be multiple points in any given cell, and this allows for the most accurate elevation values for those points.

It is also important to establish the proximity of points to each other in order to locate the potential locations of penstocks. Two different approaches can determine which points are in closest proximity, or within a certain distance, to each other. One method is to use buffers, which create polygons of a user specified radius, around each of the points in a layer. Any point that falls within that polygon is within the set distance of the point around which the circle was drawn. Points within the buffer can then be used to determine the penstocks and the potential energy generation. A set of buffers with a radius of 10,000 feet, along with the points on the rivers is shown in Figure 6.

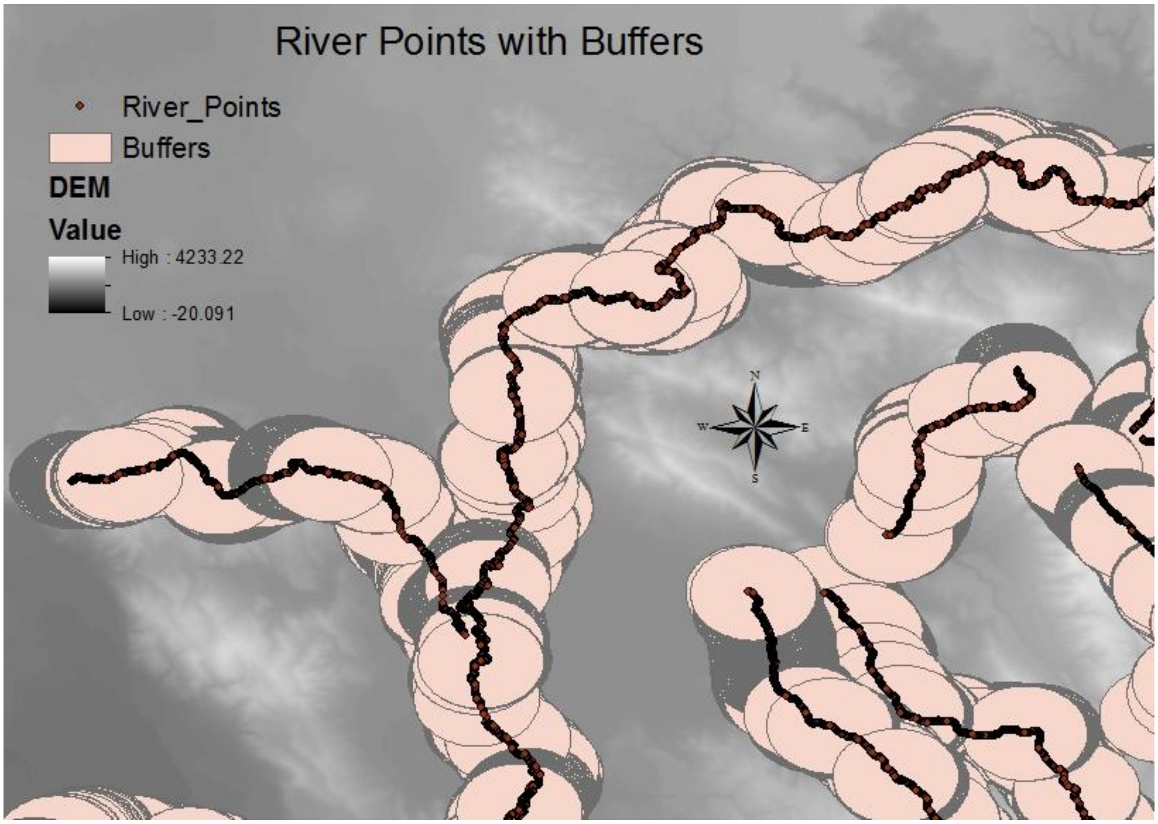


Figure 6: River Points with 10,000 foot buffers

Buffers allow for easy visualization of the points that fall within the maximum penstock length, as can be seen here, though they do not allow for the data to be easily accessible. It would be more convenient to have the points within the 10,000 foot radius presented in a table format. This can be done using the latter method of determining proximity, through the creation and use of a Near Table. A Near Table lists all of the points from the input set and the points in a second set that fall within the predetermined distance of the points in the first set of points, plus the distance between the two points, in decimal degrees. To generate a Near Table, the user can define the layers, the maximum number of points to be found in the target layers, and the maximum search radius for each point. This is similar to a buffer, though more specific, as it gives the points that would fall in the buffer, without the need to identify the points. In this case the Near Table lists the points on the rivers and the points within the 10,000 foot radius of those points. A partial near table is shown in Table 2:

Table 2: Partial Near Table

OBJECTID	IN_FID	NEAR_FID	NEAR_DIST	NEAR_X	NEAR_Y
1	11	954	0.019522	-122.530051	37.895208
2	11	953	0.018724	-122.531188	37.894884
3	11	952	0.018095	-122.531944	37.894884
4	11	951	0.017341	-122.532685	37.895137
5	11	950	0.015901	-122.533975	37.895808
6	11	809	0.015901	-122.533975	37.895808
7	11	808	0.014683	-122.535077	37.896363
8	11	807	0.013444	-122.536006	37.897193
9	11	806	0.012864	-122.536214	37.897907
10	11	805	0.01235	-122.536532	37.898358
11	11	804	0.011895	-122.536879	37.89866
12	11	623	0.026932	-122.523662	37.891453
13	11	622	0.02639	-122.524266	37.891497
14	11	621	0.025713	-122.524934	37.891702
15	11	620	0.024906	-122.525763	37.891896
16	11	619	0.024308	-122.526188	37.892343
17	11	618	0.023399	-122.526799	37.893088
18	11	617	0.022059	-122.527675	37.894248
19	11	616	0.02134	-122.528167	37.894845
20	11	615	0.020649	-122.528808	37.895112
21	11	614	0.02006	-122.52941	37.895242
22	11	613	0.019522	-122.530051	37.895208
27	11	139	0.002176	-122.547299	37.907222
28	11	138	0.002542	-122.547569	37.907535
29	11	32	0.011895	-122.536879	37.89866
30	11	31	0.011484	-122.537191	37.898935

The object id in the first column is the row number, which is automatically assigned by ArcGIS on creation of the table. The second and third columns, in_fid and near_fid give the object ID number of the point on the input table and the table of points to which the input points are being compared, respectively. The fourth column gives the distance, in degrees, between the points, while the fifth and sixth columns give the location of the near point, which was added to make displaying the points easier. Once a near table has been generated, the points need to be related back to the points in the original data layers. This can be done using either a join function, which adds the tables together, or relate function, which adds a connection between the layers. A join is simpler in this case as it allows for the data to be viewed in one table, rather than in several. It is now vital to determine if these pairs of points fall along the same river, which can be done simply by ensuring that the name of the river is the same for both points, as any penstock should run between two points on the same river or stream.

The next step is to determine the rate of flow of each portion of the river or stream. This requires a decision on how far along a stream the flow data recorded by the USGS is valid. There is no literature that indicates how far up or down stream flow data is valid, since it is extremely variable. For the purpose of this study, any river points that fall within half of the maximum penstock length, or within five thousand feet (1.5 km), of the flow monitoring site, will be used to extend the flow rate up and down stream. If only these points are used, the flow data may be extended to each of these points, which can then be used as an endpoint of a penstock. This seems to be the easiest way to extend the flow data to other points on the river. This does not guarantee accuracy; though it does result in greater accuracy than if the flow rate were extended farther up or down stream.

The potential energy for each of the pairs of points can now be calculated using equation 1. All sites with no potential energy should be eliminated. If possible, any points which would lead to a penstock crossing a hill, such as would be found inside of curves in the river, should also be eliminated. Should a potential penstock’s path run across a hill, it would require that the hill be circumvented in some way, as the penstock would otherwise have an uphill slope. This does not work, as the water would then have to be pumped uphill, which is impractical for a system that is meant to produce power. There is no straightforward way to identify the hills around which a river flows, though visualization can allow for these hills to be seen, if not avoided. The drawback to a Near Table is that a Near Table is not visualized. The next step is to make the data visual, which allows for easier access by the end-users of the hydropower information. This can be done by adding x and y values, which can be done for one of the two points when the near table is initially created, though there are several points at which x,y values can be obtained for the points in question. The easiest way is to add x and y values to the original point data. These values will also be added to the Near Table, due to the joins. This can then be used to visualize the points on the Near Table by using the XY to Line tool, which draws a line between two points, and in this case can be used to draw lines between the point pairs generated by the Near Table. This will enable the potential penstocks to be visualized on a map, making the results discernible to virtually all interested parties.

Analysis

While the methodology that has been laid out seems fairly straightforward, this process requires that the data and the results of each step be edited and interpreted to be fully understood. The processing of data includes eliminating unnecessary data and that which does not have corresponding data in the other datasets. A number of decisions must also be made in order to limit the resulting data to only the feasible locations for small hydropower development. Once all of the necessary eliminations and reductions have been made, the results can be collected and analyzed. This process resulted in a total of four hundred forty five sites which each have a potential of more than two hundred watts, for a total for one hundred seventy three megawatts that meet the feasibility criteria.

Between the large geographic area being considered, the large amount of available data for the area, and the limitations of the computer used, the data processing step required some modification to facilitate more efficient computations. The National Hydrography Dataset (NHD) used for the rivers includes a large number of data that needs to be processed. In the NHD there are more than fifty two thousand river segments, even after the dataset has been reduced to only the rivers for which flow data is available. When these line segments have been converted to points this number becomes more than eight hundred ninety five thousand points. Also, seven hundred twenty six of the river monitoring sites where flow data is available have a minimum flow rate of greater than zero during the lowest months. The Near Table looking at pairs of points along the rivers contained more than eighty million pairs of points that could be the locations of penstocks. This is a prohibitive number of pairs of points, since it would take days of uninterrupted processing for ArcGIS to compute, so it is essential to reduce the amount of data being processed. Decreasing the amount of data that needs to be processed reduces the amount of time that it takes, by eliminating unnecessary calculations. It is easier to reduce the amount of data before the data is fully processed, though reductions are dependent on a number of decisions which should be made carefully so as not to compromise the results.

A number of approaches can be used to further limit the amount of data that is being processed at any one time, thereby cutting down on the amount of time needed to process the data. Reducing the number of points being considered early in the process, rather than later is one way to slash processing time. Eliminating the sites which have a lowest average monthly flow rate of zero, thus excluding gauge sites where flow is only seasonal, is a valuable first step. This is necessary as those rivers have no flow during the summer months and therefore have no power generation potential. Shrinking the number of matches in the Near Table from the nearest thousand points to the nearest five hundred points also helped. Since most of the points did not have a thousand points within the ten thousand foot penstock length, the number of matches decreased by only a small percentage. The resulting Near Table, after it was joined with the Near Table that related flow rates to points on the river, contained approximately ten million pairs of points for potential penstocks within the ten thousand foot penstock length limit. This is still a prohibitive number of potential penstocks, so imposing additional limitations is still necessary.

The next approach to data reduction involved eliminating data from gauge sites at power plants or power generating facilities. There are several reasons for this decision. One reason to eliminate these points from consideration is that the flow rates are being measured by the entities responsible for the maintenance and the monitoring of the power facility. These groups are not necessarily interested in the flow rate of the river as a whole, but are more interested in the rate at which water flows into and out of their facility, which is the water that is responsible for generating the power at that facility. Another reason to eliminate the flow rates at power plants is that there is already power being generated at those points, which means that there is no unused potential at that point. This study is being conducted to locate the unutilized potential, not to look at the areas that have already been developed for power generation.

Another factor involved the decision that the amount of potential power generation should have a minimum value, which further reduces the number of potential sites. This is also a practical, as small amounts of potential are very unlikely to be developed. According to Papadakis (2010) the smallest form of small hydropower is picohydro, which has an average installed power generation with a minimum of two hundred Watts. It therefore seemed reasonable that this should be used as the minimum potential power generation for the sites in this study. Two hundred Watts is a very small amount of power compared to what most households use. However, it may be useful for anyone who does not need a large amount of power generation. A small amount of power can be used to increase the power available, or to supply power to small systems, in the event of power failures, which can be problematic in outlying areas, where it may take time to restore power.

While these reductions may not be ideal, and there may be large amounts of potential power available in the areas that were excluded from this study, the exclusions were made to simplify the data processing. It is also necessary to ensure that the data is not reduced to a point at which the results are overly compromised. Too much reduction can lead to the loss of potential penstock sites which could generate large amounts of power. This creates the need for a delicate balance between the amount of data being used and the time that the processing takes.

Given the large amount of data that still remains to be processed, there is a time factor in performing this analysis. This makes it preferable to find the most efficient way to process this data. For the most part, the data for this study needs to be processed in ArcGIS, due to the fact that most of the study requires that the data is evaluated based on its geographical location. This is best processed in ArcGIS using the tools available, as discussed in the methodology portion of this study. However some of the processing can be done using other software packages, such as Microsoft Excel. Excel can perform calculations on large amounts of data very quickly, while ArcGIS takes longer to do the same calculations. This is due to the method in which each package stores and processes its data, and the amount of overhead inherent in its database. Its lack of transactional processing and simple storage make Excel an excellent candidate for faster calculations. In this study, due to the large amount of data, it is faster to perform the calculations for head, efficiency (performed using an if-then-else statement), and the potential power generation for each potential site from the Near Table.

Excel can also be used to reduce the number of penstocks that are being considered, to include only one penstock per point, as only one can be constructed at any given point. This can be done using either a filter or by eliminating duplicates. A filter can be used to select unique values in a column, such as the points to which flow values have been applied. Eliminating duplicates is similar, except that it removes all of the rows that have a duplicate in the selected column. Both of these tools will keep the first unique value that it comes across and remove the others from the table, either by hiding the row or by deleting it. This means the data can be arranged in such a way that the values that are kept have the highest potential power, for example. These penstocks represent the largest generation potential at each point, which gives an idea of the largest amount of power that can be harnessed in an area. The largest potential is usually found at the longest penstocks, where there is the most head, since the higher the head height of the penstock, the larger the potential power generation capacity. The largest potential was chosen, as it represents the maximum generation capability.

The problem with this method is that while it gives the greatest potential power generation, it also gives the longest penstock lengths. The penstocks, especially the longer penstocks, generally do not follow the path of the river, which can cause problems with the placement and length of the penstocks. Kosnik (2010) found that the longer the penstock, the higher the cost for installation. This becomes an issue as higher costs result in a less appealing project to either individuals or companies that might be interested in utilizing the potential power. This is especially true when the cost of other energy generation options may cost less up front.

The potential penstocks were also determined without regard for the path of the river or for what may lie around the river. Rivers tend to wind around hills, along the lower ground between hills. Where rivers run along fairly even ground, this may not present much of a problem. The rivers in the mountains, however, can be surrounded by hills with steep walls, and often there is a larger amount of potential due to the greater elevation changes that are common. These factors were not taken into account and the potential penstocks were not placed in such a way that they would avoid the hills. While a hill would increase the head height of the penstock, and thus the power potential, the energy that it would take to pump the water up the hill could counteract any benefits that would be gained. In this case it would require energy to make energy, which is common, but not ideal. The other option for a penstock across a hill would be to tunnel the penstock under the hill. However, this would be environmentally damaging, which is not ideal for a system which is supposed to be minimally environmentally invasive. It is also evident that the penstocks may cross the river without ending at the river, which is problematic. Any penstocks should not, ideally, cross the river. These factors should be taken into account when looking at the potential penstocks, which can be visualized in the GIS environment.

After returning the data to ArcGIS (ESRI, 2011) as a table, it is helpful to visualize the potential penstocks. This is easily done using the XY to Line tool in the features toolbox. Endpoints are also fairly straightforward to display, should they be desired, though the endpoints are not necessarily needed for this study. This visualization of the data illustrates the limits of this method for locating potential penstocks, as discussed above (Figure 7).

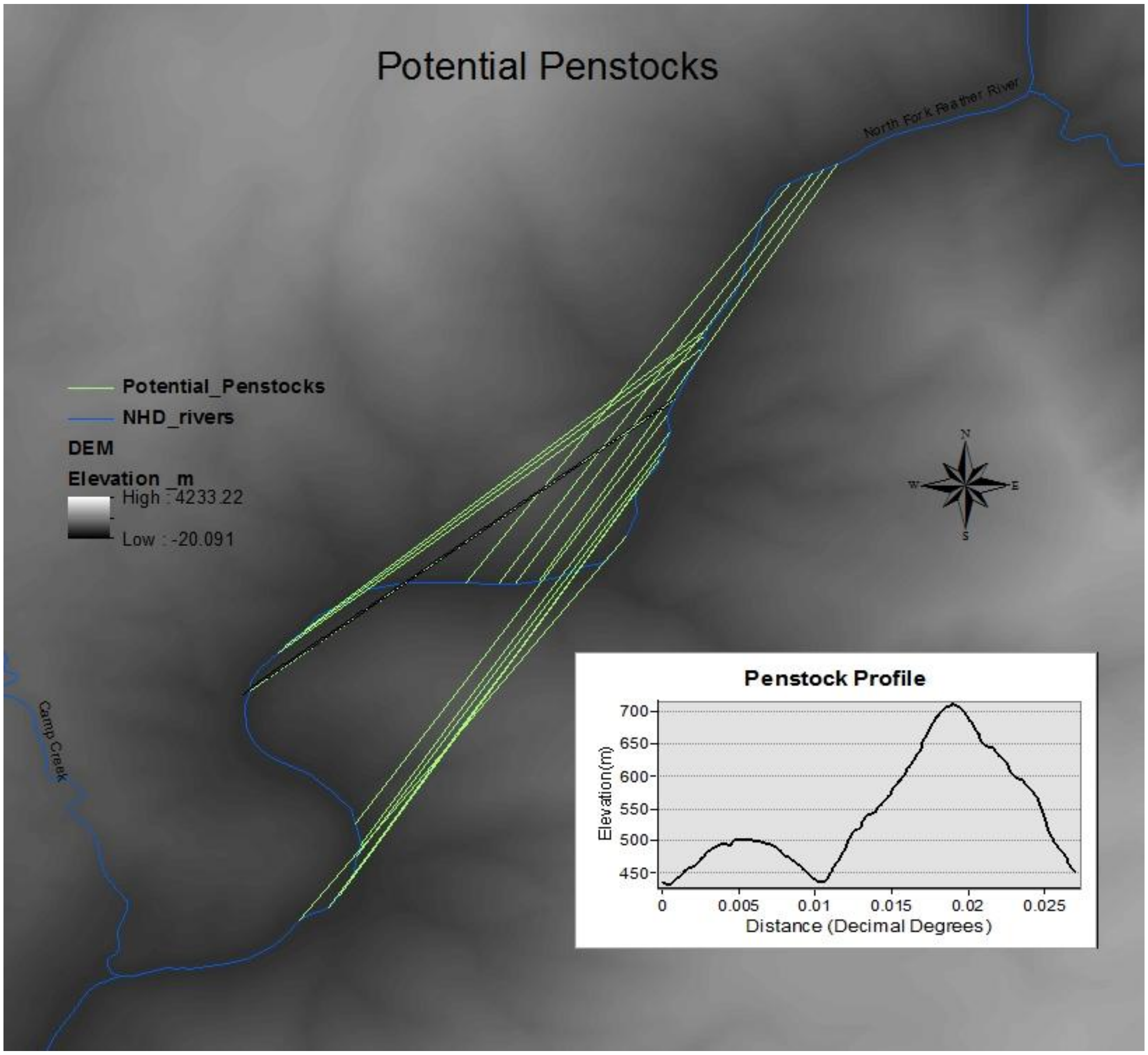


Figure 7: One set of potential penstocks that cross the river and hills, demonstrated by the graph.

Figure 7 shows penstocks crossing the river in multiple points, as well as crossing hills. The inserted graph shows the profile of the hills which a selected penstock would need to cross. It is also apparent that the penstocks shown here cannot all be developed for the simple reason that they interfere with each other. Penstocks that interfere with each other cannot be developed as they all rely on the same river and the same flow rate.

There is no easy way for such a broad study to ensure that the penstocks do not cross either a river or a hill. This makes it necessary to determine the potential in such a way that the results are not hugely compromised by the fact that some of the penstocks do cross either the river or hills or both. The most accurate way to determine which of these penstocks would be the best for development would be to go through each potential penstock individually and choose the best based on head height, length, and the locations of the hills. This would be cumbersome, and not knowing who would be doing the development and to what purpose the power would be put makes it very difficult to determine which of the individual penstocks would be best for the situation.

Consequently, it is easier to determine the undeveloped potential power generation in general rather than be specific by site. There is an easy way to generalize the potential that is available in an area. This study generalizes the power potential by gauge site, as all of the required flow data is collected at the gauge sites. In order to consider the potential in each area, in general terms, the potential of each set of penstocks was averaged. This was done using the Dissolve tool, in ArcGIS (ESRI, 2011), which combined all of the penstocks around each of the gauge points and took the average of the potential power, to come up with one value for the area. Using the average of the potential power for each of the penstocks gives an indication of the potential power generation in the area. In reality it may not be ideal to develop the potential penstock that gives the most power, instead using one that may produce less power, but is more suited to the needs to the developer. From this generalized layer of penstocks in an area, points were generated to represent the power generation available in each area (Figure 8).

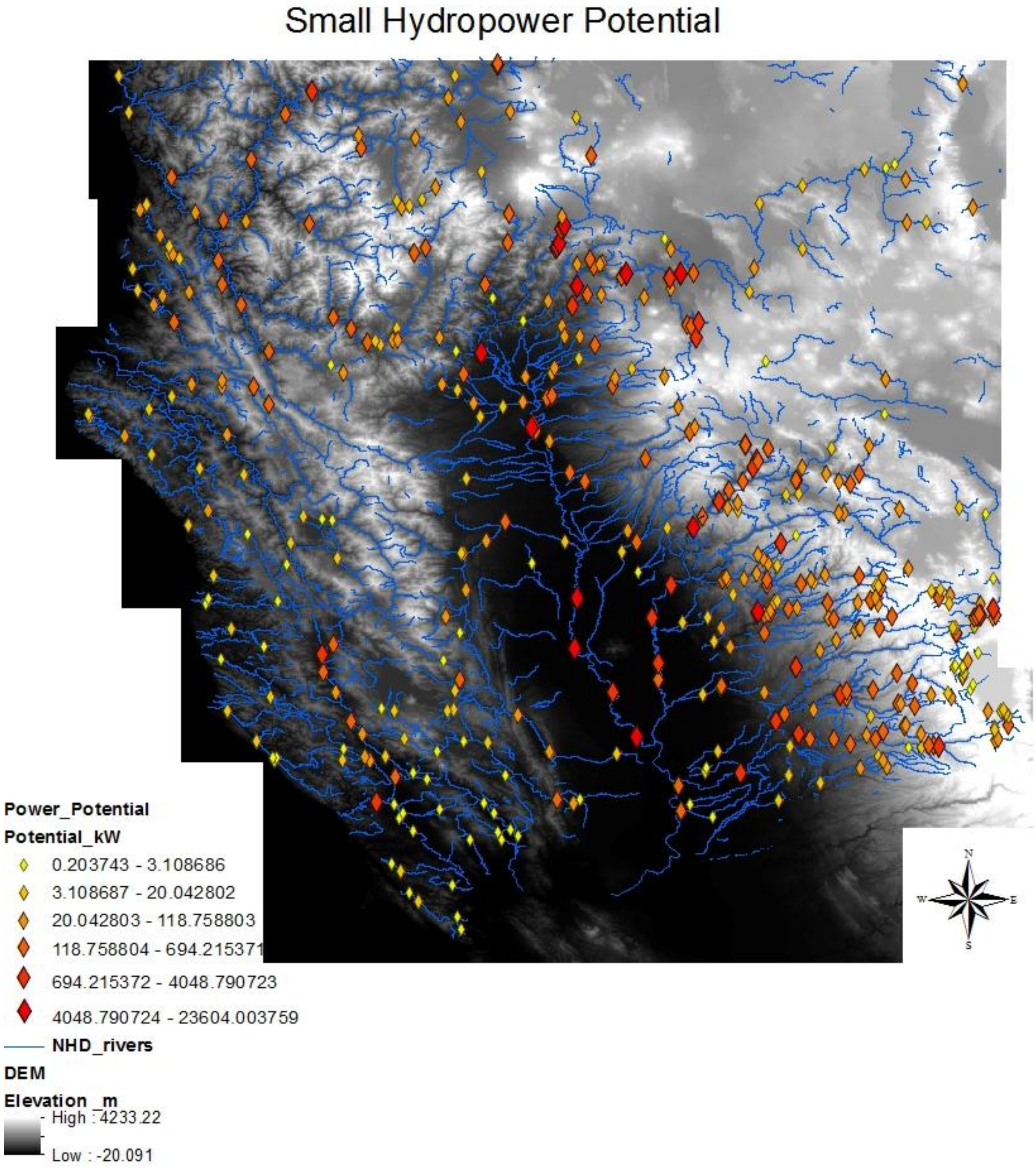


Figure 8: The potential small hydropower locations, and their relative potential.

Figure 8 shows the four hundred forty five areas around river gauge points which have potential of greater than two hundred Watts available. The points are color coded by how much power potential is available in each of the areas. Yellow represents the areas with smaller amounts of potential, while the red represents the areas with the most potential. The base for this is the digital elevation model that was used to obtain the elevation values, in meters. These sites have a total of 173.5 MW of potential available, as calculated using the equation stated in the methodology. The potential at any one of these points varies from the 203W on Redwood Creek in Napa County to the 23.6MW on the Sacramento River in Shasta County. This is a large variation in generation potential, and leads to many development possibilities.

Higher potential tends to appear in the areas where there is a greater elevation change, though both large and small amounts of potential can be seen in all terrain types. The area with the highest concentration of sites with potential is found along the Sierra Nevada Mountains to the East. Figure 9 shows a close up of a portion of Northern California, including areas of both the Sierra Nevada Mountains and the Central Valley. This shows that the amount of small hydropower potential can vary along the same river, even over short distances. This clearly emphasizes that specific development needs to be preceded by more precise studies.

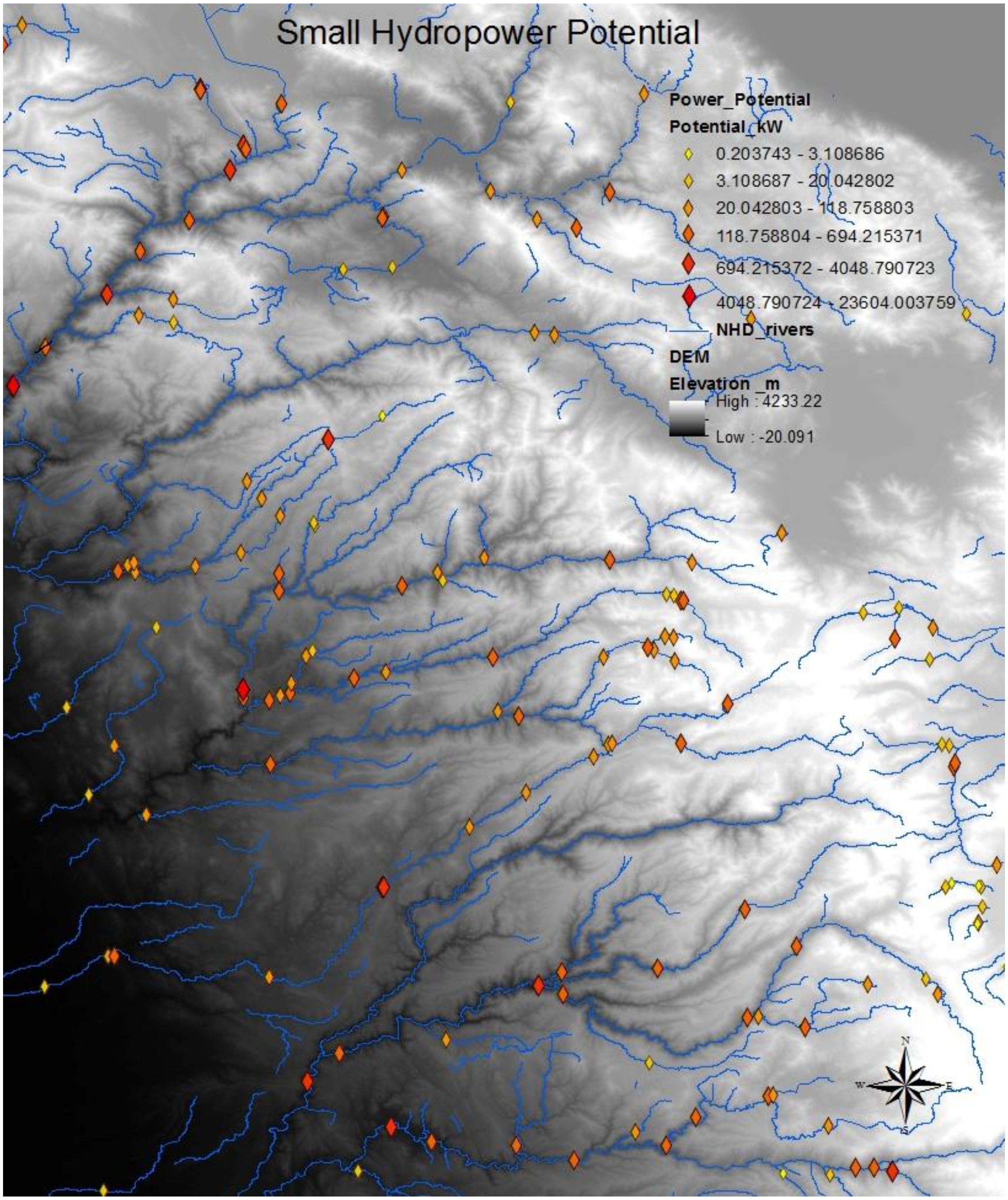


Figure 9: Close up - portion of the Sierra Nevada Mountains and the Central Valley, showing areas with small hydropower potential.

`It should be noted that the amount of potential may either increase or decrease when the penstocks are routed around hills or are cut off at the points where the penstocks would cross rivers. It may be that shortening the penstock would lose some head height, and thus some potential. It may also be that by routing a penstock around a hill, either along the river or in another direction, in a more beneficial direction if one exists, may either increase or decrease the head height and thus the potential. It should also be noted that only a small number of the penstocks found in this study can be developed. Penstocks cannot overlap, assuming that the full potential is being utilized, though there may be more than one penstock that can be utilized in the vicinity of each of the gauge points. This would actually increase the amount of small hydropower that can be developed.

Sources of Uncertainty

There are several sources of uncertainty that are present in the estimated potential for each of the sites. One is due to the limitations of the data, which is true of any study, including this one. There is uncertainty in the flow data, the head measurements, and the efficiency. Because of these points of uncertainty any development of the unutilized potential in Northern California needs to include a more specific study of each proposed site. On the ground studies should eliminate or at very least reduce the uncertainty in the estimated potential.

The flow data has some inconsistencies, which lead to some uncertainty in the estimated potential. The flow data collected by the USGS should not be considered to be completely accurate for most of the rivers that were included in this study. There are inconsistencies in the data, which can make flow rates inaccurate or unreliable. There are many collection sites for which data on the flow rate can be found, though this data may not have been collected in recent years. This data can be used as a guideline, or an example of what potential power is available at those locations, though it should not be considered to be accurate in current times. River paths and flow patterns can and do change over time. Climate also affects the flow patterns, and events of recent years, as well as scientific studies, have made it apparent that the climate, worldwide, is going through a period of change. This means that the flow rate may be different in present times than in the past. Even fifty years ago the flow rates may have been very different than they are currently. This makes the data that was collected years ago less reliable than data that was collected recently, and introduces some uncertainty to any of the sites and their respective power potential that was calculated using historical, rather than recent or current flow rates. The number of years for which flow data has been collected is also a factor in the accuracy of the estimated potential. Data that has been taken over a short time period, less than ten years, is less reliable as those years may have been either wet or dry periods. This means that the monthly flow rates may vary greatly from average years. Ten or more years is preferred for average flow rates, as it is more likely that the flow rates will average out closer to normal, accounting for the extremes of wet or dry periods.

Here, all of the flow rates were used to calculate the estimated potential, though it should be noted that these values may not be accurate for the reasons discussed above. The limitations of the flow rate due to the time frame over which the data was collected can be ascertained by the dates for which flow rate was recorded. These dates have been added to the dataset along with the flow rate. It should be noted that these dates do not reflect the inconsistencies that were present in the collection of data. For some sites there were years in which data was not collected, and for others there were months that were missing data. This creates some uncertainty, though any of these inconsistencies that would have caused large amounts of uncertainty were left out of the study. Most of the sites that are missing years of data were either left out of consideration due to the lack of data, or were comprised of historical data which would require a second look before use can be made of the findings. The other sites which are missing several years of data, which were included in this study, were missing years of historical data, which was made up for by the presence of multiple years of more recent data. This makes the missing data less important. The data sets that had missing months of data were left out if there were a large number of months for which data was not available. Sets with the same months consistently missing from the data were not included in this study. When only a few months were missing, over a long time period these months were not as important to the data overall and were thus included in this study.

Uncertainty was also inherent in the manner in which the flow rate was extended to the points that were generated along the rivers. In order to estimate the potential power generation of any pair of points along a river, its flow rate needs to be known for that point. The problem is that there are only a limited number of points along any river where the flow rate is monitored. This limits the number of points for which the flow rate is known, and thus limits the number of points for which the potential power generation of a river can be calculated. A generalization had to be made for how far the available flow rates would be extended up and down stream, as explained in the methodology. A distance of 5,000 feet was used. Accurate, site-specific flow measurements should be obtained prior to any development of the potential sites that have been earmarked by this study.

There is also some uncertainty in the elevation data. The Digital Elevation Model that is used for this study has a ten meter resolution. Previous studies used a digital elevation model with a resolution of thirty meters, making this study more accurate. A resolution of ten meters means that the elevation is only accurate to within ten meters of the point for which the elevation is evaluated. A ten meter resolution means that the area was broken up into cells measuring ten meters each. The elevation data is accurate at some point in these ten meter cells, though may not be accurate at all points within the cell. This can be accounted for by using interpolation when the elevation data is extracted from the raster files that make up the digital elevation model to the points that make up the rivers. Interpolation takes the location of the point in the cell that it resides in, as well as the elevation values of the neighboring cells. These variables are used to mathematically determine the most probable value for the elevation at that point. This increases the accuracy of the elevation value that is assigned to each point, decreasing the amount of uncertainty that is present in the elevation values that have been extracted to each of the river points. However there is still some uncertainty present, despite the statistical probability that the elevation data for any point is the likely value at that point.

There is also a level of uncertainty in the efficiency values that were used to calculate the potential power generation for each potential penstock. The table that was put together by Navigant Consulting (Kane, 2005) was based on a specific set of criteria which varies by site. These efficiencies were based on specific head heights and specific energy generation capabilities which will vary by location. This makes the efficiencies inaccurate because the efficiency would need to be calculated for each individual site. Without any way to calculate the efficiency or any way to know what these efficiency values were based on, there is no way to determine the efficiency for each potential penstock site. It may be that these efficiency values are not accurate for the sites that were located in this study, though they are useful for creating a baseline estimate for the river's power generation potential. The efficiency estimates were used to produce this base line and are the only available estimates as there is no literature that details how to determine the efficiency value for any specific site. The efficiency rating is dependent on the site and the equipment that is being used, which makes these values site specific.

Despite these uncertainties, the estimates found in this study can be used as a guideline for the available potential in these areas. There may be a larger amount of undeveloped potential available in Northern California, though it is not possible to estimate this potential without knowing the flow rates along other points on the river. Without knowing what the flow rate is, this potential is not estimated by this study. It is also important to know that the exact locations for penstocks are dependent on who is going to develop the potential, and the purpose of the development. This will determine the exact power generation possible.

The specific locations of penstocks should be determined by the entity that will be utilizing the power being generated. It may also be that the full potential does not need to be utilized for every group that plans to make use of it. A single household, or small community, may not need the full twenty three megawatts that could be generated on the Sacramento River in

Shasta County. This amount of power may be more useful to larger communities or developments, or it may be more useful to power companies who would be able to develop the power for distribution to the grid. The smaller amounts of power are more likely to be useful to single homes or small communities, rather than to larger ones. This study is representative of undeveloped small hydropower potential in the Northern half of the state of California. The elimination of the areas around power plants allows for this to be an accurate representation of what is undeveloped, and is exclusive of the developed power. The one hundred seventy three megawatts that have been found in this study offer a wide range of power that can be developed in Northern California, and a number of possibilities for this development.

Discussion

Potential for the development of small hydropower exists in many places in Northern California. While some of this potential can be developed, some may not be ideal for development due to a number of different factors, not all of which were considered in this study. It is also possible that the full potential may not be needed for the desired purposes in all of the locations with potential. Additionally, other sites in the area may have potential, but were not included in this study. Other areas, beyond the scope of this study, could certainly be explored for additional opportunities.

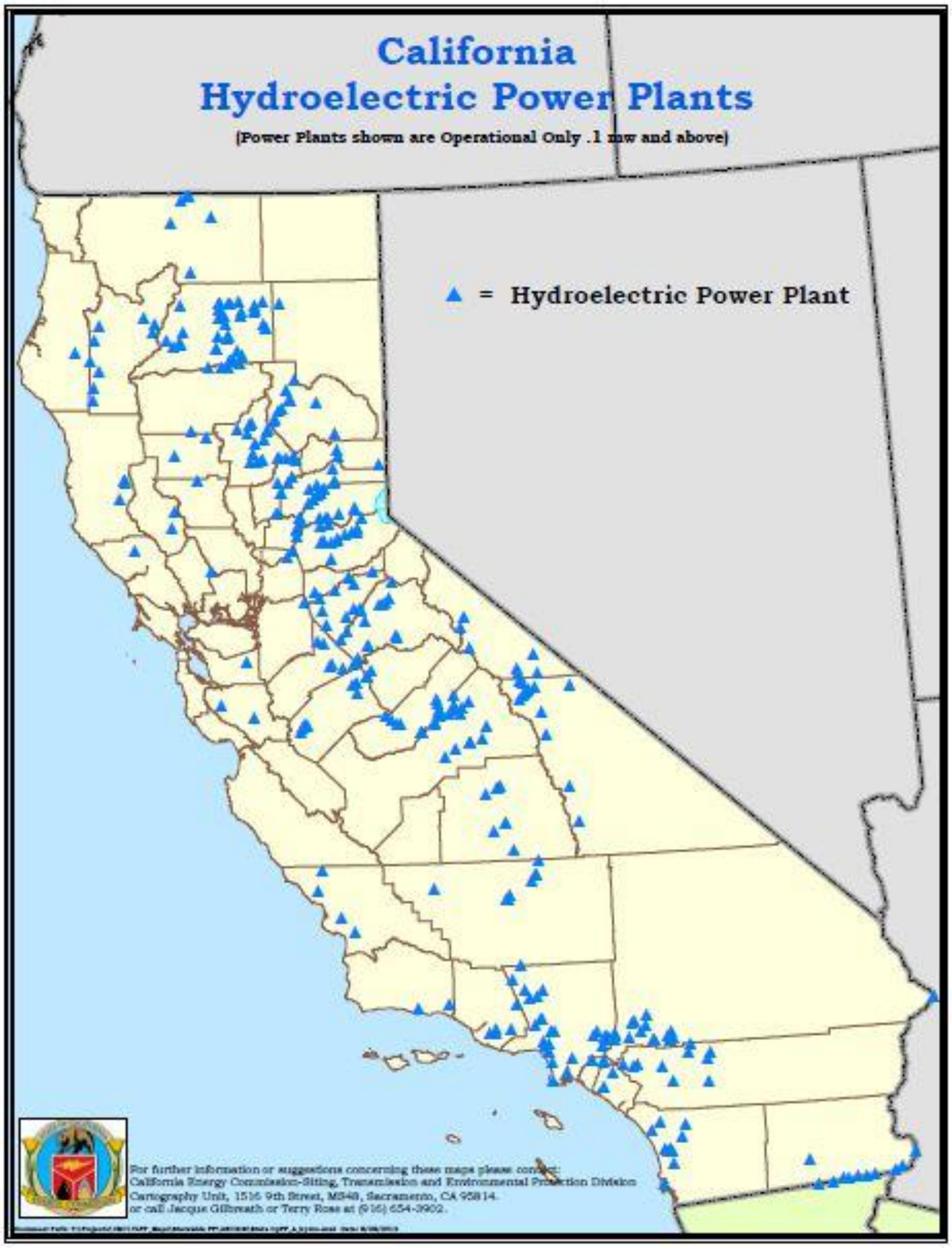
Small hydropower is one of the few options currently feasible for the generation of hydroelectric power, especially since dams are so environmentally damaging and invasive. Tidal options are also being explored as options for generating power from renewable resources, such as water, but are still mostly in the exploratory stage. Since California has some of the best environmental regulations in the world, discovering ways of generating power in an environmentally friendly manner is essential. Small hydropower is considered to be environmentally friendly, and is thus more likely to be developed than the dams that are more commonly associated with hydropower. Even though the amount of power that can be generated through small hydropower installations may be small, the potential for such power generation should not be ignored, as the combined power generated by a number of such facilities could be substantial. The possibility of generating even a small fraction of the power supply through the use of ‘clean’ technologies, such as small hydropower, is important and should not be overlooked when considering new sources for power generation.

Small hydropower projects satisfy any number of needs. Single homes or even small communities, depending on the needs and circumstances at each location, can benefit from small hydropower. Homes do not generally need a large amount of power, so where this source of power is available, it may be sufficient for them. Households generally use between seventy five and three hundred fifty kilowatt hours of power in a month (Maxwell, 2005). This indicates that small hydropower may be able to provide the power necessary in homes which have access to rivers with small hydropower potential. These systems may cost between one thousand and twenty thousand United States Dollars (Maxwell), which will affect the likeliness of any development of the small hydropower potential in any area. Hydropower can be implemented in order to increase the local power availability, or to supply the power needs of new growth. In year round streams the power provided by small hydropower is constant, rather than intermittent, making it a reliable source of power. Small hydropower generating facilities may be built for other reasons as well, such as reducing the reliance on power companies, or transitioning to a clean energy source, rather than reliance on fossil fuels. Hydropower can be developed by any number of groups, including individuals, communities, or power companies.

Another advantage to small hydropower is that the power can be both generated and consumed locally. This is beneficial for several reasons. Lessening the reliance on power from other areas will also reduce the need for power transmission lines, except for local lines to connect the turbine to the buildings where the power is needed. Without the need to transmit the power over long distances there is no need for transmission lines. This should be a short distance, rather than needing to transmit the power over a long distance. Transmission lines are expensive, both to install and maintain, and are one of the factors that determine the overall cost of the installation, according to Kosnik’s (2010) study. This may make it more economically feasible to utilize small hydropower, rather than relying on imported power, with its requisite transmissions lines. The ecological impacts of transmission lines may be substantial, such as in the forested areas, where vigilance is required to ensure that trees do not interfere with the transmission of power. This makes the local harnessing of any power an improvement, and makes the ability to generate power from a nearby river preferable to importing the power from other areas.

There are one hundred fifty six hydroelectric facilities in Northern California. Of these power generating facilities, thirty four of them are small hydropower facilities, each of which produces between one hundred kilowatts and twenty six megawatts of power. This size range indicates willingness, at least by some, to invest in small hydropower, though they are all significantly larger than the needs of a single household. Whether individuals would share this willingness likely depends on a number of factors. Individuals, like organizations, are most likely to make such an investment if it meets their needs while remaining economically feasible. While companies likely look at the same issues, the scale and the needs can be completely different. In both cases, small hydropower is most likely to be undertaken when its costs, in terms of both money and effort, do not outweigh the benefits.

It is useful to compare results of this investigation to the small hydropower that has already been developed. A list of the power generating facilities in California, and a map with the locations of these power facilities, can be found online from the California Energy Commission, at energyalmanac.ca.gov (2012). The map of the hydropower generating facilities shows a large number of hydropower facilities in California.



For further information or suggestions concerning these maps please contact:
California Energy Commission-Siting, Transmission and Environmental Protection Division
Cartography Unit, 1516 9th Street, MS48, Sacramento, CA 95814.
or call Jacque Gilbreath or Terry Rose at (916) 654-3902.

Figure 10: Hydroelectric Power facilities in California.

While this map is not easily converted to a format that is usable in a GIS environment, it is a good visual aid showing the hydropower generating facilities with a power rating of one hundred kilowatts or greater in the state. The small hydropower in the state is not entirely included in this data because of its .1 megawatt minimum, as noted on the map. Although the specifics for these locations may be obtainable, collecting the data from all of the counties would be time consuming, as each of the offices would need to be visited. Construction of small hydropower requires the filing of permits for development and for power generation, along with obtaining permission to divert water from the river or stream, even for the short distance of a penstock. Although any flow rates that were labeled as being taken at power facilities were not used in this study, in an attempt to avoid areas that were already being used to generate power, the small hydropower facilities were not so easily marked for elimination. This means that there may already be small hydropower in some of the areas identified for potential, and that any future plans should be devised in such a way so as not to compromise the needs of the existing installations.

Comparison to Previous Studies

The values found by this study vary from the values that were determined by previous studies. The potential values that Kane (2005) used in his report to the State of California are very different from those found by this study (Table 3).

Table 3: Potential power based on monthly and annual averages, and the values obtained by Kane (2005).

County	**Monthly (MW)**	**Annual (MW)**	**Kane (MW)**
Butte	8.51	23.94	97.0
Colusa	6.07	11.35	0.9
Del Norte	0.02	0.46	32.7
El Dorado	6.14	33.46	58.4
Glenn	5.78	13.42	15.1
Humboldt	2.44	37.09	55.6
Lake	0.20	4.36	12.0
Lassen	0.08	0.98	3.6
Marin	0.03	0.37	0.9
Mendocino	2.12	9.15	12.1
Modoc	0.36	2.07	4.6
Napa	>0.01	0.54	>0.1
Nevada	10.40	34.14	35.8
Placer	4.67	22.85	56.8
Plumas	10.60	26.87	78.5
Sacramento	3.37	7.01	30.0
Shasta	68.68	112.86	130.6
Sierra	2.49	49.43	118.8
Siskiyou	13.53	27.60	94.2
Solano	0.09	0.47	NA
Sonoma	2.03	11.15	NA
Sutter	5.24	8.54	0.9
Tehama	9.17	20.44	44.1
Trinity	2.31	12.07	72.5
Yolo	0.91	4.73	NA
Yuba	8.24	54.83	57.3
Total	173.5	530.15	972.5

The values stated from Kane's study were presented in a table on page 6 of his report. It can be seen that these values vary, in some cases by a large amount, even from the values calculated using the annual average flow rate. It should be noted that the values presented by Kane represent the total potential power, regardless of whether or not that potential is developable. This study, conversely, was designed to focus on the potential that is actually available for development, to the extent that this is possible to do without an intense on the ground study. Excluding the areas that are protected, or not near roads, limits the findings to the areas where development is most likely and where such development is not prevented by obvious regulations. The study that Kane used as a basis for his report was a precursor to the Idaho National Laboratory Study of 2005. That study was based on the annual flow rate, which is much higher than the lowest monthly average, used here. This may account for some of the differences between the values for small hydropower potential that were reported by Kane and those found here. Differences may also result from the limitations that were built into this study, which may have made the values in this study lower than those reported by Kane. However, in several counties, Colusa, Napa, Solano, Sonoma, Sutter, and Yolo, the potential reported by Kane is lower, in some cases a lot lower, than the potential found here. This is surprising, since the flow rate used in this study is lower than the flow rate used by previous studies. Without knowing Kane's methodologies, it is impossible to establish how these values are unexpectedly higher than previous estimates. With the additional limitations posed by this study, the values found in this study should be lower than in previous studies.

The results from the Idaho National Laboratory (Hall *et* al, 2006) study are summarized in appendix B of their report by State. The appendix does not go into a great amount of detail, though it does give a generalization for each State. The available developable power for the State of California is stated to be 10,311 megawatts, annual mean power, which is the average amount of power that can be generated over a year. This is not the same as the potential power generation in megawatts. How accurate this number may be is not considered in this study. Matching the results from the INL study to the results obtained here leads to some interesting findings. A comparison can be seen in table 4 below, with the results taken from the identical points on the rivers. This should have given results that differ mainly on the flow rate that was used.

Table 4: Comparison of results with those from the INL study, along with the flow rates used.

River	Site Number	Peterson (MW)	INL (MW)	INL flow rate (cfs)	USGS annual flow rate (cfs)
Mattole River	11469000	0.011	1.886	916.585	1292
Navarro River	11468000	0.001	0.023	3.18	464
Noyo River	11468500	0.001	0.024	3.53	209
Sacramento River	11370500	23.604	57.698	6307.515	10060
North Yuba River	11413500	6.024	14.02	674.68	1485*
Feather River	11407000	1.063	41.486	5749.72	1081

The differences in the power potential may be explainable due to the fact that this study used the lowest average monthly flow rate, which is why the flow rates used by the INL study were noted. However, the flow rates used by the Idaho National Laboratory do not match the USGS annual averages, which is problematic. The flow rate monitoring at the point on the North Yuba River that was used for comparison here has the last data collected in 1966, which makes the flow rate somewhat unreliable. This explains differences in the flow rate on the North Yuba River, but it does not explain the discrepancies for the other flow rates. Even if the working flow rate, which INL took to be half of the total flow rate, were stated here, the flow rates do not match, or resemble the measured flow rates. The Nomenclature section of their paper included the statement that “The annual mean flow rates were estimated using regional flow regression equations based on gauged stream flow rates that occurred over a period of many years” (Hall, *et al*, 2006, xvii). Regression equations are based on statistical regression models, which can be used to model behavior of systems, based on a given set of input data. Their input data, in this case, apparently included stream flow rates, acquired from gauges, which should be accurate. This method should not result in the inaccuracies that are seen between the flow rates used by INL and the annual average flow rates that were collected by the USGS monitoring sites. Regression models should be based on actual data, such as the flow rates collected by the USGS, and should result in realistic flow rates, especially as the INL method supposedly based their equations on the gauged stream flow rates. Cyr *et al* (2011) also noted that there are inaccuracies in the flow rates that were obtained in the INL study, which affect the results.

The inaccurate flow rates make the findings of the INL study suspect, and not reliable. Sites identified here are likely to be appropriate for development, though any of the potential power generation capabilities as estimated by the INL study should not be accepted without additional verification. Comparing the findings of this study with the INL results would clearly not be a worthwhile pursuit, due to the inaccuracy of INL's underlying flow rates. A simple comparison to the USGS flow rates reveals that the results of the study cannot be reliable. This is one source of discrepancies between the findings of the INL and the findings of this study, though there may be other sources of difference. One source of difference could be the different digital elevation models used in the two studies, a one third arcsecond resolution compared to a one arcsecond resolution. This may account for small amounts of difference in the head heights that were used in this study compared to INL's. This is not likely to cause a large amount of difference in the results, especially as the head heights have a margin of error in both studies.

In addition to the inaccurate flow rates contributing to part of the difference, there is also the issue of climate's effect on flow rate. Using the annual average for the flow rate completely discounts the seasonal effects of the local climate on any area covered by the INL, which is all of the United States. This leads to further inconsistencies between the estimated power potential and the actual power generation potential. Climatic differences impact the amount of power that could be generated in any one area. Using the annual average does not give the power potential year round, but only the potential during the portion of the year which has a flow rate equal to or greater than the annual average flow rate of the river. Northern California has a wet season and a dry season, affecting the amount of water that is available, and consequently the potential for hydroelectric power generation. During the times of year for which there is a flow rate lower than the annual average, perhaps half the time, it is not possible to generate the amount of power that was estimated using the annual average. Flow rates that factor in the climate of the area will yield a potential power generation estimate that should be the minimum possible over the course of the whole year. There is likely to be a larger amount of generation possible during a portion of the year, but a year round estimate is a more useful figure to developers. Although seasonal figures would also be useful, and figures based on an annual average flow rate would give insight into the potential for the high season, it is most important to know whether the minimum level of power generation would be sufficient for its intended purpose. Using the average monthly flow rates allows for the climate to be taken into account, and using the lowest value allows for the estimated power generation potential to be accurate for the year round flow of the river, and thus the year round minimum potential for hydroelectric power generation.

Further Study

There are a number of ways in which this study has been limited due to the information available as well as the scope of the study. This leads to a number of ways in which further study would be beneficial. Assuming access to additional information, subsequent studies could refine or expand these results, which would be beneficial to the identification of new potential small hydropower sites. Further knowledge of the flow rates of the rivers and streams, for example, would allow for improved estimates, as well as a possible understanding of how the flow rate should be adjusted both up and down the river, allowing for improvement in the identification of sites. On the ground studies can better identify the areas where the potential is greatest, and where penstocks would be best utilized. Other general studies in the locating of potential could lead to new methods and new locations of potential as well.

Further study and monitoring can be done to determine the potential for power generation along rivers and other areas that were not included in this study due to the lack of flow data. These studies could also produce a more accurate look at the flow rates in the area that was studied, either through updating of the older flow data to a point where the flow rate is current, or through finding a more accurate method to adapt the existing flow rate to the areas up and down stream. There may be large amounts of potential available for development in the areas which could not be covered in this study. There is potential energy in most areas where there is flowing water from which some water can be removed for a short distance, subject to local regulations. It may be that the best way to follow up on this study is to do an on the ground study, which would usually be done looking at a specific region, with a specific purpose, rather than doing such a study for the whole area with no specific purpose or need. The areas that are most likely to have large amounts of potential are the areas with large elevation changes, which can lead to a large amount of potential even when the flow rate is small. Areas where these elevation changes are most likely to be found are in the mountainous areas, the Sierra Nevada Mountains to the East, the Cascade Mountain Range to the North, and the Coastal Ranges to the West. The Sierra Nevada Mountains and the Cascade Mountains are also where winter weather is most likely to occur, which should be taken into account, since ice in the river could be a limiting factor. Being limited to water with USGS monitoring gauges, it may be that the best areas for development were not included in this study. Areas outside of this study area may have higher head heights or better flow rates than the areas that were covered, which would make them better candidates for small hydropower development.

Anyone with access to water, especially flowing water, should consider small hydropower as an option for generating power. This requires that people be made aware of their options, and any opportunities that may be available to them. This is mainly an awareness issue, which could be remedied by implementing awareness campaigns. This includes making people aware of the potential, including the methods that can be used to determine that potential. In order for ordinary people to be able to make use of small hydropower potential, they need to know how to calculate it. Studies like this one are focused on a large scale, and thus are unable to focus on each individual location where small hydropower may be realized. There may be potential in a number of areas, as long as there is access to water. Individual studies can be conducted to determine the potential power generation on a specific piece of property, which may not require the use of computer software, such as ArcGIS. Large scale studies make use of GIS software, as it makes the large amount of data easier to work with and process. Smaller studies, as would be done by individuals, do not require this large amount of data. Small scale studies may actually be hampered by the use of GIS, as the GIS layers may not contain enough detail to justify using the software for a small scale study. It is important that the information be made available as to how much potential is available, or at very least that people are given enough information to determine on their own how much potential exists. Even if the potential in a given area is not known or determined by any previous study, the estimation tools should be made broadly available, especially to those with water front property. The detailed methodology in this study lays out the process in a way that should make it accessible to others, in the hope that they may be able to make use of the information, and study or analyze the potential for their own situations, though the data available may not be adequate for every purpose.

One potential source of inadequate data may be the flow rates themselves. It is preferable that any flow data used to estimate the small hydropower potential along a river span at least ten years, up to current times. This allows for the best look at the behavior of the river over time. A ten year period would help to ensure that the flow data was not collected over either an unusually wet of dry period of time, such as drought years. Data from recent years also accounts for any changes that might have occurred, where older data may not include the effects of the changes. Changes can come in any number of forms, such as water use changes, changes in the irrigation uses of the area, or even changes in the landscape of the river. If these changes are not accounted for by past data, then the estimated small hydropower potential will be inaccurate, which may also be true in cases where the data does not span at least ten years.

The problem with relying on the flow data from gauge sites is that this limits the areas for which the potential can be estimated. It would be better if an accurate model could be created to find the flow rates in the areas where the flow rate is not measured. Any model that is developed would need to be based on the data available for the area including the available flow rates, unlike the Idaho National Laboratory study (Hall *et al*, 2006). This would allow for the model to be as accurate as possible, which is necessary to ensure that resulting estimates are as accurate as possible.

This study focused on year round generating potential, which is most useful to areas where power is needed on a daily basis year round. There may be places where power, or extra power, is only needed during part of the year. If this part of the year is during the winter rainy season, or even during the months of spring run-off, then there may be additional potential available for development. Streams with no flow during the summer months are poor choices for year round power generation. But these streams may be able to provide power during the winter to places that may not otherwise need the power during the summer. Places like winter cabins and ski resorts could benefit from power that is only available seasonally. There is an additional requirement that these streams do not freeze solid during the winter months when the power would be needed. This is a requirement for any of the potential that is located in the areas where winter weather is prevalent, which is most likely to occur in the Sierra Nevada Mountains and the Cascade Mountains, which are the only areas where significant winter weather is commonly found in California. It should also be ensured that the equipment used for any development in the winter areas is able to stand up the harsher conditions that the winter weather imposes. Further study could identify any of the areas where there may be only seasonal potential rather than year round potential. This could be accomplished by looking at seasonal averages rather than the lowest month, as was done here, to identify how much potential is available for development of seasonal small hydropower facilities.

Some areas are simply not ideal for small hydropower development, and should be left out of consideration due to their characteristics. For example, the San Francisco Bay is tidal, as are the rivers that feed into the bay. This includes the Sacramento River Delta and the smaller Petaluma River, which are tidal, along with any sloughs in the area, such as Butte Slough. Thus the large rivers that feed into the San Francisco Bay should not necessarily be used for small hydropower development. There may be areas of these rivers, past a certain point, that are not affected by the bay, such as the Sacramento River, though this should be checked before these areas are developed. Any flows that were labeled as tidal were not used in this study, due to the incompatibility of small hydropower technologies with tidal flows. Small Hydropower technologies are not meant to work with tidal flows, and these areas will be more appropriately used for tidal power generating technologies when these technologies come into common usage.

The entire San Francisco Bay could be used to generate tidal power. The Bay could house a number of tidal turbines, with the potential to generate massive amounts of power. However, any turbines in the bay and rivers should be either placed or protected in such a way as to prevent them from harming any marine life in and around the bay and its surroundings. It is also necessary to ensure that these turbines would not interfere with the current uses of the Bay, such as shipping. There are a number of shipping lanes which would affect the placement of any potential placement of tidal turbines for power generation. Further study should be done to determine the San Francisco Bay's tidal power potential, and to what extent this power can be developed, and how much power could be generated by harnessing the enormous tidal energy of the Bay.

A number of other factors, which could also cause sites to be less than ideal for small hydropower development, were not considered during the course of this study. Recreational uses should be considered when looking at any development that would affect the flow of the river, including small hydropower. Small hydropower does not remove water from the river for long stretches, but in the case of a ten thousand foot penstock, the length is not so insignificant where that temporary removal of water affects the recreational practices in the river. This makes the locations of penstocks important in areas that are popular with people who use the rivers for various recreational purposes. Some rivers are popular with whitewater rafters and kayakers, such as the American River. The South Fork of the American River has a substantial flow rate, maintained by the South Fork Dam, through areas that have significant elevation changes, which would suggest that the river should be ideal for small hydropower development. Despite this, the rafters would not be happy with development in the areas that are commonly rafted. This is what Rojanamon *et al* (2009) referred to as social or cultural significance of the river, which makes development very unlikely. It may be possible to develop some small hydropower in and around the areas that are popular with the rafters and kayakers, though they may not end up being located in the most productive areas. There could be areas where the flow rate is still substantial though the head may not be as high, where some amount of the water could be removed from the river for a short distance. While this could still be upsetting to the rafters, it would be better than taking water from the rapids they love, where the potential would be higher but the removal of any water would negatively impact recreational enjoyment. Despite the lower head, they may still produce high power, and the amount of water taken for the penstock would be limited by the needs of the rafters. Power generated in these areas could be used to power areas along the river, such as the camp grounds that are popular with the rafters. Areas which are not whitewater areas may also have recreational concerns. The Russian River, for example, is commonly used by swimmers and boaters, especially during the summer months. For rivers like this it would be best for small hydropower development to be located in the areas that are not popular swimming holes, and to ensure that there would be sufficient water at the penstock areas to avoid interfering with boaters. Issues like recreation are necessary considerations and should be taken into account early in the planning process, rather than as an afterthought.

Another form of recreation is fishing. In order for fishing to occur in any area there need to be fish in the river. The natural aquatic life in a river or stream should be taken into account, and any development should not compromise the needs of that aquatic life. A minimum flow is vital to support fish and other forms of aquatic life. This flow rate should not be compromised by the development of small hydropower, and any development should allow for the natural aquatic life to continue in the area without having its ability to support itself compromised by development.

Besides the recreational uses of a river, additional water uses need to be accounted for when planning a small hydropower installation. The Central Valley of California, between the Sierra Nevada Mountains and the Coastal Range, is where a significant portion of the nation's fruit and vegetable crops are grown. Also a large number of vineyards lie to the West of the Central Valley, especially in the areas in and around Sonoma and Napa Counties. These crops are heavily irrigated, which, of course, requires water. These crops and vineyards are people's livelihoods, and their needs should be taken into account, and not compromised, when any changes to the waterway, such as small hydropower, are planned. Irrigation does not preclude small hydropower development, though it does require that the amount of water being taken from the stream at any one point does not over tax the stream. The water remaining in the stream must always be adequate for all the people who depend on it. These area needs must be taken into account when considering any development.

Another possibility may be to generate power from unconventional sources which do not interfere with the existing uses of the river. It is possible to generate power from water that is already being taken out of the river, or is already in a penstock or pipeline of some sort. This includes water that is taken out of a river for irrigation purposes as well as water that is being released from power facilities. Farms, for example, take water from water bodies to irrigate the fields. This water could be run through a turbine to generate power before the water is used for irrigation, without harming the water quality, and to generate power that can be used by the farm. This is true of any form of irrigation water. Depending on the amount of water and the rate at which it is flowing, this could generate a large amount of power. Power generation of this sort is unconventional, but could be used to generate power without having to take additional water from the source. It does not require much additional development, and is minimally environmentally invasive, since the water is already being used and removed from the water source, and so does not require any additional water removal.

This last benefit is also true of water that is being released from power plants and power generating facilities. The released water has already been used to generate power. However, this could be used to generate some additional power by running this water through an additional turbine. Generating power this way requires only a minimum of new construction and does not affect the functioning of the power generation already being achieved. There is no environmental impact from generating additional power in this manner. This option could be further explored by the power companies, the entities most likely to take advantage of the possibilities that this represents, as an option for generating additional power from an existing facility for export to a grid. While this is not a traditional source of power generation, there may be significant potential when all of the possible power from these unconventional sources is added together. These additional sources of power generation should be studied further to ascertain their feasibility in the expansion of small hydropower generation.

Potential in Northern California is not limited to what has been considered in this study, and there are many other areas that may contain substantial small hydroelectric power potential. The feasibility of other, unconventional hydroelectric power generation techniques should be explored further. The most important factor in how much of the potential, located by this or other studies, is realized, is whether or not the people who would benefit are informed of their options. Both utilization and further study require that the information is obtainable, and understandable to the general population.

Conclusion

Northern California has areas with very real potential for small hydropower facilities, areas for which this development is feasible. The actual feasibility of any of these areas needs to be confirmed on a case by case basis, with a site specific examination. Of the areas included in this study, four hundred forty five sites have potential of more than two hundred watts available for development, barring any that has already been developed. The combined one hundred seventy three megawatts that could be developed in the locations identified in this study could increase the total amount of the power supply in the state of California. This is beneficial for a number of reasons, and an extension of similar studies to additional sites would benefit other areas as well.

Small hydropower provides additional power generating capacity without causing any environmental or ecological damage. Taking advantage of an area’s small hydropower potential can increase the power available in that area, possibly even providing all of the area’s power needs. Using hydroelectric power to provide power for the area around the site reduces the need for, and reliance on, power from power companies, who often rely on fossil fuels to generate power. Generating power by burning fossil fuel has resulted in a number of problems. Pollution is one of the largest environmental problems most commonly associated with the production of power from fossil fuels. Hydroelectric power does not emit pollution and is thus considered to be a ‘clean’ energy source.

While hydroelectric power is not the only ‘clean’ energy source, it is the best option in some areas, but not the best option in all areas. Small hydropower technologies are the best option in areas which are not clear enough for either solar or wind power. Areas which are forested, for example, are not the ideal areas for solar or wind, and may be better for hydropower development. Any form of increase in the supply of clean energy is preferable to the building of a new fossil fuel burning power plant, or the expansion of an existing plant. Small hydropower has the bonus of not emitting any greenhouse gases, which is what makes it a ‘clean’ form of energy, and preferable to conventional energy sources. The implementation of any small hydropower is dependent on discovering potential, which varies with the terrain and the climate.

Climate varies by location and cannot be ignored in any study that involves the natural world. Climate is an important factor in any study of hydropower, as the local climate affects the availability of water in an area or in any specific river or stream. It is not possible to take the weather on any one day and decide that it is indicative of weather throughout the year. The same can be said of the amount of water, and the resulting flow rate, that is present in a river. While the behavior of the weather is not constant from one year to the next, it is possible to use the weather patterns over time to determine the behavior of the weather on average, with the weather extremes balancing each other. This is why it is important to take data from as large a number of years as possible, and to look at the variations over the course of the year, such as looking at monthly data. Monthly data gives a look at the behavior of the climate over the course of a year, and using many years allows for an averaging over time, and will help to account for years with extreme weather. This is important for any study of the natural world as a source for power generation.

Consideration of climate is important, though it is equally important to verify that the data that is being used is accurate. This has been a shortcoming in previous studies, and any of their results should be verified to ensure that the underlying data is as accurate as possible. The findings of this study do offer an improvement over previous studies, because this study accounted for the local climate. Differences may have also been due to some inaccuracies that were found in the previous studies, which make any findings of those studies questionable.

Hydroelectric plants are numerous in California, including some small hydropower facilities, making additional projects more likely, as the social barriers have been overcome, at least initially. The local regulations need to be taken into consideration, though the existence of small hydropower facilities indicates that these projects are possible in California. Once the practice has been established it is more likely that the practice will be extended.

Further study is needed on a number of frontiers, and should be undertaken in the future. Such studies could allow for an increase in the amount of area that is covered accurately by data, as well as the inclusion of unconventional possibilities. Further study could advance the understanding of the necessary conditions that make small hydropower feasible, and how much power it is possible to harness given the varied circumstances that exist. Northern California has a number of different terrains, and it may be that each of these should be considered using a number of different methodologies, depending on its own unique circumstances.

The most important factor in both future development and future studies is the availability of information. Without access to information there is little possibility that much progress can be made on either front. Studies of individual properties can be conducted by people interested in harnessing energy on their property, or studies can be conducted on a larger scale. Any of these studies require that information be both obtainable and understandable. Small studies may not require the extensive use of computers, and may be done quite easily, provided that the interested parties have access to the necessary information to conduct such a study.

Studies can be conducted for any number of reasons, and the resulting hydropower potential can be put to any number of uses, each of which is dependent on the needs of the consumer. Small hydropower can be used to provide power for single homes, small communities, or other power needs. Any development, for whatever purpose, should have some research associated with its planning. There is no way to ensure that any broad study could have covered all of the issues that arise when undertaking an individual project, so some site specific investigation must be done before any project is started. Therefore, unlike the inaccurate and unexplained results of previous studies, the requisite information must be accessible and the procedures explained. Small hydropower should continue to be explored and developed.

Appendix: Small Hydropower Potential

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
1	Mad River	Humboldt	11480750	1965-1974	3.115	165.985	35.669	1900.742
2	North Fork Mad River	Humboldt	11480800	1957-1974	0.119	33.775	4.013	1139.517
3	Redwood Creek	Humboldt	11481500	1953-2011	0.212	25.464	6.392	766.348
4	Willow Creek	Humboldt	11529800	1959-1974	0.681	486.645	5.176	3697.886
5	Trinity River	Humboldt	11530000	1963-2011	19.793	346.104	138.641	2424.245
6	Lacks Creek	Humboldt	11482110	1980-1991	0.045	8.293	1.968	360.216
7	Panther Creek	Humboldt	11482125	1979-1991	0.045	16.605	0.699	256.296
8	Redwood Creek	Humboldt	11482120	1980-1989	0.538	37.566	16.785	1171.954
9	Coyote Creek	Humboldt	11482130	1979-1989	0.012	4.575	0.905	356.635
10	Bluff Creek	Humboldt	11523050	1958-1965	1.442	365.175	12.021	3045.156
11	Mareep Creek	Humboldt	11530150	1966-1969	0.062	84.519	0.291	394.648
12	Sacramento River	Glenn	11389000	1945-1995	186.608	5546.214	365.997	10877.858
13	Butte Creek	Butte	11390010	1959-1972	0.396	14.621	10.438	384.962
14	Stony Creek	Glenn	11388500	1941-1973	0.510	10.482	12.135	249.568
15	Deer Creek	Tehama	11383500	1911-2011	2.690	145.108	9.110	491.420
16	Mill Creek	Tehama	11381500	1928-2011	3.030	159.633	8.648	455.609
17	Pine Creek	Modoc	11347500	1918-1931	0.278	101.335	0.501	183.071
18	North Fork Pit River	Modoc	11344000	1929-1985	0.028	0.727	1.969	50.550
19	North Fork Pit River	Modoc	11343500	1929-1967	0.045	1.413	1.257	39.213
20	Cosumnes River	Sacramento	11335000	1907-2011	0.425	14.190	14.075	470.221
21	Deer Creek	El Dorado	11335655	2004-2011	0.057	16.110	0.441	125.548
22	Weber Creek	El Dorado	11446000	1943-1959	0.040	7.182	2.459	445.526
23	South Fork American River	El Dorado	11445000	1929-1941	3.455	242.756	27.040	1900.101
24	South Fork American River	El Dorado	11445500	1962-1995	14.725	872.131	40.033	2371.091
25	North Fork American River	El Dorado	11433800	1972-1986	17.811	1087.243	63.829	3896.291

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
26	Middle Fork American River	Placer	11433500	1911-1986	7.447	596.915	37.646	3017.354
27	Canyon Creek	El Dorado	11433400	1966-1979	0.096	30.515	0.498	157.829
28	Bear River	Placer	11423000	1941-1967	0.261	65.925	7.826	1980.307
29	Bear River	Nevada	11422500	1965-2011	3.171	1235.519	11.336	4416.056
30	Bear River	Nevada	11422000	1931-2011	8.325	3188.078	10.234	3918.951
31	Bear River	Nevada	11421790	1965-2011	0.311	79.835	0.859	220.202
32	South Yuba River	Nevada	11417500	1940-2011	1.161	239.119	12.992	2675.777
33	Middle Yuba River	Nevada	11410001	1928-1941	0.934	145.401	11.529	1793.911
34	Middle Yuba River	Yuba	11409001	1941-1969	1.869	138.733	11.871	881.236
35	Middle Yuba River	Yuba	11410000	2000-2005	0.994	86.154	1.996	172.890
36	Oregon Creek	Yuba	11409500	1911-1969	0.113	40.814	2.228	802.750
37	Middle Yuba River	Nevada	11408880	1968-2011	0.850	168.694	3.783	751.220
38	Middle Yuba River	Sierra	11408850	1967-1989	1.019	94.031	9.507	876.901
39	Pit River	Shasta	11366500	1910-1943	63.996	1.943	115.378	3.504
40	Sacramento River	Shasta	11342500	1910-1941	3.579	1.957	28.989	15.847
41	Sacramento River	Shasta	11342000	1944-2011	6.363	382.156	34.106	2048.486
42	Sacramento River	Shasta	11341500	1910-1923	5.409	644.102	20.986	2499.219
43	Sacramento River	Siskiyou	11341400	1959-1970	1.388	245.137	6.884	1216.275
44	Dry Creek	Lake	11453200	1959-1980	0.006	0.715	0.822	103.808
45	Putah Creek	Lake	11453500	1904-2011	0.065	2.145	5.865	193.178
46	Cache Creek	Lake	11451000	1944-2011	0.118	15.496	10.624	1394.601
47	Cache Creek	Lake	11450500	1911-1915	1.727	10.013	13.479	78.135
48	North Fork Cache Creek	Lake	11451500	1930-1981	0.102	6.534	5.413	347.000
49	North Fork Cache Creek	Lake	11451300	1985-2009	0.425	147.492	4.502	1563.181
50	North Fork Cache Creek	Lake	11451100	1971-2011	0.034	1.957	3.108	179.050
51	Little Stony Creek	Colusa	11384600	1966-1982	0.021	1.490	1.630	114.421
52	Stony Creek	Colusa	11384500	1913-1934	0.821	96.646	4.196	493.830
53	Mad River	Trinity	11480410	1980-2010	1.671	218.658	8.848	1158.018

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
54	Hayfork Creek	Trinity	11528500	1953-1974	9.061	400.059	15.319	676.351
55	Dry Creek	Placer	11447293	1999-2011	0.425	13.541	2.124	67.714
56	Bear River	Placer	11423800	1989-2011	0.340	38.920	0.464	53.096
57	Bear River	Yuba	11423500	1904-1927	1.161	200.222	13.551	2336.925
58	Deer Creek	Nevada	11418500	1935-2011	0.139	77.786	3.512	1968.644
59	Dry Creek	Yuba	11420700	1964-1980	0.178	19.510	2.145	234.546
60	Dry Creek	Yuba	11420500	1948-1961	0.108	30.903	3.141	901.937
61	South Honcut Creek	Yuba	11407500	1950-1986	0.021	3.359	1.048	168.084
62	North Yuba River	Yuba	11413520	1966-2004	0.212	210.183	8.380	8293.951
63	North Yuba River	Yuba	11413500	1994-1966	7.362	6023.503	43.099	35261.395
64	Putah South Canal	Solano	11454210	1994-2011	1.388	88.425	7.439	474.111
65	Putah Creek	Yolo	11454000	1959-2011	2.435	138.958	13.391	764.081
66	Putah Creek	Yolo	11454500	1905-1931	0.091	0.811	14.756	132.068
67	Trinity River	Trinity	11523200	1957-2011	1.218	163.401	11.789	1581.995
68	Rush Creek	Trinity	11525530	2003-2011	0.065	7.366	1.235	139.670
69	Coffee Creek	Trinity	11523700	1910-1966	1.388	262.030	8.299	1567.333
70	South Fork Scott River	Siskiyou	11518200	1958-1960	0.207	46.608	1.666	375.629
71	East Fork Scott River	Siskiyou	11518050	1959-1974	0.079	8.773	2.960	327.468
72	Sugar Creek	Siskiyou	11518300	1957-1960	0.024	4.873	0.546	110.500
73	Deer Creek	Tehama	11383000	1928-1931	1.671	476.532	4.118	1174.672
74	Bailey Creek	Shasta	11376120	1990-2011	0.510	151.606	0.545	161.973
75	North Fork Battle Creek	Shasta	11376050	1986-2011	0.099	22.790	0.101	23.252
76	North Fork Battle Creek	Shasta	11376025	1980-2011	0.227	16.643	0.712	52.285
77	Old Cow Creek	Shasta	11372350	1996-2011	0.765	372.656	1.166	568.205
78	Eagle Creek	Modoc	10360230	1961-1970	0.062	50.802	1.194	973.663
79	Little Cow Creek	Shasta	11373300	1957-1965	0.246	31.909	4.005	518.713
80	Pit River	Shasta	11365000	1965-2011	86.083	694.395	136.615	1102.014
81	Squaw Creek	Shasta	11365500	1944-1966	0.538	55.162	6.560	672.573
82	Hatchet Creek	Shasta	11364300	1990-1998	0.396	95.646	1.046	252.417
83	Roaring Creek	Shasta	11364200	1990-1996	0.368	161.275	1.312	574.743
84	Pit River	Shasta	11364000	1925-1937	49.838	9799.632	72.184	14193.690

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
85	Pit River	Shasta	11363000	1943-2011	3.936	585.340	15.973	2375.355
86	East Fork Nelson Creek	Shasta	11362945	1993-1998	0.071	43.466	0.438	269.178
87	Iron Canyon Creek	Shasta	11363930	1966-1998	0.096	59.541	0.153	94.484
88	Nelson Creek	Shasta	11362890	1993-2007	0.311	100.148	0.438	140.952
89	Kosk Creek	Shasta	11363500	1911-1916	1.161	152.514	9.849	1293.861
90	McCloud River	Shasta	11367800	1964-2011	6.286	2456.796	8.814	3444.604
91	McCloud River	Shasta	11367760	1966-1998	2.464	888.088	4.136	1490.974
92	McCloud River	Shasta	11367700	1955-1959	28.600	13067.698	39.127	17877.693
93	McCloud River	Siskiyou	11367500	1931-2011	21.776	3440.860	25.995	4107.572
94	Angel Creek	Siskiyou	11367300	1955-1959	0.340	47.613	1.520	212.993
95	McCloud River	Siskiyou	11367200	1955-1959	20.416	4118.674	26.123	5269.922
96	Mud Creek	Siskiyou	11367000	1927-1932	0.136	31.473	0.288	66.728
97	Deer Creek	Tehama	11382550	1961-1970	1.501	424.820	3.764	1065.457
98	Deer Creek	Tehama	11382500	1928-1932	0.566	37.515	1.242	82.258
99	Mill Creek	Tehama	11381000	1928-1932	0.651	103.899	1.675	267.264
100	Manzanita Creek	Shasta	11376038	1979-1981	0.065	26.651	0.143	58.672
101	Hat Creek	Shasta	11355500	1926-1994	3.455	712.786	3.994	824.003
102	Blue Creek	Humboldt	11530300	1965-1978	2.379	167.047	21.511	1510.680
103	Indian Creek	Plumas	11401125	1965-1980	0.252	50.500	1.345	269.505
104	Baxter Creek	Lassen	10355000	1913-1919	0.025	2.198	0.321	27.655
105	Willow Creek	Lassen	10358500	1950-1994	0.311	26.715	0.939	80.568
106	Arroyo Corte Madera Del Presidio	Marin	11460100	1965-1986	0.007	0.476	0.212	14.881
107	Corte Madera Creek	Marin	11460000	1951-1993	0.010	0.333	0.764	25.662
108	Novato Creek	Marin	11459500	1946-2011	0.008	0.426	0.359	18.020
109	Sonoma Creek	Sonoma	11458500	1955-2011	0.022	1.546	1.997	143.382
110	Napa River	Napa	11456000	1929-2011	0.024	0.543	2.670	61.724
111	Mad River	Humboldt	11480780	1972-1976	3.030	101.647	45.117	1513.583
112	Mad River	Humboldt	11481000	1962-2011	0.555	10.161	38.566	706.074
113	Little River	Humboldt	11481200	1955-2011	0.174	12.712	3.883	282.951
114	Redwood Creek	Humboldt	11482200	1970-1981	0.623	57.239	20.153	1851.705

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
115	Redwood Creek	Humboldt	11482500	1911-2011	0.991	25.493	28.665	737.332
116	Little Lost Man Creek	Humboldt	11482468	1974-1989	0.013	6.246	0.276	129.463
117	Hunting Creek	Lake	11453550	1969-1976	0.017	3.392	0.914	182.587
118	Cache Creek	Yolo	11451760	1960-1986	1.671	69.427	17.116	711.285
119	Mattole River	Humboldt	11468900	2001-2011	0.224	6.929	10.088	312.421
120	Honeydew Creek	Humboldt	11468990	1973-1977	0.176	24.513	4.282	597.871
121	Bull Creek	Humboldt	11476600	1960-2011	0.071	6.637	3.336	312.834
122	Larabee Creek	Humboldt	11476700	1959-1965	0.255	14.494	7.939	451.505
123	Mattole River	Humboldt	11469000	1911-2011	1.388	11.384	36.763	301.614
124	North Fork Mattole River	Humboldt	11469500	1951-1957	0.212	13.074	4.859	299.110
125	Pit River	Modoc	11348500	1904-2011	1.161	16.660	6.881	98.743
126	Stony Creek	Glenn	11385500	1933-1941	1.133	74.127	8.042	526.310
127	Stony Creek	Glenn	11387000	1901-1978	2.407	97.856	18.581	755.432
128	Grindstone Creek	Glenn	11386500	1935-1972	0.051	3.449	5.519	373.504
129	Stony Creek	Glenn	11387200	1909-1983	1.529	49.496	19.532	632.238
130	Elder Creek	Tehama	11379500	1948-2011	0.085	9.955	2.976	348.722
131	Dobbyn Creek	Humboldt	11475100	1972-1976	0.269	20.639	8.132	623.874
132	Little Van Duzen River	Humboldt	11477700	1958-1967	0.127	32.370	4.834	1228.121
133	Mad River	Trinity	11480500	1962-1994	1.954	143.859	10.474	771.190
134	Van Duzen River	Humboldt	11478000	1911-1951	0.425	29.549	21.540	1498.445
135	Van Duzen River	Humboldt	11477500	1953-1974	0.139	59.295	10.942	4675.980
136	Laguna Creek	Sacramento	11336585	1995-2011	0.027	0.319	0.369	4.421
137	Sacramento River	Sacramento	11447650	1948-2010	348.297	566.701	677.153	1101.769
138	Morrison Creek	Sacramento	11336580	1959-2011	0.164	1.883	0.607	6.961
139	Sacramento River	Yolo	11447500	1948-1979	356.792	515.767	676.256	977.574
140	Arcade Creek	Sacramento	11447360	1963-2011	0.174	4.554	0.505	13.240
141	Magpie Creek	Sacramento	11447330	1995-1997	0.014	0.390	0.074	2.082
142	Jackson Creek	Nevada	11414700	1989-1996	0.037	43.264	0.046	53.902
143	Little Truckee River	Sierra	10341950	1993-1998	0.125	4.487	3.129	112.680

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
144	Middle Yuba River	Sierra	11407815	1994-2011	0.396	166.803	2.551	1073.483
145	Middle Yuba River	Sierra	11407900	1964-1987	1.557	649.731	3.352	1398.328
146	Middle Yuba River	Nevada	11408550	1987-2011	0.108	14.021	0.778	101.346
147	Middle Yuba River	Nevada	11408501	1928-1964	0.110	14.832	3.069	412.131
148	Haypress Creek	Sierra	11410400	1960-1966	0.139	95.100	1.223	838.147
149	Berry Creek	Sierra	11391460	1973-1981	0.167	111.574	0.323	215.797
150	Big Grizzly Creek	Plumas	11391500	1925-1980	0.136	51.774	0.985	375.134
151	Hat Creek	Shasta	11357000	1921-1922	3.200	175.524	13.607	746.406
152	Hat Creek	Shasta	11356500	1911-1913	4.814	332.904	5.256	363.485
153	Lost Creek	Shasta	11358020	1989-2011	0.045	35.057	0.479	370.929
154	Lost Creek	Shasta	11358000	1929-1930	1.501	1105.161	1.549	1140.610
155	Pit River	Shasta	11355010	1975-2011	34.840	4750.151	53.381	7278.100
156	Pit River	Shasta	11355000	1921-1950	4.672	217.731	13.137	612.191
157	North Fork Cosumnes River	El Dorado	11333500	1911-1987	0.283	17.067	6.021	362.907
158	Feather River	Butte	11407000	1968-2011	15.376	1063.477	30.611	2117.184
159	Dry Creek	Butte	11390210	1970-1974	0.040	1.310	2.000	66.084
160	Butte Creek	Butte	11390000	1930-2011	3.697	205.418	11.705	650.347
161	Big Chico Creek	Butte	11384000	1930-1986	0.676	118.156	4.234	739.963
162	West Branch Feather River	Butte	11405300	1957-1986	0.076	14.689	8.987	1726.724
163	Butt Creek	Plumas	11401000	1905-1921	0.878	845.666	2.908	2801.410
164	North Fork Feather River	Plumas	11399500	1959-2011	0.963	369.063	1.488	570.391
165	Butt Creek	Plumas	11400500	1936-2011	8.467	3451.459	8.890	3624.003
166	Butt Creek	Plumas	11400000	1936-1964	0.821	318.837	2.205	856.192
167	Pine Creek	Lassen	10359250	1950-1961	0.037	3.051	0.208	17.230
168	Lights Creek	Plumas	11401300	1957-1962	0.088	14.441	1.142	187.810
169	Cache Creek	Yolo	11452000	1942-1976	1.557	76.294	19.601	960.180
170	Cache Creek	Yolo	11451950	1983-1986	2.549	100.281	13.769	541.782
171	Sacramento River	Colusa	11389500	1945-2010	180.945	5263.241	329.762	9591.988
172	Redwood Creek	Napa	11458200	1958-1973	0.001	0.204	0.299	43.088
173	Milliken Creek	Napa	11458100	1970-1983	0.028	1.804	0.577	37.508
174	Dry Creek	Napa	11457000	1951-1966	0.002	0.243	0.567	81.264

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
175	Napa River	Napa	11458000	1959-2011	0.051	1.486	5.997	174.845
176	Conn Creek	Napa	11456500	1929-1975	0.021	0.494	0.841	19.550
177	Pope Creek	Napa	11453600	1961-1980	0.023	1.231	2.334	125.229
178	Bear River	Placer	11424000	1965-2011	0.566	7.340	11.413	147.923
179	Feather River	Sutter	11421700	1942-1983	74.473	435.933	202.600	1185.929
180	Feather River	Yuba	11407700	1964-1976	81.835	809.546	165.909	1641.226
181	North Honcut Creek	Butte	11407300	1960-1981	0.042	3.299	1.423	110.492
182	Feather River	Butte	11407150	1968-1998	68.810	2023.850	141.741	4168.911
183	Hayfork Creek	Trinity	11528400	1956-1965	1.133	90.484	3.344	267.056
184	Big Creek	Trinity	11528440	1960-1967	0.010	0.722	1.122	79.471
185	Indian Creek	Trinity	11525670	2004-2011	0.133	13.864	1.165	121.332
186	Trinity River	Trinity	11526000	1943-1951	4.616	123.504	44.005	1177.469
187	Weaver Creek	Trinity	11525800	1958-1969	0.045	5.871	1.608	208.346
188	Grass Valley Creek	Trinity	11525630	2004-2011	0.311	33.721	1.348	145.970
189	Rock Creek	El Dorado	11444201	1986-2010	0.153	119.113	1.331	1037.092
190	Rubicon River	Placer	11433200	1958-1984	1.189	127.290	11.862	1269.535
191	Middle Fork American River	Placer	11433300	1958-2011	11.950	1814.701	31.746	4821.021
192	North Fork of Middle Fork American River	Placer	11433260	1965-1984	0.821	199.939	8.286	2017.354
193	Bear River	Placer	11421770	1966-1998	0.176	47.661	0.623	169.025
194	Bear River	Placer	11421710	1987-2008	0.210	34.104	0.260	42.283
195	South Yuba River	Nevada	11414250	1965-2011	0.193	82.921	2.968	1278.139
196	South Yuba River	Nevada	11414000	1942-1994	0.708	200.895	5.639	1600.244
197	South Yuba River	Nevada	11414210	1985-2003	0.119	91.505	0.295	227.213
198	Poorman Creek	Nevada	11417100	1961-1971	0.278	52.927	1.925	367.227
199	South Yuba River	Nevada	11417000	1942-1972	0.680	130.286	8.205	1572.909
200	Canyon Creek	Nevada	11414450	1989-2003	0.082	32.848	0.084	33.582
201	Walker Creek	Glenn	11390660	1965-1981	0.130	1.991	0.631	9.648
202	Stony Creek	Tehama	11388000	1955-1990	2.435	188.338	15.244	1178.969
203	Walker Creek	Marin	11460800	1959-1984	0.028	1.943	1.547	106.091

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
204	Laguna de Santa Rosa	Sonoma	11465750	1998-2011	0.102	0.600	2.313	13.600
205	Mark West Creek	Sonoma	11466800	2005-2008	0.059	0.969	7.791	126.931
206	Russian River	Sonoma	11467000	1939-2011	21.644	1558.655	64.656	4656.116
207	Russian River	Sonoma	11464000	1939-2011	5.125	264.878	40.409	2088.318
208	Dry Creek	Sonoma	11465200	1985-2011	2.747	64.196	8.371	195.641
209	Dry Creek	Yuba	11420000	1948-1960	0.096	19.364	1.072	215.535
210	South Fork Feather River	Butte	11396350	1962-1987	2.067	168.453	7.778	633.829
211	South Fork Feather River	Butte	11396200	1963-2011	0.311	112.103	2.045	736.026
212	South Fork Feather River	Butte	11396300	1957-1961	0.850	52.910	8.780	546.867
213	Sucker Run	Butte	11396400	1965-1987	0.125	98.999	0.802	637.407
214	Sucker Run	Butte	11396395	1989-2010	0.105	66.206	0.332	209.878
215	North Fork Feather River	Butte	11404500	1911-2011	21.832	4130.620	48.362	9149.961
216	North Fork Feather River	Butte	11404330	1985-2011	4.672	407.280	20.875	1819.679
217	Grizzly Creek	Plumas	11404000	1929-1944	0.022	5.829	0.754	201.700
218	Grizzly Creek	Plumas	11404300	1985-2011	0.142	20.082	0.624	88.517
219	Bucks Creek	Plumas	11403530	1986-2011	0.119	116.480	0.189	185.522
220	Bucks Creek	Plumas	11403700	1980-2011	3.766	1755.075	4.592	2140.056
221	North Fork Feather River	Plumas	11403200	1986-2011	4.106	226.435	14.833	817.988
222	East Branch North Fork Feather River	Plumas	11403000	1950-1982	3.002	191.309	29.029	1850.210
223	Antelope Creek	Tehama	11379000	1960-1982	1.076	112.286	4.246	443.109
224	Sacramento River	Tehama	11378000	1902-1968	151.778	315.050	318.164	660.420
225	Paynes Creek	Tehama	11377500	1949-1966	0.012	0.940	2.097	169.788
226	Sacramento River	Tehama	11377100	1963-2011	169.519	865.490	318.164	1624.406
227	Battle Creek	Tehama	11376500	1940-1961	5.777	398.338	12.819	883.977
228	Battle Creek	Shasta	11376550	1961-2011	7.306	417.879	14.180	811.080
229	Coleman Canal	Shasta	11376450	1978-1985	7.221	184.290	8.835	225.484
230	Bear Creek	Shasta	11374100	1959-1967	0.207	34.444	2.228	371.287

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
231	South Cow Creek	Shasta	11372200	1956-1972	0.510	24.263	3.281	156.191
232	South Cow Creek	Shasta	11372080	1984-2011	0.133	18.203	0.139	19.062
233	Oak Run Creek	Shasta	11373200	1957-1966	0.074	34.738	0.459	216.534
234	Clover Creek	Shasta	11372700	1957-1959	0.227	118.009	1.516	789.601
235	Silver Fork American River	El Dorado	11439501	1922-2011	3.030	564.938	11.726	2186.387
236	South Fork American River	El Dorado	11443500	1967-2011	1.019	393.215	4.019	1550.360
237	Grass Lake Creek	El Dorado	1.03E+08	1971-1974	0.048	59.465	0.298	368.016
238	Silver Creek	El Dorado	11442000	1922-1961	0.991	231.855	11.527	2696.656
239	Brush Creek	El Dorado	11442700	1987-2011	0.091	85.200	0.145	136.211
240	Upper Truckee River	El Dorado	1.03E+08	1990-2011	0.283	14.814	2.215	115.891
241	Trout Creek	El Dorado	10336770	1990-2011	0.147	147.723	0.300	300.836
242	Trout Creek	El Dorado	10336775	1990-2011	0.252	3.621	0.635	9.124
243	Pilot Creek	El Dorado	11432500	1946-1960	0.026	8.080	0.754	233.978
244	Cold Creek	El Dorado	10336778	2001-2003	0.119	17.023	0.195	27.952
245	Trout Creek	El Dorado	10336780	1960-2011	0.481	9.803	1.013	20.633
246	Upper Truckee River	El Dorado	10336610	1971-2011	0.311	7.847	2.748	69.223
247	Trout Creek	El Dorado	10336790	1972-1992	0.311	8.554	0.720	19.772
248	Oregon Creek	Yuba	11409400	1968-2011	0.150	41.825	0.744	207.276
249	Oregon Creek	Yuba	11409300	1967-2000	0.079	18.891	1.960	467.101
250	North Yuba River	Sierra	11413000	1930-2011	4.276	496.079	21.325	2474.093
251	North Yuba River	Yuba	11413100	1968-1987	5.578	465.727	36.525	3049.339
252	Rock Creek	Sierra	11412000	1910-1933	0.025	16.509	0.715	473.414
253	Goodyears Creek	Sierra	11412500	1911-1933	0.116	21.993	1.061	200.962
254	Deadwood Creek	Yuba	11413320	1994-2011	0.091	131.396	0.134	194.371
255	Lost Creek	Butte	11396000	1961-2010	0.136	33.841	0.988	245.996
256	Slate Creek	Plumas	11413300	1962-2011	0.283	86.286	2.861	871.916
257	Slate Creek	Plumas	11413250	1962-2011	0.034	7.136	2.906	610.282
258	Lost Creek	Plumas	11395300	1960-1970	0.187	51.634	1.611	445.003

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
259	South Fork Feather River	Plumas	11395200	1963-2011	0.280	67.941	0.791	191.780
260	Fall River	Plumas	11394620	1963-1978	0.076	21.611	1.170	330.664
261	South Fork Feather River	Plumas	11395030	1963-2011	1.926	1065.620	3.021	1672.084
262	South Fork Feather River	Plumas	11394800	1960-1978	0.011	1.921	0.823	143.134
263	Spanish Creek	Plumas	11401900	1958-1963	0.340	19.329	3.096	176.117
264	Spanish Creek	Plumas	11401920	2009-2011	0.481	16.408	4.079	139.022
265	Spanish Creek	Plumas	11402000	1933-2011	0.821	148.887	7.528	1364.804
266	Spanish Creek	Plumas	11402500	1911-1933	0.736	120.428	6.696	1095.242
267	North Fork Feather River	Plumas	11401112	1969-2011	2.888	697.114	3.645	879.706
268	Indian Creek	Plumas	11401500	1906-1993	0.793	31.737	14.879	595.560
269	Butt Creek	Plumas	11401100	1969-1981	0.453	279.171	0.450	277.281
270	Middle Yuba River	Sierra	11408700	1957-1966	0.736	175.990	5.567	1330.794
271	Canyon Creek	Nevada	11416500	1927-2011	0.085	35.916	0.987	417.141
272	Canyon Creek	Nevada	11414470	1989-1998	0.125	36.499	0.303	88.825
273	Canyon Creek	Nevada	11414500	1926-1930	0.510	198.219	2.381	926.053
274	Jackson Creek	Nevada	11415000	1926-1930	0.040	25.172	0.472	299.517
275	North Yuba River	Sierra	11410500	1923-1944	1.331	330.015	6.373	1580.213
276	Downie River	Sierra	11411000	1910-1926	1.472	111.326	6.910	522.416
277	Middle Fork Feather River	Plumas	11393000	1910-1927	1.529	85.122	14.287	795.324
278	Middle Fork Feather River	Plumas	11393500	1911-1962	1.671	100.677	15.471	932.268
279	South Branch Ward Creek	Plumas	11401165	1990-1998	0.085	140.520	0.115	189.595
280	Little Grizzly Creek	Plumas	11401180	1964-1979	0.190	83.579	1.370	603.591
281	Red Clover Creek	Plumas	11401150	1958-1965	0.311	122.925	1.963	774.797
282	Indian Creek	Plumas	11401200	1957-1980	1.529	92.511	10.473	633.604
283	Trinity River	Trinity	11526250	2002-2011	11.072	675.400	37.426	2283.027
284	North Fork Trinity River	Trinity	11526500	1911-1980	1.048	153.055	12.289	1795.263

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
285	South Fork Salmon River	Siskiyou	11522300	1957-1965	1.359	255.080	14.364	2695.626
286	Middle Fork American River	Placer	11427760	1965-1985	0.510	253.332	2.942	1462.417
287	Shackleford Creek	Siskiyou	11519000	1956-1961	0.249	144.602	1.517	880.373
288	Moffett Creek	Siskiyou	11518600	1958-1967	0.025	4.819	0.388	74.134
289	Scott River	Siskiyou	11519500	1941-2011	1.416	91.247	17.847	1150.201
290	Little Shasta River	Siskiyou	11516900	1957-1978	0.130	55.147	0.549	232.596
291	Klamath River	Siskiyou	11512500	1923-1961	35.113	2812.261	51.434	4119.437
292	Fall Creek	Siskiyou	11512000	1933-1959	0.934	572.429	1.135	694.981
293	Cache Creek	Yolo	11452500	1903-2011	0.224	9.390	15.206	638.270
294	Sacramento River	Sutter	11391000	1940-1981	200.483	4805.924	306.698	7352.079
295	Sacramento River	Colusa	11390500	1945-2010	181.511	706.521	295.143	1148.824
296	Antelope Creek	Siskiyou	11489500	1952-1979	0.396	132.172	1.015	338.410
297	Butte Creek	Siskiyou	11490500	1952-1960	0.184	10.357	0.695	39.040
298	Horse Creek	Lassen	11352500	1929-1967	0.144	18.053	0.645	80.791
299	Pit River	Lassen	11352000	1904-1970	0.368	22.470	12.254	747.990
300	Willow Creek	Lassen	11351000	1930-1931	0.105	7.056	0.172	11.593
301	Pit River	Modoc	11349000	1929-1970	1.218	13.241	7.587	82.508
302	Lagunitas Creek	Marin	11460400	1983-2011	0.198	12.544	1.346	85.203
303	Lagunitas Creek	Marin	11460600	1974-2011	0.173	2.895	2.702	45.286
304	Walker Creek	Marin	11460750	1983-2011	0.144	11.211	0.983	76.315
305	Laguna de Santa Rosa	Sonoma	11465680	1998-2011	0.008	0.273	0.953	31.681
306	Santa Rosa Creek	Sonoma	11466320	1999-2011	0.099	1.072	2.700	29.204
307	Santa Rosa Creek	Sonoma	11465800	1959-1970	0.006	0.866	0.524	72.844
308	Franz Creek	Sonoma	11463940	1963-1968	0.003	0.513	0.683	111.044
309	Maacama Creek	Sonoma	11463900	1961-1981	0.021	1.410	2.322	156.273
310	Burney Creek	Shasta	11360500	1911-1970	0.368	21.468	1.848	107.792
311	Hat Creek	Shasta	11358700	1988-2011	0.125	35.239	0.134	37.814
312	Pit River	Shasta	11362500	1954-2011	4.870	480.173	14.513	1430.791
313	Hat Creek	Shasta	11359500	1921-1922	13.026	1596.745	3.746	459.209

ID	River Name	County	USGS ID	Time Range	Minimum Monthly Flow (m^3/s)	Minimum Monthly Potential (kW)	Annual Average Flow (m^3/s)	Annual Average Potential (kW)
314	Pit River	Shasta	11362000	1922-1927	48.705	4492.896	58.828	5426.739
315	Fall River	Shasta	11353700	1958-1967	11.185	68.478	13.018	79.702
316	Bear Creek	Shasta	11353500	1921-1926	0.007	1.137	0.728	116.988
317	Warm Springs Creek	Sonoma	11464860	1973-1983	0.016	4.233	0.839	224.048
318	Dry Creek	Sonoma	11464500	1941-1980	0.040	2.667	4.529	304.694
319	Russian River	Mendocino	11463000	1951-2011	5.862	201.131	26.888	922.624
320	Russian River	Mendocino	11462500	2010-2011	3.993	61.285	22.713	348.633
321	Russian River	Mendocino	11462080	2009-2011	4.021	150.927	16.960	636.596
322	Russian River	Mendocino	11461000	1911-2011	0.017	0.508	5.033	147.969
323	East Fork Russian River	Mendocino	11462000	1959-2011	5.975	1151.659	9.033	1741.027
324	East Fork Russian River	Mendocino	11461500	1941-2011	3.681	466.631	9.028	1144.377
325	South Fork Trinity River	Humboldt	11529000	1950-1982	2.945	157.986	51.002	2736.068
326	Red Cap Creek	Humboldt	11523030	1958-1965	0.538	92.839	5.077	876.086
327	Russian River	Sonoma	11463500	1910-1913	0.368	11.330	22.816	702.221
328	Dry Creek	Sonoma	11465000	1983-2011	2.605	67.148	5.963	153.700
329	Big Sulphur Creek	Sonoma	11463170	1980-2011	0.034	9.634	1.233	349.519
330	Big Sulphur Creek	Sonoma	11463200	1957-1972	0.178	31.321	5.689	998.813
331	Kelsey Creek	Lake	11449500	1946-2011	0.096	7.638	2.080	165.036
332	Highland Creek	Lake	11449000	1954-1962	0.002	0.235	0.582	69.178
333	Highland Creek	Lake	11449010	1965-1977	0.002	0.209	0.665	81.926
334	North Fork Cottonwood Creek	Shasta	11375700	1956-1980	0.283	19.829	4.757	333.136
335	North Fork Cottonwood Creek	Shasta	11375500	1907-1913	0.156	21.083	3.968	537.184
336	Clear Creek	Shasta	11371500	1911-1913	0.963	0.339	6.128	2.156
337	Grass Valley Creek	Trinity	11525600	1975-2005	0.340	23.282	1.360	93.194
338	Clear Creek	Shasta	11371000	1950-1993	0.425	46.178	5.898	641.166

ID	River Name	County	USGS ID	Time Range	Minimum Monthly		Annual Average	
					Flow (m^3/s)	Potential (kW)	Flow (m^3/s)	Potential (kW)
339	Little Truckee River	Nevada	10344400	1968-2011	1.246	81.530	4.606	301.423
340	Independence Creek	Sierra	10343000	1968-2011	0.311	166.891	0.625	334.698
341	Little Truckee River	Sierra	10343200	1993-1995	0.453	43.428	1.266	121.349
342	Little Truckee River	Sierra	10342000	1947-1972	0.110	5.772	2.526	132.011
343	Dog Creek	Sierra	10347300	1956-1961	0.005	2.082	0.130	53.266
344	Long Valley Creek	Lassen	10354000	1989-1994	0.012	0.703	0.220	13.026
345	Little Last Chance Creek	Plumas	11391400	1958-1980	0.068	16.493	0.756	183.588
346	Pit River	Modoc	11348200	1965-1970	1.501	15.358	4.812	49.242
347	Elk Creek	Siskiyou	11522200	1956-1964	0.991	231.887	6.470	1513.894
348	Klamath River	Siskiyou	11520500	1912-2011	39.077	956.480	108.039	2644.421
349	Mill Creek	Del Norte	11532620	1974-1981	0.207	10.441	3.532	178.399
350	Rowdy Creek	Del Norte	11532700	1957-1962	0.116	6.178	5.204	276.892
351	Silver Fork American River	El Dorado	11438000	1924-1944	1.897	755.404	5.859	2332.784
352	Upper Truckee River	El Dorado	10336580	1990-2011	0.088	28.815	1.018	334.029
353	Grass Lake Creek	El Dorado	10336593	1971-1974	0.048	27.906	0.298	172.705
354	Upper Truckee River	El Dorado	10336600	1960-1986	0.269	16.108	1.903	113.953
355	Taylor Creek	El Dorado	10336626	1968-1992	0.204	31.526	1.233	190.726
356	Rubicon River	El Dorado	11427960	1991-1998	0.093	47.435	0.172	87.262
357	Rubicon River	El Dorado	11428000	1910-1986	0.153	19.837	1.470	190.745
358	Meeks Creek	El Dorado	10336640	1971-1975	0.006	0.246	0.461	20.024
359	General Creek	El Dorado	10336645	1980-2011	0.034	2.571	0.469	35.472
360	Madden Creek	Placer	10336655	1971-1973	0.022	25.374	0.132	153.735
361	Madden Creek	Placer	10336658	1971-1973	0.003	3.048	0.132	129.353
362	Blackwood Creek	Placer	10336660	1960-2011	0.074	5.378	1.021	74.578

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363	Ward Creek	Placer	10336676	1972-2011	0.042	11.805	0.733	203.586
364	Ward Creek	Placer	10336670	1972-1976	0.017	7.343	0.249	107.755
365	Ward Creek	Placer	10336675	1991-2011	0.015	2.638	0.791	136.386
366	Ward Creek	Placer	10336674	1991-2011	0.015	1.820	0.446	53.081
367	Truckee River	Placer	10337500	1909-2011	4.502	88.727	6.425	126.618
368	Dollar Creek	Placer	10336684	1972-1974	0.001	0.577	0.031	15.858
369	Truckee River	Placer	10338001	1944-2011	4.899	377.908	8.997	694.087
370	Truckee River	Placer	10338000	1944-2011	4.899	313.360	8.755	560.051
371	Donner Creek	Nevada	10338700	1993-2011	0.249	16.656	2.144	143.285
372	Donner Creek	Nevada	10338500	1929-2011	0.204	10.030	0.993	48.852
373	Martis Creek	Nevada	10339401	1942-1980	0.125	17.980	1.070	154.456
374	Truckee River	Nevada	10339419	1993-1998	3.370	429.844	16.653	2124.249
375	Gray Creek	Nevada	10345490	2001-2007	0.269	115.786	0.699	300.742
376	Prosser Creek	Nevada	10340500	1963-2011	1.019	199.013	2.514	490.820
377	Bronco Creek	Nevada	10345700	1993-1998	0.204	124.351	0.445	271.261
378	Truckee River	Nevada	10344505	2002-2011	7.844	920.641	15.220	1786.390
379	Truckee River	Nevada	10344501	1911-1980	2.492	351.715	5.209	735.219
380	Little Truckee River	Nevada	10344500	1969-2011	2.464	353.655	4.880	700.609
381	Truckee River	Nevada	10346001	1909-1980	11.157	1242.584	21.331	2375.757
382	Sagehen Creek	Nevada	10343500	1953-2011	0.074	6.478	0.338	29.784
383	Bidwell Creek	Modoc	10360900	1960-1982	0.133	49.701	0.610	227.719
384	Camp Creek	El Dorado	11333000	1954-2004	0.150	36.710	1.670	408.614
385	North Fork Cosumnes River	El Dorado	11330000	1948-1953	0.173	69.039	2.632	1052.150
386	Sly Park Creek	El Dorado	11332500	1946-1955	0.031	13.995	0.684	307.329
387	Garcia River	Mendocino	11467600	1962-1983	0.425	10.967	9.359	241.655
388	Navarro River	Mendocino	11468000	1950-2011	0.266	1.173	14.231	62.700
389	Big River	Mendocino	11468092	2001-2007	0.102	5.956	7.355	429.742
390	Noyo River	Mendocino	11468500	1951-2011	0.176	1.379	5.912	46.452
391	Sacramento River	Tehama	11377200	1967-1970	228.234	5924.464	416.258	10805.163

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392	South Fork Cottonwood Creek	Tehama	11375820	1962-1978	0.057	1.633	6.053	174.570
393	South Fork Cottonwood Creek	Tehama	11375870	1976-1986	0.156	4.496	9.195	265.450
394	South Fork Cottonwood Creek	Tehama	11375900	1981-1985	0.181	4.703	13.458	349.208
395	Cottonwood Creek	Shasta	11376000	1940-2011	2.067	73.098	25.223	891.918
396	Cottonwood Creek	Shasta	11375810	1971-1986	0.566	20.807	14.547	534.452
397	Cow Creek	Shasta	11374000	1949-2011	1.076	20.152	19.442	364.112
398	Clear Creek	Shasta	11372000	1964-2011	1.869	204.067	5.062	552.774
399	Sacramento River	Shasta	11370500	1963-2011	178.396	23604.004	284.867	37691.380
400	South Fork Pit River	Modoc	11345500	1928-2011	0.765	96.175	2.294	288.520
401	South Fork Pit River	Modoc	11344500	1929-1931	0.212	14.950	1.095	77.074
402	Pudding Creek	Mendocino	11468540	1963-1971	0.003	0.226	0.589	39.097
403	Middle Fork Ten Mile River	Mendocino	11468600	1964-1973	0.105	6.273	2.234	133.750
404	Dunn Creek	Mendocino	11468850	1961-1964	0.010	4.064	0.083	34.990
405	South Fork Eel River	Mendocino	11475800	1965-2011	0.765	22.055	22.329	644.103
406	Chamise Creek	Humboldt	11474700	1972-1976	0.022	5.184	2.116	503.224
407	East Branch South Fork Eel River	Humboldt	11475940	1966-1972	0.147	7.832	7.990	425.003
408	Ti Creek	Siskiyou	11522260	1960-1964	0.221	137.551	0.710	442.377
409	South Fork Gualala River	Sonoma	11467295	2000-2006	0.020	0.391	4.471	88.184
410	East Fork Scott River	Siskiyou	11517950	1970-1973	0.021	3.245	1.082	165.383
411	East Fork Scott River	Siskiyou	11517900	1970-1973	0.071	24.185	0.621	212.203
412	Shasta River	Siskiyou	11516750	1962-1967	0.218	9.533	2.069	90.447
413	Shasta River	Siskiyou	11517000	1911-2011	1.019	23.883	3.852	90.242
414	Shasta River	Siskiyou	11517500	1933-2011	1.014	77.496	5.200	397.262
415	Cottonwood Creek	Siskiyou	11516600	1964-1971	0.037	3.588	1.402	136.680

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416	American River	Sacramento	11446500	1955-2011	53.519	2781.873	104.033	5407.586
417	South Fork Gualala River	Sonoma	11467500	1950-1971	0.204	3.967	12.331	239.919
418	Wheatfield Fork Gualala River	Sonoma	11467485	2000-2007	0.040	1.387	8.521	298.019
419	South Fork Gualala River	Sonoma	11467510	1991-2011	0.054	0.847	10.623	167.216
420	North Fork Gualala River	Mendocino	11467553	2000-2006	0.176	6.950	6.317	250.059
421	Rancheria Creek	Mendocino	11467800	1959-1968	0.082	4.943	4.136	248.981
422	South Fork Big River	Mendocino	11468070	1960-2001	0.025	2.148	1.579	134.521
423	Willits Creek	Mendocino	11472160	2003-2011	0.001	0.283	0.225	44.973
424	Outlet Creek	Mendocino	11472200	1956-1994	0.040	2.588	11.355	741.344
425	Goforth Creek	Mendocino	11473980	1965-1968	0.007	5.306	0.223	181.378
426	Tenmile Creek	Mendocino	11475700	1957-1974	0.034	1.820	4.825	258.429
427	Mill Creek	Mendocino	11473530	1961-1965	0.150	11.544	1.272	97.834
428	Elk Creek	Mendocino	11473800	1964-1973	0.059	3.453	5.534	321.357
429	Williams Creek	Mendocino	11473100	1961-1969	0.013	1.015	2.380	185.456
430	Short Creek	Mendocino	11473600	1958-1969	0.002	0.229	0.679	78.532
431	Camp Creek	El Dorado	11331500	1948-1956	0.102	50.554	1.606	796.203
432	Plum Creek	El Dorado	11440500	1922-1939	0.006	2.968	0.224	117.616
433	Alder Creek	El Dorado	11439999	1970-1981	0.024	18.798	0.801	618.629
434	South Fork American River	El Dorado	11439500	1922-2011	0.793	145.993	8.933	1644.769
435	South Fork Silver Creek	El Dorado	11441500	1984-2011	0.153	49.203	0.376	120.840
436	Silver Creek	El Dorado	11441900	1960-2011	0.708	344.746	2.544	1239.003
437	Silver Creek	El Dorado	11441800	1987-2011	0.252	131.024	0.336	174.549
438	Silver Creek	El Dorado	11441000	1924-1960	0.178	109.655	5.897	3624.992
439	South Fork RubiconRiver	El Dorado	11430000	1962-2011	0.269	126.996	0.600	283.269
440	Rubicon River	Placer	11431000	1910-1964	0.595	165.987	16.090	4491.249
441	South Fork Rubicon River	El Dorado	11430500	1965-1962	0.198	85.381	3.409	1468.225
442	Gerle Creek	El Dorado	11429500	1971-2011	0.252	85.819	0.267	90.758

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443	Rubicon River	Placer	11428800	1965-2011	0.481	278.077	1.070	618.249
444	Middle Fork American River	Placer	11427500	1964-2011	0.252	186.471	0.592	438.038
445	Fordyce Creek	Nevada	11414100	1966-2011	1.019	436.238	3.636	1556.121

Works Cited

Atkins, William Arthur. "Hydroelectic Power." *The Reference Shelf: US National Debate Topic 2008-2009: Alternative Energy* 80.3 (2008): 149-52. Print.

California Energy Commission. "California Hydroelectric Power Plants." 2012.Web. <http://energyalmanac.ca.gov/powerplants/Statewide_PP_8.5X11_hydro.pdf>.

Cole, David B. "Niagara Falls." *Encyclopedia Americana.* 2002nd ed. Danbury, Connecticut: Grolier Educational, 2002. 297-299. Print.

Cyr, Jean-François, Mathieu Landry, and Yves Gagnon. "Methodology for the Large-Scale Assessment of Small Hydroelectric Potential: Application to the Province of New Brunswick (Canada)." *Renewable Energy: An International Journal* 36.11 (2011): 2940-50. Print.

Gesch, D., et al. "The National Elevation Dataset: Photogrammetric Engineering and Remote Sensing." 68.1 (2002): 5. Print.

Gesch, D. B. "The National Elevation Dataset." *Digital Elevation Model Technologies and Applications: The DEM Users Manual.* Ed. D. Maune. 2nd ed. Bethesda, Maryland: American Society for Photogrammetry and Remote Sensing, 200799. 118. Print.

Hall, Douglas G., et al. *Feasibility of the WAter Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants*. DOE-ID-11263 Vol. Idaho National Laboratory, 2006. Print.

Hirji, Rafik, and Richard Davis. *Environmental Flows in Water Resources Policies, Plans, and Projects [Electronic Resource] : Findings and Recommendations / Rafik Hirji and Richard Davis*. Washington, D.C. : World Bank, 2009, 2009. Print.

Kane, Mike. *California Small Hydropower and Ocean Wave Energy Resources*. CEC-500-2005-074 Vol. Sacramento, California: Califronia Energy Comission, 2005. Print.

Kosnik, Lea. "The Potential for Small Scale Hydropower Development in the US." *Energy Policy* 38.10 (2010): 5512-9. Print.

Maxwell, Steve. "Homestead Hydropower." *The Reference Shelf: US National Debate Topic 2008-2009: Alternative Energy* 80.3 (2008): 157-9. Print.

Mount, Jeffery F. *Cailfornia Rivers and Streams - the Conflict between Fluvial Process and Land use*. Berkeley, California: University of California Press, Berkeley, 1995. Print.

Niagara Falls [Electronic Resource (Video)] / Public Broadcasting Service (U.S.). Anonymous New York, N.Y. : Films Media Group, 2011], c2006, 2006.

Papadakis, Maria. "MICROHYDRO POWER." *Green Energy*. Ed. Dustin Mulvaney and Paul Robbins. Thousand Oaks, CA: SAGE, 2010. 292-95. *SAGE Reference Online*. Web. 2 Feb. 2012.

Punys, Petras, et al. "Tools for Small Hydropower Plant Resource Planning and Development: A Review of Technology and Applications." *Energies (19961073)* 4.9 (2011): 1258-77. Print.

Rojanamon, Pannathat. "Application of Geographical Information System to Site Selection of Small Run-of-River Hydropower Project by Considering engineering/economic/environmental Criteria and Social Impact." *Renewable & sustainable energy reviews* 13.9 (2009): 2336-48. Print.

State of California. *Public Resource Code*.Print.

U.S. Bureau of Reclamation, Mid-Pacific Region, MPGIS Service Center. "Linear Hydrologic Features." 2008.Web. <http://atlas.ca.gov/download.html#/casil/inlandWaters>.

U.S. Department of Commerce, U.S. Census Bureau, Geography Division. "TIGER/Line Shapefile, 2007, California Local Roads." 2007.Web. <http://www.census.gov/geo/www/tiger>.

U.S. Geological Survey in cooperation with U.S. Environmental Protection Agency. "National Hydrography Dataset." 1999.Web. <http://nhd.usgs.gov/index.html>.

USGS National Atlas and the Interagency Wild and Scenic River Coordinating Council. "US Wild and Scenic Rivers." 2009.Web. <http://www.rivers.gov/rivers/mapping-gis.php>.

USGS Water Resources. "USGS Surface-Water Data for California." 2012.Web. <http://waterdata.usgs.gov/ca/nwis/sw>.

Weather Channel, The. "Monthly Averages." 2012.Web. <www.weather.com>.