A Pre-Feasibility Study for a Micro-Hydropower Facility on Willow Creek at Creede, Colorado

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PREFACE

This report was prepared by Prof. Kenneth M. Strzepek of the Civil, Environmental, and Architectural Engineering at the University of Colorado at Boulder with input from Christy Perez, Senior, Electrical and Computer Engineering and Darcy Sterrett, Senior, Civil, Environmental, and Architectural Engineering at the University of Colorado at Boulder. Ms. Perez and Ms. Sterrett, conducted their efforts as part of an independent study activity supervised by Prof. Strzepek.

Partial funds for this project were provided by the Community Development Office of Colorado State University and Civil, Environmental, and Architectural Engineering at the University of Colorado. A presentation of the preliminary results and a field visit to Creede took place in May of 1995. The town leaders of Creede were wonderful hosts are thanked for their hospitality.

Finally, the authors would like to thank Dr. Richard Hallock, Community Development Office of Colorado State University and Prof. Stein Sture, Chair, Civil, Environmental, and Architectural Engineering at the University of Colorado for their support of this project.

This project is a wonderful example of how Colorado Higher Education can make a direct contribution to the needs of communities in the state and for all involved particularly the students to benefit.

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I. Introduction

Hydropower is the conversion of kinetic energy in flowing water into mechanical energy of a spinning turbine and then into electrical energy as the turbine spins a electrical generator. There are two key concepts that need to be understood in designing a potential hydropower installation, *power* and *energy*. Power is the time rate at which work is done or energy is transmitted, usually expressed mechanically as horsepower and electrically as kilowatts. Energy is power exerted over time, electrical energy production or usage is measured in Kilowatt-hours.

For example a 100 watt light bulb, needs 100 watts of power to produce light, if the bulb is continuously on for 10 hours it has consumed 100 watts time 10 hours for a total of 1000 watt-hours of electrical energy or 1 kilowatt-hour (Kilo means 1000).

Water in a river or lake in the highlands, Lake A in Figure 1, has potential energy related to its elevation, 1500 feet. As water flows to a lower elevation, Lake B 500 feet, it loses 1000 feet of potential energy. The lost potential energy is converted into kinetic energy of the flowing water. This

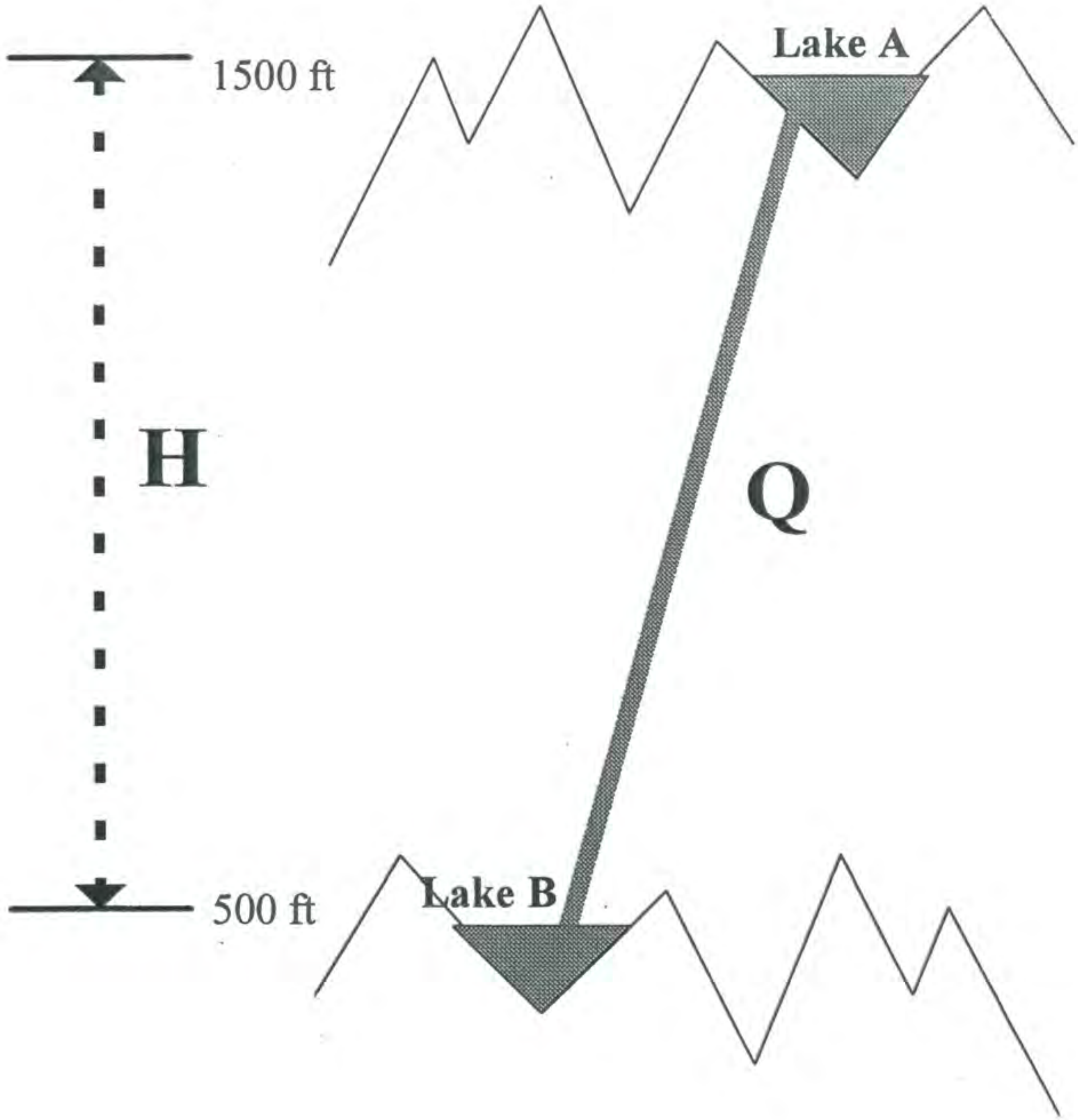

Figure 1 Basic Elements of Hydropower Engineering

transformation of potential energy to kinetic energy is exactly equal to the difference in elevation of the water. Thus water flowing from Lake A at 1500 feet to Lake B at 500 feet loses 1000 feet in potential energy, but the flowing water as it enters Lake B has a kinetic energy of 1000 feet. This kinetic energy or loss of potential energy is refereed to as Head, and denoted *H*, in this report. The kinetic energy or Head of the flowing water can be converted to mechanical energy of a spinning turbine and then into electrical energy as the turbine spins a electrical generator.

The electrical power that can be generated by a hydropower plant at the entrance to Lake B is related to the Head and amount of the flowing water. The amount of water flowing is called the "discharge" and is denoted *Q*, in this report, and is measured in unit of cubic feet per second (cfs). The electrical power, denoted *P*, in this report, and measured in kilowatt (kW), that can be generated by a hydropower plant is determined by the following equation, where e is the efficiency of energy conversion in the turbine and generator system.

$$P = \frac{Q * H * e}{11.8}$$

You can see from the equation above that you can produce large amounts of hydropower if you have a large or high head and large Q. You can produce significant hydropower with either a very high head and small flow or very large flow and small or low head.

Hydropower plants are classified by their power generation capacity. Over 20,000 kilowatts (20 megawatts) is considered large scale and less than 20 megawatts is considered small-scale hydropower. Small-scale hydropower is further broken down into the three classes listed below.

Small Scale Hydropower Classification

Hydropower Range	Classification
1 to 20 megawatts	Small-Scale Hydro
100 to 1000 kilowatts	Mini Hydro
less than 100 kilowatts	Micro Hydro

In hydropower design, head, H, is something that is fixed based on the topographic features of the region. However, discharge varies over time. The variation of flow over time is called a hydrograph. In the Rocky Mountain region, a typical hydrograph for a mountain stream is dominated by a large flow in the late spring, early summer due to snowmelt and then low flows the rest of the year. Figure 2 is a hydrograph of the flow in the East River at Almont, Colorado, showing the typical large spring runoff and low flow the rest of the year. The variation of Q means that the hydropower potential on a mountain stream will vary greatly. This variation of flow is an important aspect in the design of a micro-hydropower plant facility.

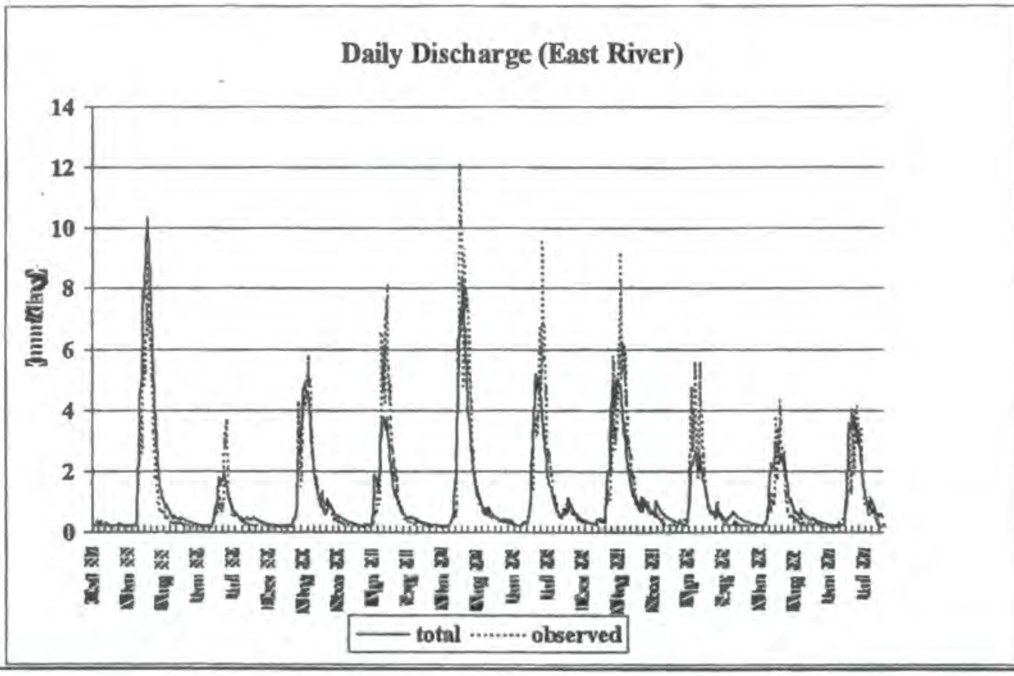

Figure 2 East River Daily runoff hydrograph .

In addition to *Q* and *H*, the power equation contained the turbine efficiency, *e*. With modern engineering technology, turbines can be very efficient. However, the big problem is that turbines are only very efficient for a very specific discharge. Figure 3 below is a graph of the variation of the efficiency of a typical turbine plotted against discharge. One can see that for fixed-blade turbine (those found in micro-hydro facilities) the efficiency drops rapidly when the discharge is less than or greater than the design flow.

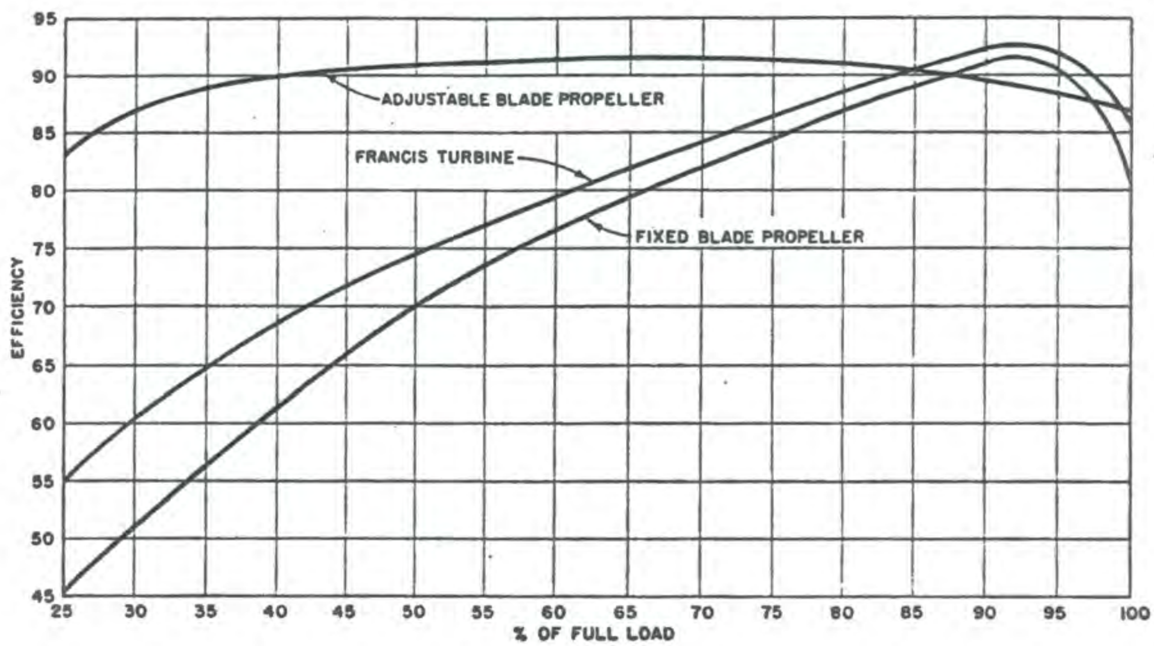

Figure 3. Turbine Efficiency Graph

Electrical energy generation which is the continuos accumulation of the electrical power production over time, is the product of the a hydropower facility that can be sold and is the commodity that consumers demand. Because of the high capital cost of hydropower equipment, the proper design and selection of power capacity is key to the financial viability of a micro-hydropower facility. The cost structure of turbine/generator system usually precludes one from harnessing the high power potential of the spring runoff. The high spring runoffs from mountains streams, seen in Figure 2 account for most of the annual flow of in the stream. The key to micro-hydro financial viability is determining where the non-peak runoff is such that it can provide sufficient flow over the year to produce enough energy to cover the costs of the installation and maintenance. The following section will discuss the technical, hydrology and electrical, issues of hydropower development of Willow Creek at Creede, CO.

II. Technology of Micro-hydropower on Willow Creek

The Hydrologic System

In order to select an appropriate turbine, an analysis on the flow data of Willow Creek was performed. A 30 year record of the normal monthly mean discharge based on daily readings was obtained from the United States Geological Survey. This monthly data was used to calculate the total annual discharge, and also the average, standard deviation, and skewness of the discharge for each month. The total annual discharge is the sum of the monthly discharge for each month of the year, while the average is the expected value of monthly discharge for that month. The standard deviation is a measure of the certainty of being near the average, and the skewness is a measure of the asymmetry of the shape of the distribution of the monthly flow data.

The data is listed in Table 1 and the Total Annual Discharge graph is plotted in Figure 4. This graph shows that the average total annual discharge is about 22 cubic feet per second. Also, the graph shows a peak of about 40 cfs and a minimum of near 8 cfs which indicates that the discharge of Willow Creek does vary in substantially in years of droughts or floods. However, the Average Monthly Discharge bar chart, known as a Hydrograph, Figure 5, shows that throughout each year the flow fluctuates greatly from month to

WILLOW CREEK AT CREEDE, CO
Normal monthly mean discharge (All days)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	TOTAL
1952	6.61	5.59	4.39	3.74	3.54	3.47	25.30	109.50	141.40	35.40	22.30	16.60	31.49
1953	11.40	5.56	5.05	4.56	4.05	5.58	12.60	40.00	60.50	25.00	19.30	7.82	16.79
1954	6.54	5.35	3.76	3.26	3.85	3.15	21.80	40.90	19.60	21.60	20.50	12.40	13.56
1955	9.73	6.11	4.27	3.44	2.90	2.80	8.20	46.10	45.50	14.80	21.20	7.59	14.39
1956	5.62	4.52	3.56	3.13	2.87	3.30	12.80	53.90	33.60	17.60	6.27	4.73	12.66
1957	4.99	4.94	3.98	3.82	3.84	4.02	12.50	49.00	216.20	81.40	45.00	20.70	37.53
1958	11.70	10.40	6.95	5.39	4.66	4.32	14.60	165.70	109.50	24.40	16.50	12.20	32.19
1959	7.77	6.10	4.73	3.75	3.50	3.56	9.85	40.80	51.40	15.10	19.30	10.60	14.71
1960	18.50	16.80	7.69	4.61	3.53	6.75	31.80	80.50	103.20	27.60	13.60	9.02	26.97
1961	7.50	5.56	4.37	3.00	3.90	3.52	10.20	50.50	40.00	14.50	17.50	17.90	14.87
1962	18.30	11.60	7.45	6.50	5.80	4.29	42.20	132.00	83.40	31.60	14.00	10.00	30.60
1963	8.70	5.91	4.82	3.40	3.20	5.57	17.70	29.60	13.20	9.11	11.00	11.70	10.33
1964	7.63	4.71	3.41	3.00	2.80	3.85	5.20	57.00	36.40	23.20	31.90	12.60	15.98
1965	8.36	7.03	5.50	5.00	5.00	5.06	25.70	112.30	146.10	64.60	33.90	17.60	36.35
1966	16.70	11.60	9.00	7.83	6.00	6.94	17.70	72.20	38.40	24.90	30.50	9.98	20.98
1967	7.92	5.58	4.53	4.15	4.11	8.53	10.40	31.20	31.90	18.10	18.80	19.80	13.75
1968	9.35	5.37	3.95	3.84	3.79	4.45	7.13	70.10	98.90	30.70	41.30	15.40	24.52
1969	9.16	6.69	6.27	4.63	3.36	3.55	13.50	67.40	41.40	33.40	23.10	21.10	19.46
1970	23.70	16.30	9.94	7.02	6.45	5.27	7.68	123.50	78.00	36.90	28.10	65.60	34.04
1971	30.10	9.56	7.40	7.53	8.05	8.47	12.50	40.30	45.40	18.90	14.70	11.80	17.89
1972	11.30	9.74	7.05	6.87	5.93	14.10	33.30	72.30	57.50	16.80	11.20	11.10	21.43
1973	18.70	8.33	6.79	4.96	4.85	5.28	8.18	87.90	147.90	61.40	21.00	12.90	32.35
1974	3.31	5.37	6.06	4.43	4.16	4.97	6.37	46.00	23.60	15.10	9.42	4.84	11.14
1975	4.31	4.04	3.61	3.38	3.14	3.09	6.50	70.30	138.40	62.20	21.00	13.80	27.81
1976	7.02	5.40	4.25	3.43	3.89	4.38	13.20	66.50	68.80	23.20	20.40	13.40	19.49
1977	11.30	5.81	3.04	3.00	2.73	3.07	10.30	18.30	10.60	7.80	8.24	7.99	7.68
1978	5.60	4.18	3.48	2.85	2.69	3.61	9.35	38.80	82.90	24.30	10.10	6.79	16.22
1979	5.91	6.47	9.50	3.77	4.19	5.06	23.00	116.90	195.00	74.20	24.10	12.30	40.03
1980	7.36	5.58	4.91	4.86	5.16	4.93	12.40	60.50	128.00	28.50	14.10	11.90	24.02
1981	7.17	5.51	5.30	2.43	2.85	2.72	11.80	18.80	27.50	21.40	21.70	22.80	12.50
1982	15.90	9.47	5.75	4.99	3.90	3.45	10.50	52.40	93.80	33.80	43.20	49.60	27.23
AVERAGE	10.59	7.26	5.51	4.41	4.15	4.87	14.98	66.49	77.68	30.24	21.07	15.57	21.90
STAN. DEV.	6.10	3.25	1.87	1.44	1.26	2.27	8.84	35.20	53.64	18.90	9.98	12.30	9.04
SKEWNESS	1.57	1.73	0.86	1.02	1.29	2.54	1.54	1.08	0.93	1.46	0.92	3.06	0.42

Table 1. Willow Creek Flows

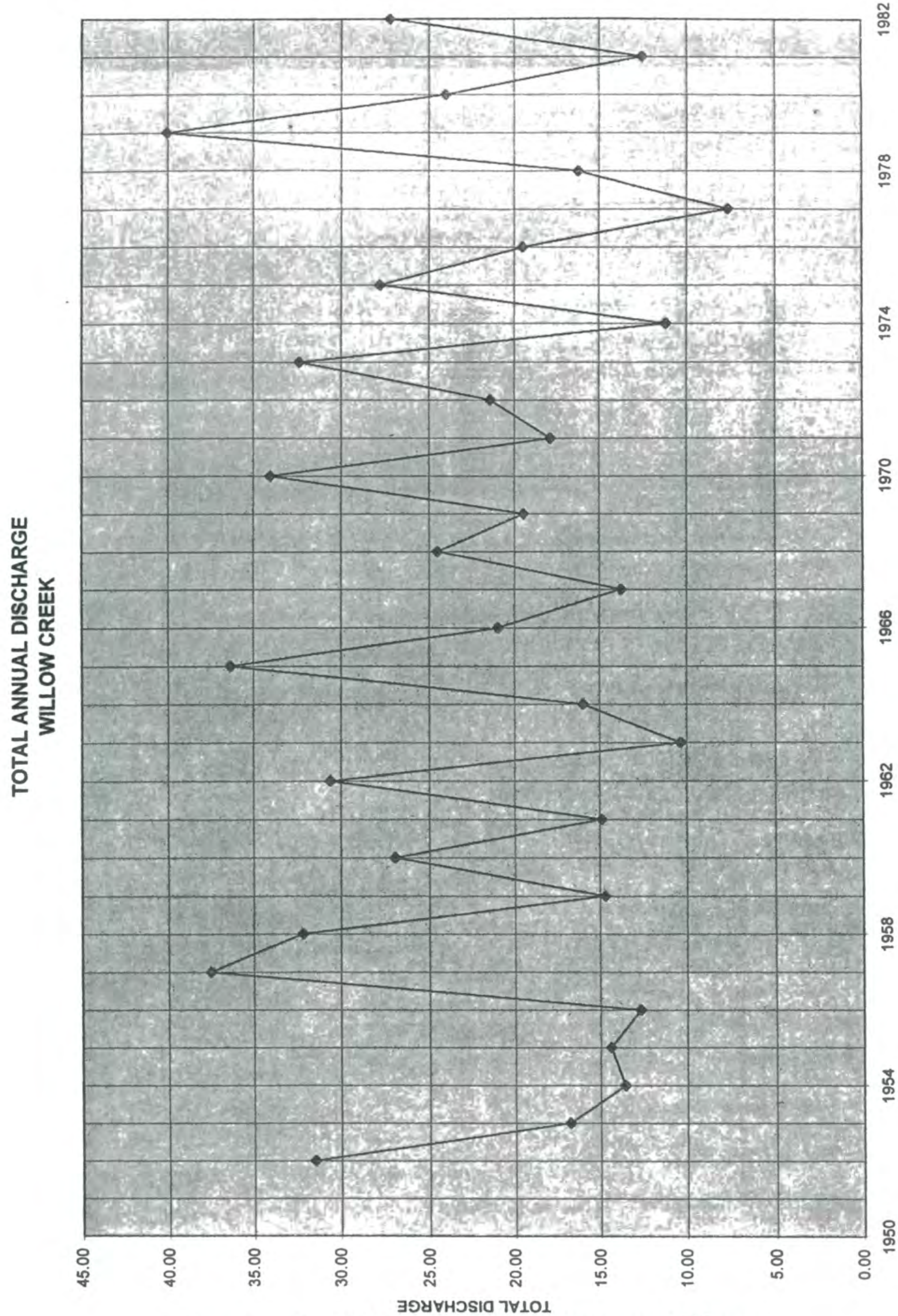

Figure 4. Willow Creek Annual Flows

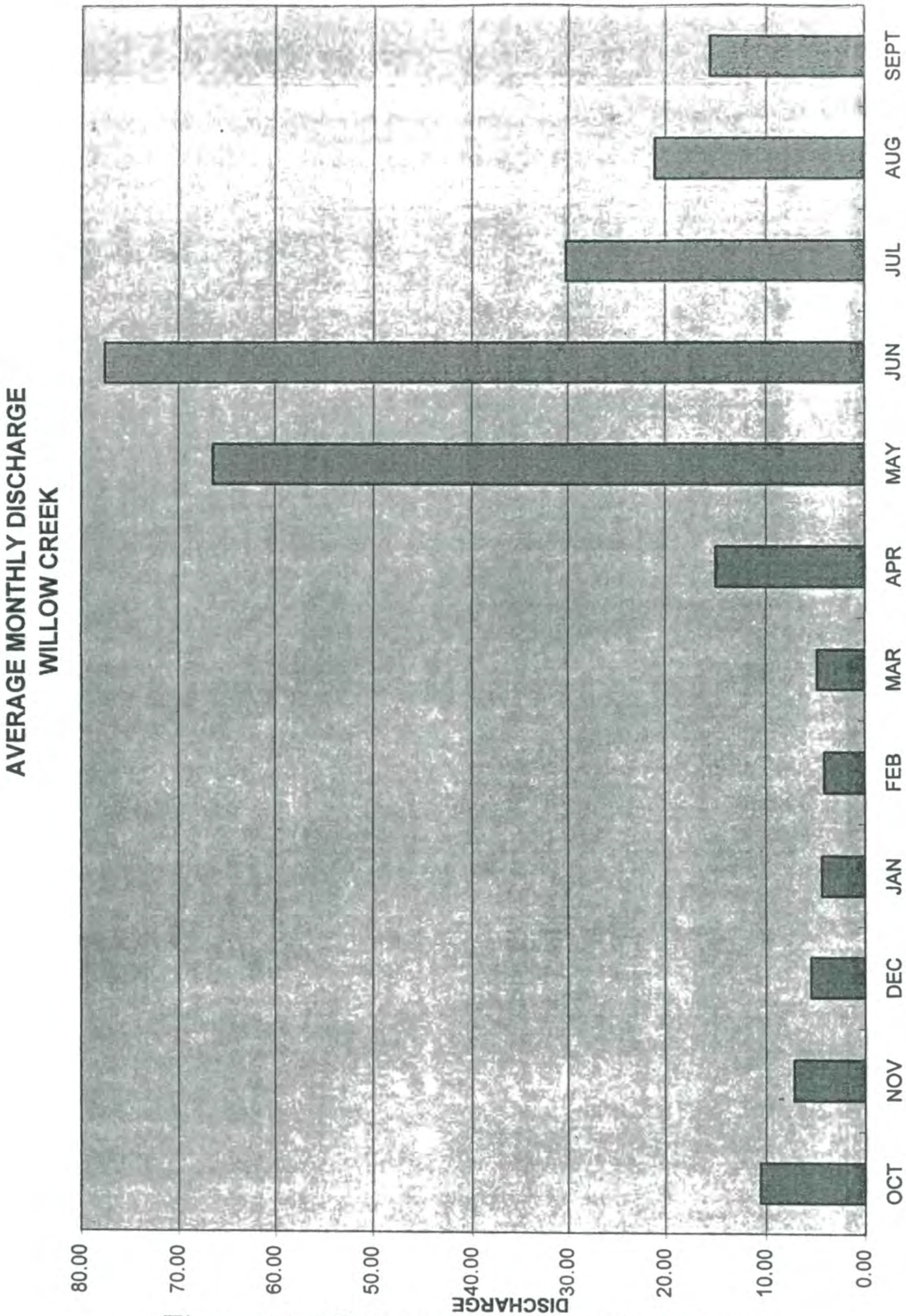

Figure 5. Willow Creek Monthly Flows

month with a minimum of 4 cfs and a maximum of 78 cfs. The monthly variance of the discharge is important when selecting a turbine, as each type of turbine can operate only for certain ranges of flows. Table 2 shows the maximum and minimum energy and power that can be generated at head values ranging from 10 feet to 50 feet for the maximum and minimum flows observed in Willow Creek, see Table 1. This table shows that raising the head for a given flow has the same effect upon power generation as higher flow rates for a given head. A higher head can be obtained by placing the turbine further downstream, by building a storage structure that will raise the water level higher before it enters the turbine, or by piping the water from upstream maintaining a higher elevation.

This leads to the question of what value of flow should be used for the design value of the turbine. The Flow Duration Curve is used to determine what level of flow can be relied upon for different percentages of the time. Figure 6 is flow duration Curve for Willow Creek at Creede. The horizontal axis is the percent of time that the corresponding flow value on the vertical axis will be exceeded. For example, the 10% exceedance value is 60 cfs, which means that 10% of the time the flow will be 60 cfs or greater, and likewise 90% of the time the flow can be expected to be 60 cfs or less. The value used for design in micro-hydropower design is the 30% exceedance value, which is

TABLE OF POWER AND ENERGY
FOR VARIOUS HEAD VALUES

maximum flow = 216.2 cfs
minimum flow = 2.43 cfs

HEAD	POWER (kW)		ENERGY (kWh)	
(ft)	MAX	MIN	MAX	MIN
10	183.2203	2.059322	1605010	18039.66
12	219.8644	2.471186	1926012	21647.59
14	256.5085	2.883051	2247014	25255.53
16	293.1525	3.294915	2568016	28863.46
18	329.7966	3.70678	2889018	32471.39
20	366.4407	4.118644	3210020	36079.32
22	403.0847	4.530508	3531022	39687.25
24	439.7288	4.942373	3852024	43295.19
26	476.3729	5.354237	4173026	46903.12
28	513.0169	5.766102	4494028	50511.05
30	549.661	6.177966	4815031	54118.98
32	586.3051	6.589831	5136033	57726.92
34	622.9492	7.001695	5457035	61334.85
36	659.5932	7.413559	5778037	64942.78
38	696.2373	7.825424	6099039	68550.71
40	732.8814	8.237288	6420041	72158.64
42	769.5254	8.649153	6741043	75766.58
44	806.1695	9.061017	7062045	79374.51
46	842.8136	9.472881	7383047	82982.44
48	879.4576	9.884746	7704049	86590.37
50	916.1017	10.29661	8025051	90198.31

Table 2. Willow Creek Hydropower Potential

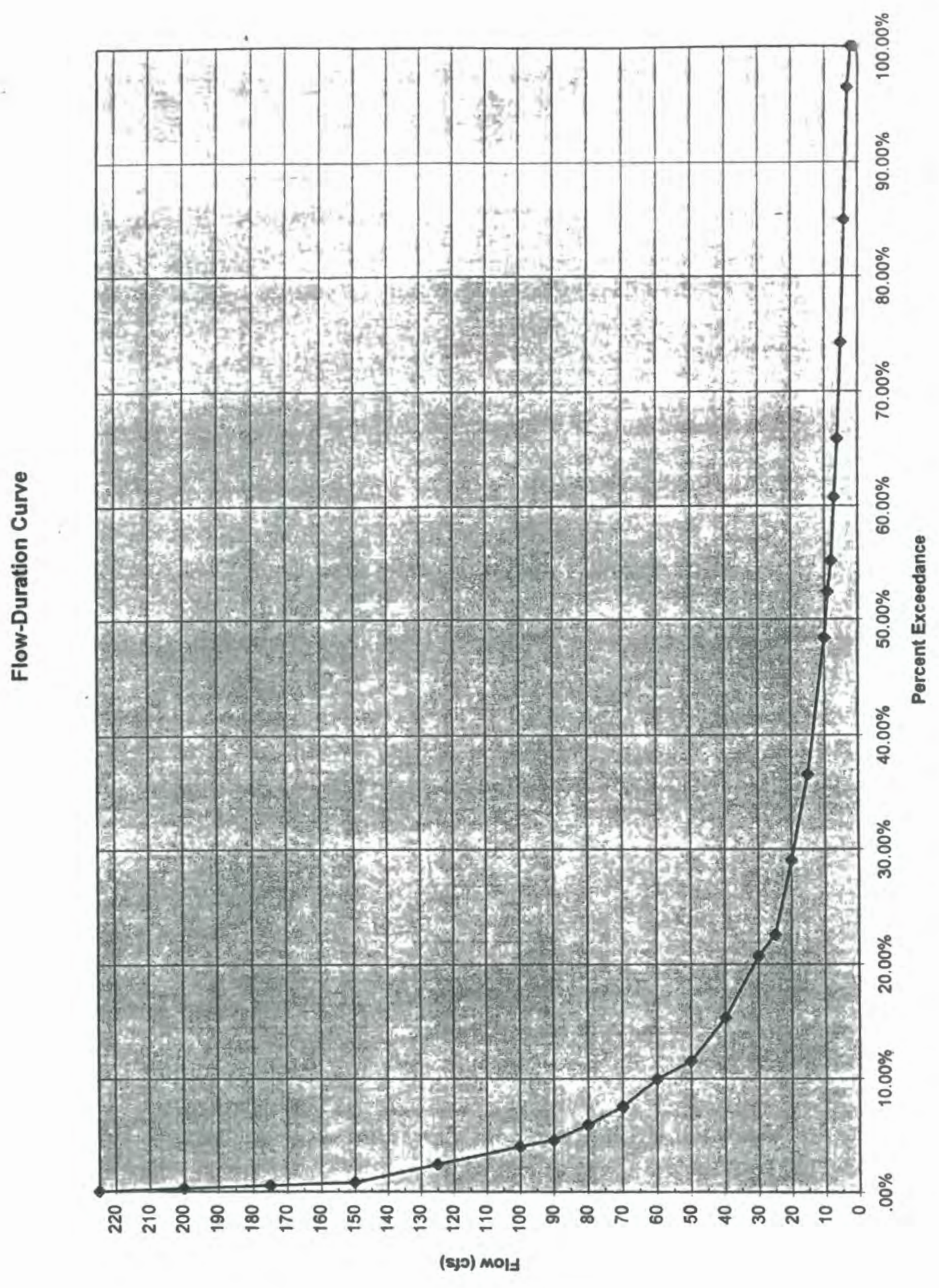

Figure 6. Willow Creek Flow-Duration Curve

approximately 20 cfs for Willow Creek. If a turbine is selected that will use only the values of flow that can be relied upon 30% of the time, the energy that could be produced from the flow level that is present the other 60% of the time is sacrificed. These upper levels of flow are very expensive to obtain because they are only present for a small percentage of the time, so it is overall more efficient and practical to generate power within the lower range of flows.

With a design flow of 20 cfs and a design head of 20 feet (available from existing structure at the upstream-end of Flood Sluice). Willow Creek has a potential design capacity without considering turbine efficiency of 35 kilowatts. This capacity can be maintained for approximately 5000 hours to produce 175,000 kilowatt-hours of electrical energy.

For the town of Creede to generate hydropower, the options are as follows. Utilizing the existing head level, power can be generated constantly at varying rates according to the fluctuations of the flow in Willow Creek, or power can be generated at a fixed flow at only the time of day of peak demand and water stored upstream for the time when it is needed. These two options are possible without raising the head but most likely will only be able to supply part of the electricity that the town demands. Each of these options requires different installations of the generating equipment. If the existing conditions of Willow Creek are to be utilized, the equipment can be installed directly into the run of the river. If a storage area were to be built, then a storage setup of the equipment would be used. If the flow were diverted through a pipeline or in order to use the flow only part of the time, the equipment is installed in a diversion channel.

Recommendation

After contacting more than 5 mini/micro hydro turbine makers and based on the hydrologic conditions of Willow Creek, it is recommended that a Windsor Cross-flow turbine be used. This turbine maintains the highest efficiency over a wide range of flows by it use of one-third/two-thirds split blade technology. For the Creede site a 24 kilowatt unit is recommended.

The Electrical System

Figure 7 is a block diagram illustrating how water energy is converted into electrical energy and transferred to the electrical grid. A key consideration in all micro-hydropower designs is whether the electrical power generated will be consumed locally or supplied to the grid. Local consumption requires that a local distribution system be built, where as connecting to the grid means a single, but costly connection to the power grid. In the latter case, the electrical energy generated at the micro-hydropower plant enters a power pool, and is "wheeled" anywhere in the grid. So the power generated is not necessarily consumed locally, but is sold to a regional grid. The town continues to buy power from the grid and their bill is credited each month by the amount of power sold to the grid. Unless the micro-hydropower is intended to a single industrial user, the most common design is to connect to the grid.

The question of connecting to the grid or not is an important one, because it affect the selection of the generator unit. Generator can be either synchronous or asynchronous. Synchronous generators rely on the power grid to provide the necessary electrical field to start and govern the spinning speed.

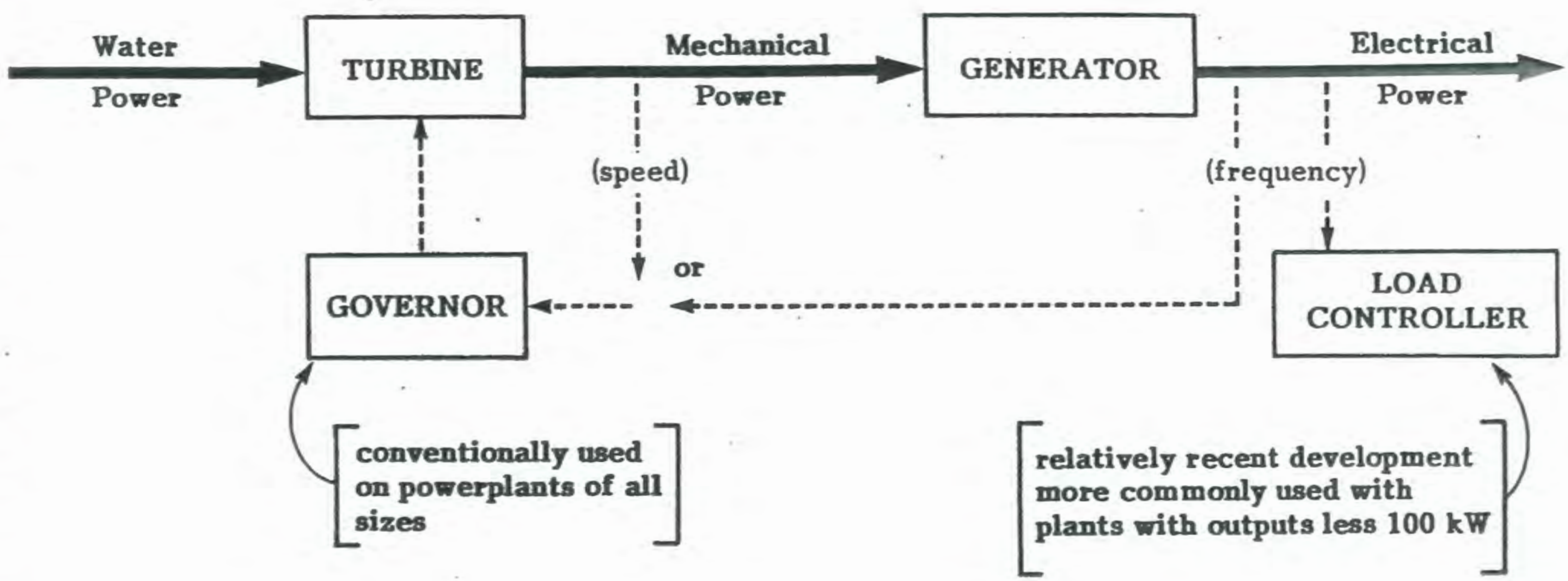

Figure 7. Block Diagram of Generating System

Asynchronous generators use their own electricity for start-up and governing purposes. Synchronous generators are the more efficient unit.

The institutional and economic considerations of the feasibility of micro-hydropower on Willow Creek will be discussed in following sections.

III. The Institutional Aspects of Micro-hydropower in Southwestern Colorado

The producing of hydropower is the easy part, how does the power get to the customers. There are three options, "Self-supply to a local grid," "Self-supply to the user side of the Meters," and selling the generated power to the "regional grid".

Self-Supply to a local Grid

If the power is to be used locally in a local grid, the power generator, the Town of Creede (Creede), must own the local grid. This would require Creede to incorporate as a "municipal electric" and purchase from the current owners, San Luis Valley Rural Electrical Cooperative, the local grid to be supplied by the micro-hydro generating facility.

Self-Supply to User Side of Meter.

There is an alternative to becoming a municipal electrical and owning the grid. The self-supplied electricity could be delivered to the user side of the meter. This way the locally produced energy would not impact or interact with the San Luis Valley Rural Electrical Cooperative equipment. However, this is only practical for a single or a few large users, otherwise there would be a dual distribution system. Each user must have special equipment to constantly monitor the supply from the micro-hydro facility and be able to switch instantly to the grid supply.

Selling the generated power to the "regional grid"

The Federal Energy Regulatory Commission (FERC) United States Department of Energy, guarantees that any energy produced by renewable sources can have a market. However, there are three requirements that must be met:

- All power must be sold to the regional Grid. For Creede this is Tri-State Generation and Transmission.
- The supplier must provide at the transmission level with
  - a supply that is protected with Relays
  - a dedicated line to the sub-station

- The supplier must pay "wheeling" charges. These are the administrative costs of selling power on the grid.

The price for the power produced depends on the amount and reliability of supply. This will be discussed in the next section.

Recommendation

From technical (to supply power primarily to residential and commercial businesses), administrative, and economic viewpoints, it is the recommended that the institutional structure be to" sell the power to the grid."

In the following section on the economic analysis, this structure is assumed.

III. The Economics of Micro-Hydropower for the Town of Creede

In performing an economic analysis of a micro-hydropower generating facility at Creede selling its power to the grid we must under take three steps: 1) determine the price the grid will pay for the supplied energy 2) determine the cost of the micro-hydropower generating facility, and 3) perform a Benefit/Cost analysis on the project.

1) The price the grid will pay is the lowest price that Creede must pay for it energy in each month. The price Creede pays for electricity is determined via a contract with the San Luis Valley Rural Electric Cooperative. The tariff rates are based on the peak Power Demand (kilowatts) reached in each month. The tariffs are charged both on peak Power Demand (kilowatts) in each month and the amount of energy used in each month. The Rate Structure is listed in Table 3 below.

Table 3. San Luis Valley Rural Electric Cooperative Electric Tariffs

	Primary		Secondary	
Monthly Peak Demand (kW)	**Power Rate** \$/kilowatt	**Energy Rate** ¢/kilowatt-hour	**Power Rate** \$/kilowatt	**Energy Rate** ¢/kilowatt-hour
45-500	**51.00**	**6.1**		
500 - 1000	**9.70**	**4.07**	**10.00**	**4.20**
> 1000	**9.70**	**3.5**	**10.00**	**3.5**

San Luis Valley Rural Electric Cooperative, 1995

An analysis of demand was made to find out the average cost paid by Creede. Data provided by the San Luis Valley Rural Electric Cooperative, showed an annual and summer peak usage in July 94 of 2,100 kilowatts and winter peak in March 1995 at 1,000 kilowatts. This data is for the Creede Billing district which includes the town of Creede and the surrounding regions. Further analysis suggests that for the town of Creede the summer peak is 1,250 kilowatts and the winter peak is 800 kilowatts. It was also estimated that summer load factor (the ratio of average daily power demand to peak daily power demand) was 0.5 and for the winter monthly 0.6.

Cost of Creede's Electricity

Based on the data and assumptions above, the average cost of electricity for Creede is

```
    Summer:          June, July, August
Peak Capacity        1,100 kilowatts
Energy Use           1,100 kW X 0.5 X 31 X 24 =
                     409,200 kilowatt-hours


Capacity       1,100 kW  X  $10         =  $11,000
Energy         409,200 kW-h X $0.035 =     $14,322

Total                                      $25,322

Cost per kilowatt $25,322/409,200   =   $0.062

    Winter:          September to May

Peak Capacity        800 kilowatts
Energy Use           800 kW X 0.6 X 31 X 24 =
                     357,120 kilowatt-hours


Capacity       800 kW  X  $10           =  $ 8,000
Energy         357,120 kW-h X $0.042 =     $14,999

Total                                      $22,999

Cost per kilowatt $22,99/357,120   =   $0.064
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For further analysis a cost of $0.0639 per kilowatt is used.

Cost of the Micro-Hydropower Unit

A preliminary cost estimate for the turbine, synchronous generator, and equipment to link to the grid was obtained from Windsor Machinery. For a 24 kilowatt rated unit the Capital Costs are estimated at $80,000. The turbine has an expected lifetime of 20 years. If the turbine is purchased via a loan or municipal bonds at a 10% interest rate over 20 years the annual costs will be $9,400, at 7% interest $7,552, and at 5% interest $6,400. Annual operating and maintenance cost are estimated at $1000 per year.

Benefit/Cost Analysis

In the section above, the annual costs of installing and operating the plant were estimated. In this section we will estimate the revenues from selling the generated power and compare the revenues to the costs.

With a 20 feet head and 20 cfs discharge at 30% exceedance, a gross power capacity of 35.4 kilowatts is obtained. The Windsor Cross-flow turbine has an efficiency of 70% so the net power output of the unit is rated at 25 fr

kilowatts. If there are an estimated 20% generator and transmission losses , the unit can generate 120,00 kilowatt-hours and deliver 96,000 kilowatt-hours to the grid per year. At an average price of $0.0639 per kilowatt-hour, this results in an average annual revenue of $6134.00.

Comparing Revenue in Table 4 below show that even with a 5% interest rate the project looses money. However, it does save fossil fuels and aids in reducing CO_2 emissions and air pollution.

20 CFS x 448.8 = 8976 gpm
SAY 9000

Table 4. Benefit/Cost Analysis of 20 feet head Design

Per Crane 24" ϕ @
9000 gpm V = 7.18 ft/s
ΔP = 0.242 PSI/100 ft

Interest Rate	Revenue	Costs	Net Revenue
10	**6,134**	**10,400**	**-4,266**
7	**6,134**	**8,552**	**-2,418**
5	**6,134**	**7,400**	**-1,266**

ΔP for flow = .242 x 50 = 12.1
12.1 x 2.307 = 27.9' hd
entrance loss = $V^2/2g_c = \frac{(7.18)^2}{64.4} = .11$ ft
SAY 28' hd loss in pipe
80 - 28 = 52 ft Remaining

Alternative Design

eff xmission loss
$\frac{(52)(20)(.70)(.8)}{11.8} = 49.3$ KW x 8760 hr/yr = 432,000 K/yr

Currently, there is a flood control sluice running through the center of Creede. This is an open channel, which can not be used in hydropower generation. However, there is a vertical drop of approximately 80 feet over the length of the sluice. To utilize this vertical drop and convert it into Head for hydropower generation, the water must be piped. In this design, a 2 foot PVC pipe carrying 20 cfs would be laid in or along the sluice. The pipe would be

5000 feet long and would require very little construction, it would need to be secured well to avoid damage during the spring flood season. With this design the annual costs of installing and operating the plant would increase. Assuming that the pipe and increased generation capacity adds $30,000 to the capital cost for a total of $110,000. If the turbine is purchased via a loan or municipal bonds at a 10% interest rate over 20 years, the annual costs will be $12,925, at 7% interest $10,384, and at 5% interest $8,822. Annual operating and maintenance cost are estimated at $1500 per year.

If we assume that 1/2 of the vertical drop is lost to friction in the pipe then we get an additional head of 40 feet. With a 60 feet net head and 20 cfs discharge at 30% exceedance, a gross power capacity of 106.2 kilowatts is obtained. The Windsor Cross-flow turbine has an efficiency of 70% so the net power output of the unit is rated at 75 kilowatts. If there are 20% generator and transmission losses, the unit can generate 375,000 kilowatt-hours and deliver 300,000 kilowatt-hours to the grid per year. At an average price of $0.0639 per kilowatt-hour, this results in an average annual revenue of $19,170.

Comparing revenues and costs in Table 5 below, show that even with a 10% interest rate the project makes money. In addition, it saves fossil fuels and aids in reducing CO_2 emissions and air pollution.

Table 5. Benefit/Cost Analysis of 60 feet head Design

Interest Rate	Revenue	Costs	Net Revenue
10	**19,170**	**14,425**	**4,745**
7	**19,170**	**11,884**	**7,286**
5	**19,170**	**10,322**	**8,848**

The disadvantage of this design is that a 2 foot diameter pipe will be running down the center of Creede.

V. Recommendations

1) After contacting t more than 5 mini/micro hydro turbine makers and , based on the hydrologic conditions of Willow Creek, it is recommended that a Windsor Cross-flow turbine be used. This turbine maintains the highest efficiency over a wide range of flows by it use of 1/3 by 2/3 split blade technology.

2) From technical, administrative, and economic viewpoints, it is the recommended that the institutional structure to be used be "to sell the power to the grid."

3) A design that includes a pipeline that follows the Willow Creek Sluice to maximize vertical head should be selected. This design appears to be financially attractive in addition to utilizing a renewable energy source and reducing pollution from fossil fuel burning.

4) A full-scale feasibility study of hydropower development on the Willow Creek at the town of Creede should be undertaken.

5) It is recommended that the town of Creede contact:

> ***Harry Trbush***
> ***Windsor Machinery: Developers of Renewable Energy Resources***
> ***Box 157***
> ***Orbitlane, RD 3***
> ***Hopewell Junction, NY 12533***
> ***(914) 897-4194***

to undertake the feasibility study. In a national survey of small-scale hydropower developers, he was the most knowledgeable in micro-hydro development and conditions found on Willow Creek. He was highly recommend by suppliers of Mini-hydro turbines that did not supply micro-turbines.

A Pre-Feasibility Study for a Micro-Hydropower Facility on Willow Creek at Creede, Colorado

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