MACDONALD COLLEGE OF MCGILL UNIVERSITY

STAND ALONE ENERGY FOR REMOTE SITE IN KODIAK, ALASKA

SENIOR PROJECT SUBMITTED TO
J SHEPPARD

THE FACULTY OF THE AGRICULTURAL ENGINEERING

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ABSTRACT

Electric generation is a technical and logistical challenge in remote locations not serviceable by utility grids. Conventional fossil fuel generation has considerable economic and environmental costs. The following design project ~~is a~~ proposes an energy system to meet the needs of a homestead and fishing site on the island of Kodiak in Alaska which has a daily load of about 50 kWh. Renewable energy options, including photo electricity, wind power and micro hydropower have been examined and compared for the site. The conclusion was to base the system on a micro hydro plant with lead acid battery storage. The system, operating with a diesel back up is expected to provide about 46 kWh/day, taking into account all potential losses.

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INTRODUCTION: OBJECTIVES

Generation of electricity in remote locations presents the homesteader and engineer with considerable technical and logistical challenges. As late as the 1950's, much of rural North America was either serviced by on-site, owner operated systems, or simply did without. Though today most North American locations are connected to utility grids, there are still many sites, particularly in northern and maritime regions, which remain unconnected due to economic or physical unfeasibility. Many sites have no choice but to rely on fuel burning generators for power. However, where feasible, renewable energy options such as wind, photovoltaics and hydro may provide suitable and even economically favourable alternatives.

This project presents a case study of one remote site in Kodiak Alaska. The site is the location of a year round homestead and of a salmon set net site. It is distant from any towns or civilization, accessible only by boat or sea plane. The site owner plans to live on the site year round with his family. For reasons connected to economics and life-style choices he wishes to be independent as possible from outside supply lines. At the same time he wishes to have all modern electrical conveniences. Furthermore he has plans to install a greenhouse and set up a small scale fish and game storage facility, mostly for the processing of high grade sea food products.

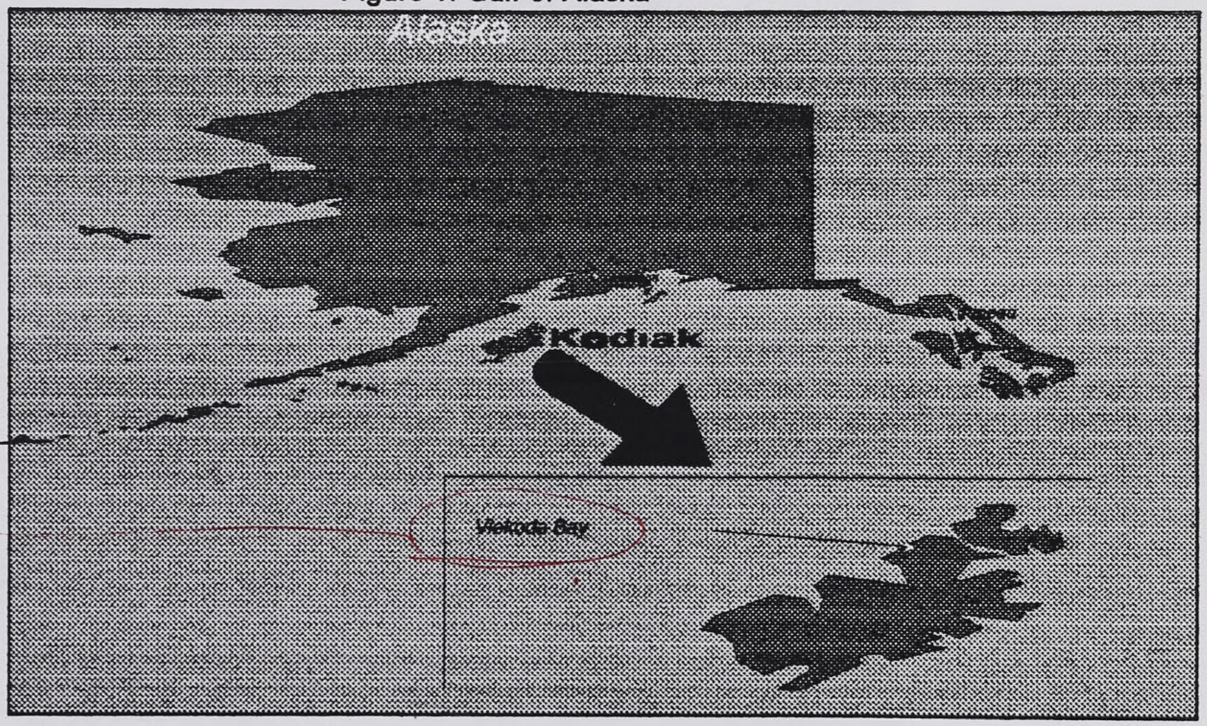
The objectives of this project are:

1. To design an energy generation system to provide for the site's electrical needs
2. To assess and use locally available renewable resources in making the design
3. To design it to be as environmentally friendly as possible.

Site Description

Kodiak is a large hilly island in the Gulf of Alaska. (See Figure 1). It is mostly uninhabited reserve. The main industries of Kodiak are fishing, fish processing and tourism.

Figure 1. Gulf of Alaska



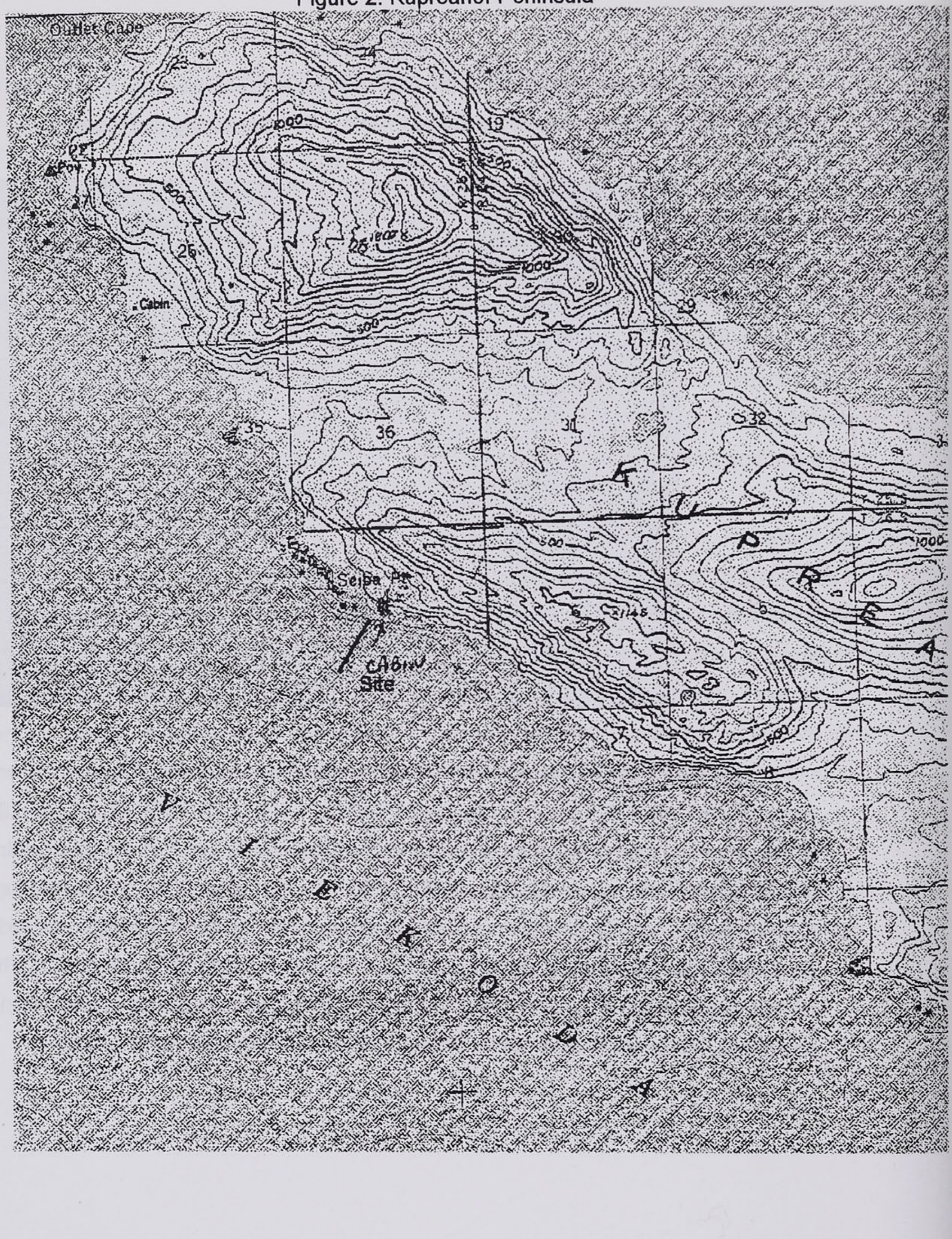
Better draft map.

I can't read it.

The site being examined is situated in Viekoda Bay side of the Kupreanoff Peninsula on the northwest coast of Kodiak Island. (See Figure 2) It is a moderately sloped area, the extents of the property ranging from sea level to 122 m (400 ft) elevation. It is covered by pine woodlot, alpine meadow and some alder marsh. The soil is mostly shallow sandy loam resting on basalt. A small stream cuts through the property , flowing all year round. Being well exposed to the Shelikoff Strait, the climate of the site is influenced western maritime conditions. The main climatic features are shown on Table 1. The weather is characterized by damp, often overcast conditions, moderate to high winds. Winters are moderately cold and very wet.

Figure 2. Kupreanof Peninsula

Figure 2. Kupreanof Peninsula



why is the map so dark?

Table 1. Western Kodiak Climate

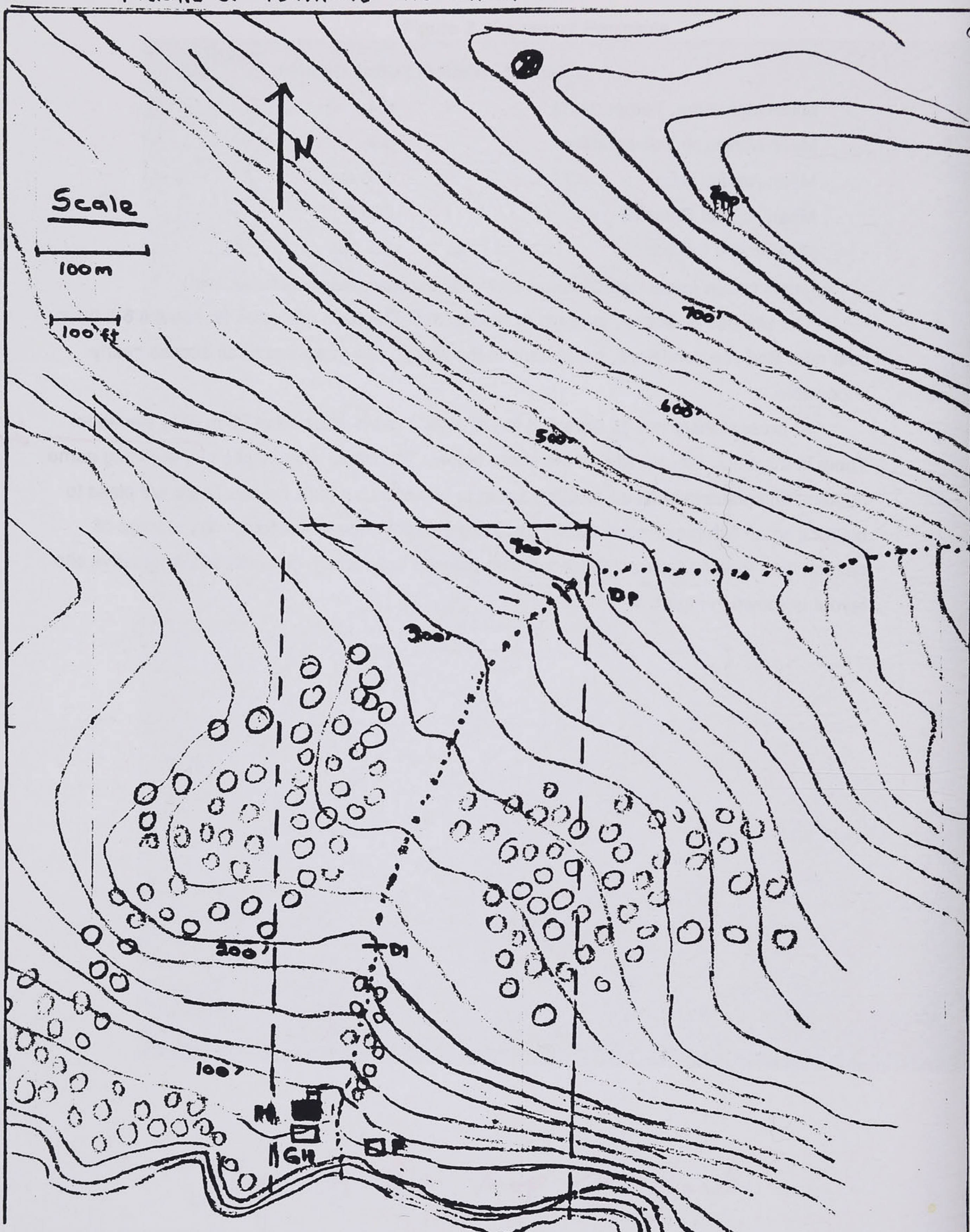
Mean Maximum. Temperature	8.4
Mean Minimum.Temperature	0.3
Mean Annual Rain	576 mm
Mean Annual Snowfall	609.6
Mean Wind Speed	6.9 m/s

(USDI,Climatic Atlas of Outer Continental Shelf Water and Coastal Regions of Alaska, 1981)

The site has no access to roads or land routes. The town of Kodiak is about a 6-8 hour boat ride. Bad sea conditions, particularly in the winter, can make sea or air access nearly impossible.

At present there is a 10.9m x 7.3 m (36' x 24') cabin situated at 28 m (92') elevation. There is a salmon set net site off the shore below. The owner also makes a business of outfitting game hunters, and plans to build an auxiliary cabin to be used as a bunk house. There are plans to build t a small fish preparation facility including a walk in freezer for temporary storage of salmon, sea food and game. There are also plans to build small greenhouse . A tentative site layout is shown in Figure 3.

FIGURE 3: TENTATIVE SITE LAYOUT



LEGEND

- - - property line
······· stream
○○○ wood lot
—— elevation (ft)
H existing cabin
proposed structure
GH greenhouse
F Freezer
DI existing dam
DP proposed dam
⊗ possible wind mill site

LOAD ANALYSIS

The first task in designing an energy generation system is in assessing the electrical load which it will service. Table 4 shows a break down of various appliances used, their rated power and an estimate of the average number of hours of use per week and day, in order to arrive at the total kilowatt hours (kWh) consumed per day. It is assumed that where possible , especially for domestic consumption, conserving measures are undertaken. For instance, it is assumed that fluorescent lighting is used as opposed to less efficient incandescent, and that energy efficient refrigeration is employed. The total daily load is 33 kWh/day. This figure represents the energy consumption at the load end , not taking into account generation, transmission and storage inefficiencies.

Table 2. Electrical Load for Site

Load	Wattage	Hours/day	Days/week	Watt Hours
Lighting				
Kitchen	40	4	7	1120
Bedroom	20	2	7	280
Bathroom	15	2	7	210
Living Room	30	3	7	630
Bunk house	20	4	7	560
Refrigerator(DC)*		540 Wh/day	7	3780
Ceiling Fan(DC)	36	6	7	1512
Stereo	30	3	6	540
VCR	30	2	5	300
TV	170	2	5	1700
Short wave (DC)	25	12	7	2100
Washer	1	250 Wh/load	2	500
Dryer	1	500 Wh/load	2	1000
Food Processor	300	0.1	4	120
Business				
Lighting	50	4	4	800
Freezer(DC or AC)	1500	12	7	126000
Hoist (DC)	750	0.5	5	1875
Greenhouse				
Lighting	1500	8	7	84000
Fans (DC)	18	24	7	3024
			kWh/week	230
			Per Year	11963
Av Power Demand	4.11	kW	Per day	32.86
Average Power Supply	4.44	kW	With Inefficiecies	35.52

All loads assumed AC unless stated

* Using Sunfrost Refrigerator

** Using propane dryer

Heavy Loads

As can be seen , the largest loads are those presented by the freezer and the greenhouse lighting. It should be noted that the freezer unit would not be operated continuously throughout the year, as it is mostly in use during fishing periods, mostly between June and September. The load from the greenhouse is also variable ranging from almost nothing in mid summer to up to 8 hours a day in winter when days are short.

Though it is beyond the scope of the project, some attention should be dedicated to the refrigeration unit. It is assumed, based on the equipment being examined by the site owner, that the cooling load will be in the vicinity of 1.5-2.0 kW. One way to reduce the load would be using hold-over plates to store coldness. The options for running the freezer are to either drive the compressor off a separate engine or use an AC or DC driven motor. The problem with a separate engine is that not only would it depend on fuel, but it would also be inefficient; when the cooling box is charged, the load can be much less than the engine output. Electric motors motors are more efficient for freezers.(Smead, 1993) Running any refrigeration off of batteries constitutes a serious drain, and will result in high currents. This is increased if an AC motor is run off of an inverter. If an AC motor is used, the power source, whether it is an inverter or direct from a generator, must be able to supply starting wattage, up to four times the nominal power rating.

AC or DC

Power can be used in one of two forms, either AC or DC. . Much of the problem is rooted with the large load of the freezer unit (about 18 kWh/day). For the most part, for lighting and domestic appliances it may be preferable use AC , as using DC would require finding specialized appliances which are often more expensive and lower quality than readily available AC components. However, for such loads that involve electric motors such as refrigeration compressors, pumps and fans, it may be preferable to use DC, as DC motors are more efficient. (Schaeffer, 1994). An advantage of DC is that it is more readily stored in batteries. If batteries are used for storage, all energy to be stored must be converted to DC. To use energy stored in batteries, a 75% charge/discharge inefficiency must be accounted for.(Smith, 1980). Any AC loads run off the batteries would have to be run through an inverter, adding another 5-20% inefficiency .

Not clear here. Does this mean that the losses are 75% of the generated energy?

The actual choice of whether to run all or part of the system on AC or DC is tentative and depends mostly on the desire of the site owner and the choice of appliances made. The most appropriate choice will also depend on the means of generation, as some sources, such as photo voltaic cells only produce DC. In making the final load calculation it was assumed that the load will be distributed as represented, making the final load on the supply side, or generation load, of 36 kWh/d.

Present Energy Sources

At present the electrical needs are met by a small 1.0 kW gasoline generator set. Heating is provided by wood stove, which is also used to pre-heat water. Cooking and water heating is provided by propane. This project only deals with direct electrical loads, though there is potential for providing for cooking, space and water heating with electricity. One problem is that the propane and wood burning equipment are already installed. A bigger problem is that electrical heat generation would draw very high current from the system. This may seriously enlarge and complicate the proposed system. Because wood is readily available, electrical space heating can not compete from an economical point of view. It was decided that though using propane creates an outside dependence, it simplifies matters to keep using it for cooking and water heating.

ALTERNATIVES

Various options of on site generation include renewable sources such as photovoltaics, wind and microhydro. Renewable sources fit in well with the project objectives as they allow for relatively independent power generation (i.e. they don't depend on a fuel source), as well as being clean and generally environment friendly. In light of growing awareness of the limits of our fuel resources on earth, and of the pollution problems which they create, there are a whole range of philosophical arguments supporting the use of renewable energy sources. These arguments must be weighed against economic and technical downfalls of renewable energy when compared to fossil fuels. One main problem with renewable energy is that the technology is relatively underdeveloped from both a technical and commercial point of view. The other problem is a bad reputation earned by cases of inappropriate matching of equipment with local resources and by mismanagement of installed systems. With proper management, siting and assessment of resource potential, renewable systems could prove quite competitive with conventional sources.

Conventional Sources

Conventional energy sources to be discussed include generators powered by internal combustion engines running on fossil fuels. These fuels include diesel, gasoline and propane gas. Table 5 shows their energy content and average efficiency. (Actual efficiency depends on the load).

Table 2. Fossil Fuel Effiiciency and Cost

	Diesel	Gas
Energy Density (kWh/kg)	11.77	12.36
Energy Density (kWh/L)	10.55	8.89
Small Engine Efficiency	0.34	0.2
*Cost at Pump (per gal)	$1.19	$1.43
(per L)	$0.31	$0.38
Cost (per kWh)	$0.09	$0.21

(Dunn,1986)

*The prices are present pump prices in the town of Kodiak. They do not account for shipping expenses. They are also subject to inflation. The prices also do not account for the capital investment.

The main advantages of internal combustion generators are that they are a well understood and simple to operate and install. Energy is available on demand at a flick of a switch. In any remote system, it is wise to include a fuel generator as a back up or emergency standby.

The obvious disadvantage is that depending on as diesel or gas generator set means depending on outside supply lines. The generators are noisy and emit a fair deal of pollution. Since the generator must be sized for a peak load, much energy and fuel would be wasted in times when the load is below the rated out put of the generator.

Photo electricity

Northern areas experience an average insolation or solar energy flux of 125 W/m^2.(Renewable guy) One way to harness this energy is with photo voltaic cells which use the photoelectric effect on a sheet of semiconductor material such as silicon to generate a current. The upper theoretical limit of the efficiency photo voltaic conversion is about 25%, while most cells can only achieve about 12.7%.(Dunn,1986) This efficiency is also subject to reduction by shading, dust and overcast conditions. Commercial units are rated like batteries , in terms of amp-hours (Ah) and voltage. Their output, in amps, can be calculated by multiplying the Ah rating by the local equivalent insolation time expressed in terms of hours of bright sun. The average insolation level for the Gulf of Alaska is between 1-3 hours per day.(Schaeffer,1994) Total energy is derived by multiplying by cell voltage. $E_{(Wh)} = V_{(volts)} x I_{cell\,(amps)} x\ t_{insolation}{}_{(hours)}$

Table 4. compares the output of various units.

Table 4. Photo voltaic units

Amp Hours	2294	A-h
System Voltage	24	V
Design Insolation	1	h
PV Current	2294	A

	Quad Lam	Siemens PC-4
Module rated amps	5.6	4.4
# in parallel	410	521
Nominal Voltage	17	17
# in series	2.00	2
Total	819	1043
Cost- Modules	$99.75	$495.00
Mount	$22.25	$42.00
Total	$99,95	$559,967.64
Cost/ 10 years	$1.98	$2.79

The main advantage of PV cells is that they are easy to install and manage. The are modular, meaning cells can be added or turned off as needed, making for flexibility in system design. They also produce no pollution nor noise. They produce pure DC, appropriate for direct battery charging.

The biggest problem with PV power, particularly in northern locations is the high capital investment and cost per kWh. Northern locations do not make ideal locations for PV due to the varying diurnal cycle through the year, in particular due to the very short days of winter. The system would be over designed for the summer and totally non productive at times in the winter. Due to the often overcast conditions on Kodiak, the degree of insolation would probably be even lower than assumed.

Wind

The power in the wind is calculated by the formula

$$P = \frac{1}{2} Cp\ \rho_{air}\ A_{rotor}\ V^3_{wind}$$

$$Cp = aerodynamic\ efficiency$$

$$\rho_{air} = density\ of\ air$$

$$A = swept\ area\ of\ wind\ rotor$$

$$V = wind\ speed$$

It is necessary to multiply this by the mechanical and electrical efficiency of the generator.

The average annual wind speed at the site is about 6.9 m/s, fluctuating between 4.8-8.4 m/s. The wind varies diurnally, seasonally and with height of the rotor off the ground. In order to access the wind power potential, it is necessary to estimate the frequency of various wind speeds (or calms) which determine system output. A useful tool is a Weibull distribution, which gives a distribution curve. though any distribution can't be exact, and won't tell when the wind is going to blow, it does give a conservative estimate for calculating wind energy over a long period. (Gipe, 1993) A distribution for the site is given in Table 4. Since the aerodynamic and mechanical efficiencies of different systems vary, output is calculated using the manufacturers performance curve of output power vs. wind speed. The various powers multiplied by the Weibull frequency of that wind speed, by the number of hours of that period gives the output for that wind speed bin.

Table 5. Wind Power and Energy Based on Wind Speed Distribution

Wind Speed m/s	p(V) (Weibul Distribution)	Hours/yr (p(V)/2 x 8760)	Bergey power kW (from curve)	energy kWh (h/y x kW)	Whisper power kW (from curve)	energy kWh (h/y x kW)	Jacobs power kW (from curve)	energy kWh (h/y x kW)
0	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	0.0134	58.85	0.00	0.00	0.00	0.00	0.00	0.00
1	0.0266	116.52	0.00	0.00	0.00	0.00	0.00	0.00
1.5	0.0392	171.87	0.00	0.00	0.00	0.00	0.00	0.00
2	0.0511	223.82	0.00	0.00	0.00	0.00	0.00	0.00
2.5	0.0619	271.42	0.00	0.00	0.00	0.00	0.00	0.00
3	0.0716	313.86	0.00	0.00	0.00	0.00	0.00	0.00
3.5	0.0800	350.48	0.00	0.00	0.05	17.52	0.00	0.00
4	0.0869	380.81	0.00	0.00	0.13	47.60	0.19	70.56
4.5	0.0923	404.58	0.05	20.23	0.33	133.51	0.28	112.20
5	0.0962	421.66	0.10	42.17	0.50	210.83	0.44	187.51
5.5	0.0986	432.16	0.19	82.11	0.75	324.12	0.59	253.22
6	0.0995	436.30	0.28	122.16	1.00	436.30	0.77	335.49
6.5	0.0991	434.49	0.38	165.11	1.25	543.11	0.97	422.42
7	0.0975	427.24	0.48	205.07	1.45	619.50	1.22	522.46
7.5	0.0947	415.16	0.64	265.70	1.70	705.77	1.50	621.50
8	0.0910	398.93	0.80	319.15	1.90	757.97	1.83	728.08
8.5	0.0865	379.28	0.90	341.35	2.15	815.45	2.18	826.40
9	0.0814	356.93	1.00	356.93	2.25	803.10	2.60	927.56
9.5	0.0759	332.62	1.10	365.88	2.70	898.07	3.04	1012.11
10	0.0700	307.03	1.20	368.43	2.90	890.38	3.00	921.08
10.5	0.0641	280.80	1.30	365.04	3.05	856.43	3.00	842.39
11	0.0581	254.51	1.40	356.31	3.10	788.97	3.00	763.52
11.5	0.0522	228.66	1.42	324.69	3.15	720.27	3.00	685.97
12	0.0465	203.67	1.44	293.28	3.15	641.55	3.00	611.00
12.5	0.0410	179.88	1.47	264.42	3.10	557.62	3.00	539.63
13	0.0359	157.55	1.50	236.32	3.05	480.52	3.00	472.64
13.5	0.0312	136.86	1.47	201.18	3.00	410.58	3.00	410.58
14	0.0269	117.93	1.44	169.82	2.90	341.99	3.00	353.78
14.5	0.0230	100.80	1.29	130.04	2.75	277.21	3.00	302.41
15	0.0195	85.49	0.60	51.29	2.65	226.54	3.00	256.46
15.5	0.0164	71.93	0.56	40.28	2.45	176.23	3.00	215.79
16	0.0137	60.06	0.52	31.23	2.21	132.72	3.00	180.17
16.5	0.0114	49.76	0.54	26.87	1.80	89.56	3.00	149.27
17	0.0093	40.91	0.56	22.91	1.70	69.54	3.00	122.72
17.5	0.0076	33.38	0.57	19.03	1.60	53.41	3.00	100.14
18	0.0062	27.03	0.58	15.68	1.60	43.25	3.00	81.09
18.5	0.0050	21.73	0.59	12.82	0.00	0.00	3.00	65.18
19	0.0040	17.33	0.60	10.40	0.00	0.00	3.00	52.00
19.5	0.0031	13.72	0.60	8.23	0.00	0.00	3.00	41.17
20	0.0025	10.79	0.60	6.47	0.00	0.00	3.00	32.36
20.5	0.0019	8.42	0.00	0.00	0.00	0.00	3.00	25.25
21	0.0015	6.52	0.00	0.00	0.00	0.00	3.00	19.56
21.5	0.0011	5.01	0.00	0.00	0.00	0.00	3.00	15.04
22	0.0009	3.83	0.00	0.00	0.00	0.00	3.00	11.48
22.5	0.0007	2.90	0.00	0.00	0.00	0.00	3.00	8.70
23	0.0005	2.18	0.00	0.00	0.00	0.00	3.00	6.55
23.5	0.0004	1.63	0.00	0.00	0.00	0.00	3.00	4.89
24	0.0003	1.21	0.00	0.00	0.00	0.00	3.00	3.63
24.5	0.0002	0.89	0.00	0.00	0.00	0.00	3.00	2.67
25	0.0001	0.65	0.00	0.00	0.00	0.00	3.00	1.95
25.5	0.0001	0.47	0.00	0.00	0.00	0.00	3.00	1.42
		8760	Total	5240.59	kWh/y	13069.62	kWh/y	13319.99 kWh/y
			Average Power	0.60	kW	1.49	kW	1.52 kW
			Capacity Factor	0.40		0.50		0.51
			Total	$9,683.97		$8,483.97		$6,000.00
			$/kWh 10y	$0.18		$0.06		$0.05

Assuming mean wid speed=6.9 m/s, Weibul k=2, Tower Height=20m

As can be seen there is an appreciable amount of energy that can be harvested. Wind power is non-polluting. It is also relatively cheap, possibly competitive with fossil fuels.

The main disadvantage of wind is it's variability and unpredictability. Though in the Kodiak area, the wind is statistically higher in the winter and at mid-day, at most probable peak load times, it can still be dead calm at periods of peak demand and gusting when there's no load. The other main objection is aesthetic, as most people find wind towers unsightly. Though they don't pollute, they do produce noise . They have also been known to cause bird deaths, which could be a problem at the site due to a population of bald eagles in the region.

The main site specific problem is that the site is on the side of a hill. Slopes and foots of hills are subject to eddy turbulence which not only diminishes power, but shortens system life. The hill also obstructs all easterly winds. the only way to mitigate this problem would be to site the system on the nearest crest. This would mean installing it 398 m from the cabin. This not only would make for difficult monitoring, but would involve the installation of 800 m of heavy gauge wire. Tower erection is difficult enough without having to consider transport of equipment up hill. Finally the only suitable crest is outside of the property lines.

Hydro Power

Though water generated power has wide spread and large scale conventional application, it is also a renewable source of energy. Microhydro, or hydro generation of less than 100 kW, is relatively undeveloped and is often overlooked by remote site owners. the site being considered features a stream which runs all year round. The stream starts at a pond at about 274 m (900 ft) elevation and enters the property at an elevation of about 106 m (350ft). This makes for a potential head of about (106-28)m=78 m . The stream is already used to household water; the supply comes from a small dam at about 61 m (200 ft) elevation. The stream flow has been measured at the dam, by measuring the height of flow over the weir;(See Table 6.)

Table 6. Stream Flow on Site

Date	Flow (gpm)	Flow (m^3/s)
21/5/91	248	
5/6/91	239	
4/7/91	196	
8/8/91	179	
30/8/91	175	
25/9/91	188	
15/10/91	202	
20/3/92	216	
3/4/92	219	
16/11/92	217	
	Average	

Measured by weir as reported by owner.

Table should be completed

Table 7

Ranking of Options

Criteria	Weight	Wind	Hydro	Photo	Diesel
Cost	10	31	51	1	17
Independance	8	29	33	18	0
Availibility	10	18	41	6	34
Durability	8	21	28	10	21
Av Output/Av Load	7	8	16	23	23
Reliability of Data	6	17	6	17	21
Environmental Impact	4	10	5	20	6
Pollution	4	13	13	13	0
Installation Ease	3	3	5	10	12
Maintenance	5	7	7	29	7
	Score	156	205	147	141

As can be seen the hydro system ranks highest. Therefore it was decided to go for a microhydro system with a diesel back up.

MICRO HYDRO SYSTEM

The main components of the micro-hydro system are the dam and water diversion, the pen stock, the turbine, storage and control box. A general layout is shown in Figure 2. the system is designed to operate at a head of 6.3 L/s and a total head (Ht) of 78 m.

Water Diversion

The purpose of the dam is to divert the water into the pen stock. There is not enough information for a detailed design of the dam, but a general design is shown in Figure 3. It is a simple dam, similar to the dam already built for water supply. The weir wall can be made of 1 1/4" treated plywood. Rocks are piled against the outer wall to give support. they are piled such that they allow the overspill to flow gently downstream without eroding the stream bed and the foot of the dam. The floor of the basin is lined with impermeable polyethylene liner, covered with coarse gravel. a grate is installed to block large debris that may come downstream. The basin of the dam may be excavated to provide sufficient depth.

Figure 4. Diversion Structure

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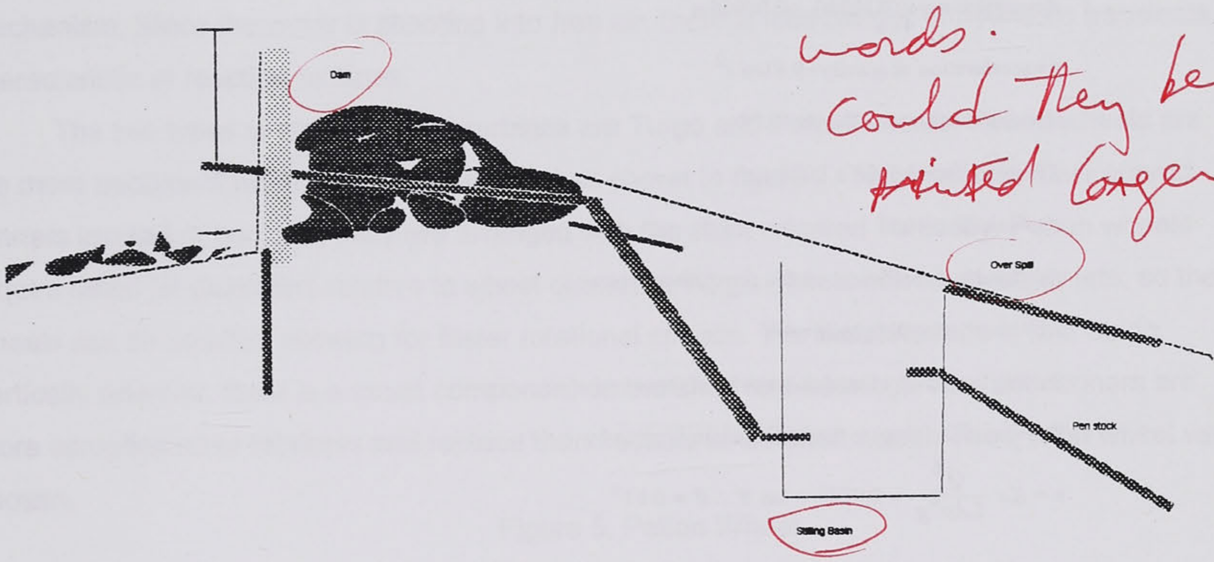


Since the stream flows all year, it doesn't need to provide storage. It must maintain enough water depth such that the entrance is high enough off the bottom so it won't draw in too much sediment. The water level must be high enough above the entrance to provide sufficient pressure on the entrance orifice.

The orifice is simply a length of 105 mm (4") pipe sticking through the wall. A gate valve is installed to adjust the flow rate. From the dam, water flows into a settling basin. This is simply an oil drum partly buried in the ground. Silt and sand is allowed to collect on the bottom. The flow into the pipe to the basin is controlled by pipe flow as represented by the following equation:

$$Q = Ap\frac{\sqrt{2gHd}}{\sqrt{1+Ke+Kb+Kv+KcL1}}$$

$Q = flow = 0.00789\,m^3/s$

$Ap = \text{pipe area} = \frac{\pi}{4}(0.105m)^2 = 0.00866m^2$

$g = \text{acceleration of gravity} = 9.81\,m/s^2$

$Ke = \text{entrance loss coefficient} = 0.78$

$Kb = \text{bend loss} = 0.6$ *for a* $90°$ *bend*

$Kv = valve\,loss = 0.11$

$Kc = \text{head loss coefficient} = 0.251$ *for 4" smooth pipe*

$L1 = \text{length to settling basin} = 4\,m$

Solving for $Hd = 0.15$ m, dam water level above basin

The maximum slope to the settling basin is given by

$$s = Kc\,\frac{Q^2}{2Ap^2 g} = 0.0106 = \tan\theta \;\therefore\; \theta = 0.61°$$

The end of the pen stock sticks into the barrel, 1m above the bottom. Another gate valve is used to control flow. Water over flows into a 154 mm (6") pipe which carries it back to the stream.

The pen stock is 105 mm (4") PVC pressure pipe laid 245 m to the site. PVC was chosen over steel as it is lighter and easy to work with. It is not to be buried over one meter and is sufficiently durable. The maximum pressure would be the result of sudden closure at the low end, causing water hammer. This would amount to 3.2 MPa in a 4" pipe. The pipe is rated for 16 MPa. (see Appendix 3) It is smooth so as to lessen friction losses. The effective head (He) developed at the end of the pen stock is given by the Bernoulli equation. Taking the free water surface and the turbine outlet as boundary conditions, it reduces to:

$$He = Ht - Hf = \Delta z - \frac{v2}{2g}(1 + Ke + Kv + Kb + Kx + f\,\frac{L}{Dp})$$

$\Delta z = 78.64\,m$

$v = Q/Ap = 0.729\,m/s$

$Ke = 0.78$, $Kb = 0.8(2\;\; 45°$ *bends*$)$, $Kv = 4($*for 2 gate valves*$)$, $Kx = 1$

$L = 245\,m, \quad Dp = 0.105\,m$

$f = 0.019$ *for calculated* $\text{Re} \approx 76000$, *smooth pipe*

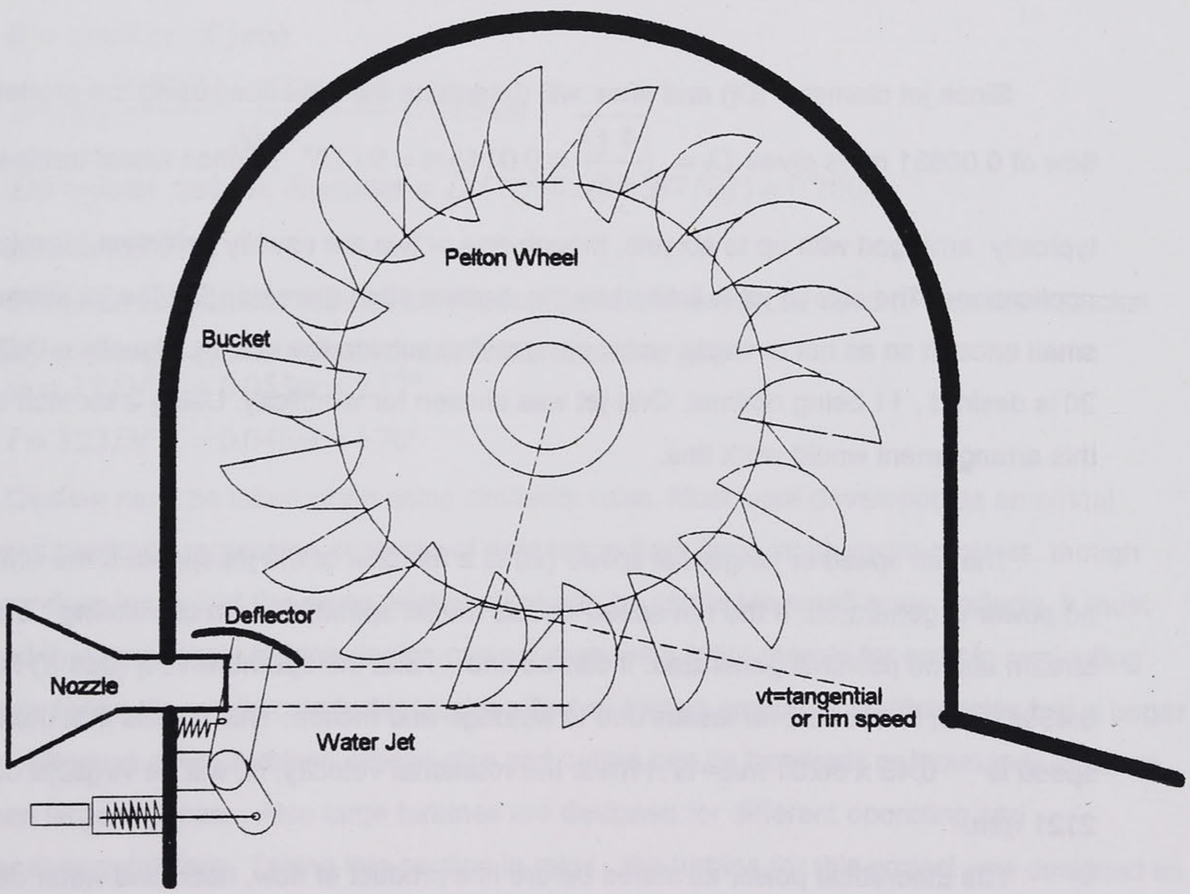
$\therefore He = 77.31\,m$

<u>Turbine</u>

There are a number of turbine types used in microhydro applications including reaction, axial, cross flow and impulse turbines. The most appropriate for high head, low flow applications such as this is the impulse turbine. (Strohmer, 1981) The turbine is basically a wheel with buckets or runners arranged radially around the rim like a Ferris wheel. It functions by shooting a high speed water jet through a nozzle into the buckets, spinning the wheel. It is a fairly simple mechanism. Since the water is shooting into free air, there is less danger of hydraulic transients characteristic of reaction turbines.

The two types of small impulse turbines are Turgo and Pelton wheels. Pelton wheels are the more traditional water wheel arrangement as shown in figure 5. Turgo wheels have curved runners instead of buckets. They are arranged with the shaft oriented vertically. Pelton wheels require small jet diameters relative to wheel diameter. Turgo wheels can have larger jets, so the wheels can be smaller, allowing for faster rotational speeds. The disadvantage is that being vertically oriented, there is a thrust component on the shaft and bearings. Also the runners are more complicated to fabricate and replace than buckets of a Pelton wheel. The Pelton wheel was chosen.

Figure 5. Pelton Wheel



There are few very small scale turbine manufacturers. Appendix 2 lists those surveyed, including reported specifications. There is also included specifications of home built models. Most of the systems on the market for homesteaders are not designed for output of more than 1.5 kW. They are often made of cast bronze, or even plastic which does not last long. Stainless steel is preferable, lasting up to 20 times longer than bronze. Small Hydroelectric Systems and Equipment Company (SHSE) sells plans for a 6" turbine which can be fabricated by a welder. The SHSE turbines have the best reported performance and are able to attain high outputs. Unfortunately, the design plans did not arrive in time for presentation, so instead an attempt was made to design the system based on reported parameters and fluid mechanic principals.

The total effective head at the nozzle is converted to dynamic head of the jet. The jet speed is given by

$$v_j = C_j\sqrt{2gH_e}$$

$$C_j = \text{jet discharge coefficient} = 0.976$$

$$\therefore v_j = \textit{jet speed} = 38.01 m/s$$

Since jet diameter (Dj) and area will determine the total flow, using the predetermined flow of 0.00631 m^3/s gives $D_j = \sqrt{\frac{4}{\pi}\frac{Q}{v_j}} = 0.0145m \approx 9/16"$. Pelton wheel turbines are typically arranged with up to six jets, though one or two are usually sufficient for microhydro applications. The size of jet is limited by the turbine pitch diameter (D); the jet stream must be small enough so as not to waste water on spraying outside the bucket. Usually a D:Dj ratio of 9-20 is desired , 11 being optimal. One jet was chosen for simplicity. Using a six inch turbine with this arrangement would work fine.

The rim speed or tangential speed (vt) is a function of the jet speed. If the rim speed is 0, no power is generated. If the rim speed equals the jet speed, the rim is "running " from the jet stream and no power is generated. It can be shown that the optimum vt:vj ratio (f) is 0.5. Usually 0.45 is used, to account for losses due to windage and friction. This means that the optimum rim speed is 0.45 x 38.01 m/s=17.11m/s. the rotational velocity, N, will be vt/(pD)x 60 s/min= 2121 rpm.

The theoretical power as stated before is a product of flow, head and water density. The efficiency is a function of water to steel friction (k), angle of discharge from the bucket (q) and mechanical losses in the shaft (h_m) and windage. For stainless steel the friction loss coefficient is taken as 0.25. The optimum angle of discharge would be 0°, allowing for full force of flow in the tangential direction. However the exiting stream would then interfere with the oncoming jet and bucket. Therefore the buckets are designed to discharge the jet at an angle q of 10-15° .. The total hydraulic power , P_h, delivered to the generator will be $P_h = Q\rho(1-\phi)(1+\frac{\cos\theta}{\sqrt{1+k}})\phi v_j^2$. (Barna,1964) Plugging in all the numbers gives 4.24 kW.

Assuming no water leakage the only other losses are mechanical, h_m can be estimated at 95%. . Since the original theoretical power is P=QgHt =4.83 kW, this would give a hydraulic efficiency of 83%. . Assuming further efficiency of 50% for generator efficiency, based on commercial specifications, the total electric output would be 2.01 kW, for an overall efficiency of 2.01/4.83 =41%. Though conservative compared to many systems at 50-75%, it is within realistic range.

Literature on turbomachinery uses similarity laws to define turbine constants to design turbine geometry. The important constant for impulse turbines is specific jet speed , Nsj .

$$Nsj = N\frac{\sqrt{P_h/i}}{He^{1.25}} = 2121\frac{\sqrt{4.2}}{77^{1.25}} = 20.18$$

(i = number of jets)

$$D = Dj\frac{(250.74 - 1.796Nsj)}{Nsj} = 0.154m$$

$$Do = \text{outer turbine diameter} = D\,(1.028 + 0.0137Nsj) = 0.200m$$

(deSiervo,1978)

Based on correlations with specific speed, jet diameter can be used to determine bucket width (w) and length (l) and height (h) and width of casing (W)

$$w = 3.2Dj^{0.96} = 0.055m = 2.17''$$

$$l = 3.23Dj^{1.07} = 0.040m = 1.70''$$

Caution must be taken when using similarity rules. Most were developed as empirical equations based on regression analyses of data taken from large scale hydro projects. though literature does imply that the same relationships can be applied to small scale projects, it must be noted that large scale turbine design can get away with more margin for error in evaluating efficiency than with small scale turbines; the effect of friction and other inefficiencies has a larger relative effect on micro turbines, whose size and output can be hundreds or thousands of times less than large turbines. . Also large turbines are designed for different operating and maintenance conditions. Taking this caution in mind , the turbine for this project was designed as presented in Figure 6-9.

Figure 6. Turbine Design

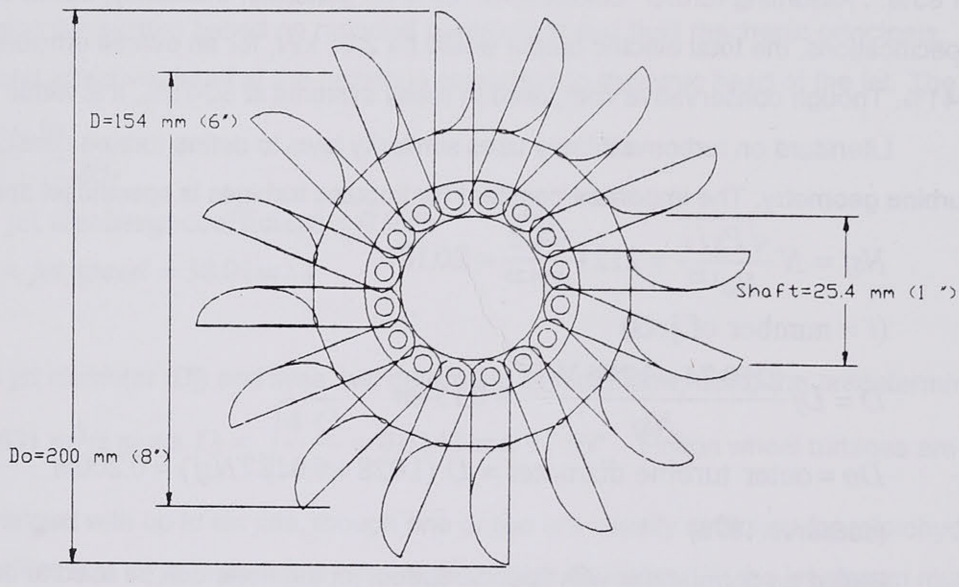


Figure 7. Bucket Design

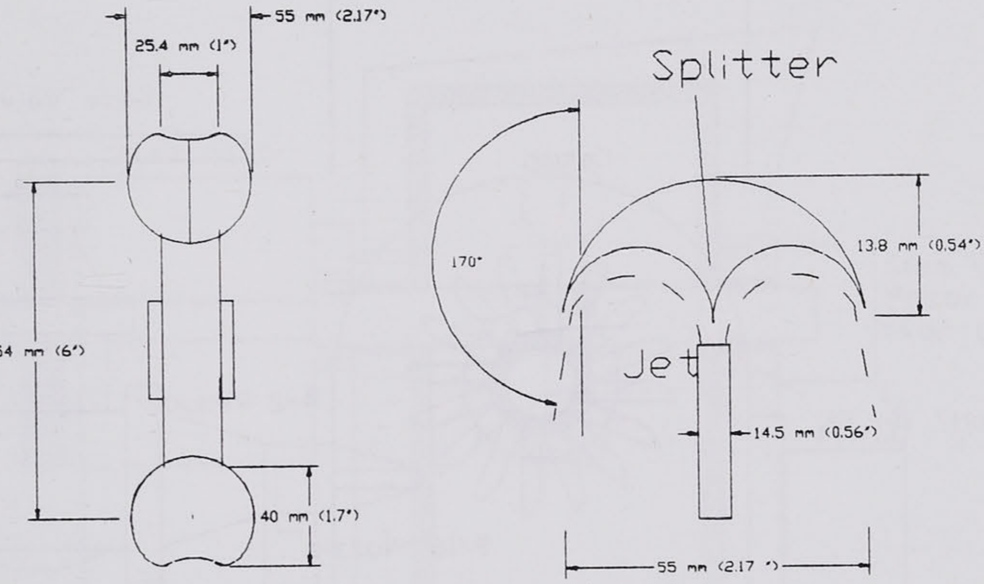


Figure 8. Microhydro Set Up: Side View

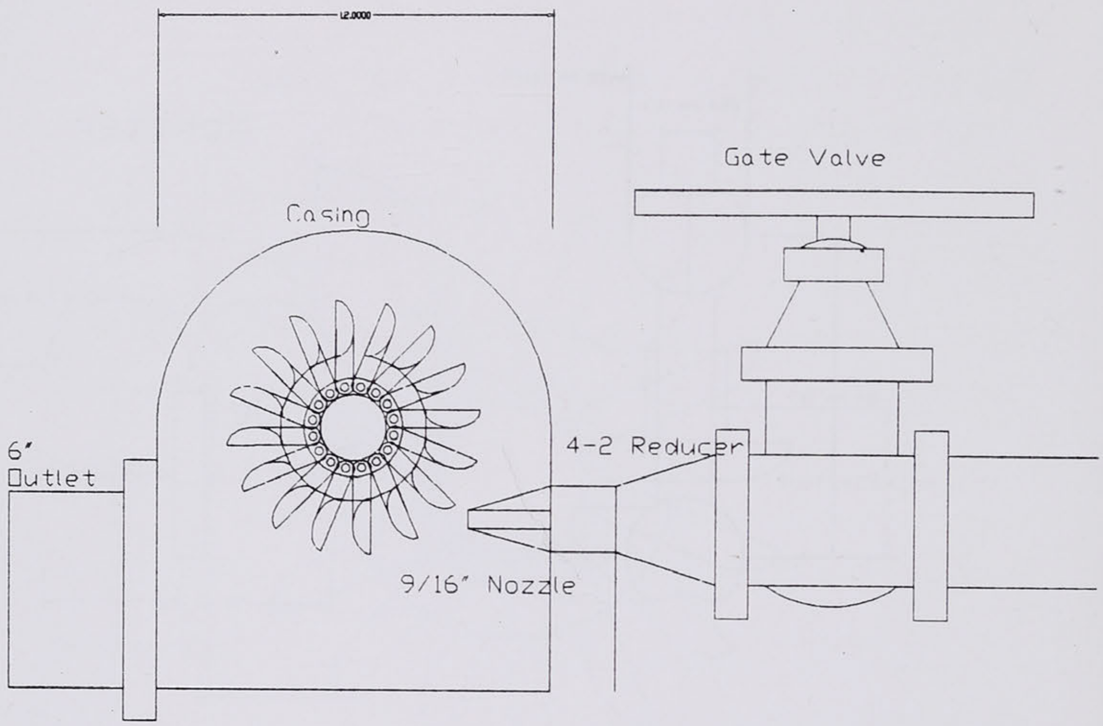
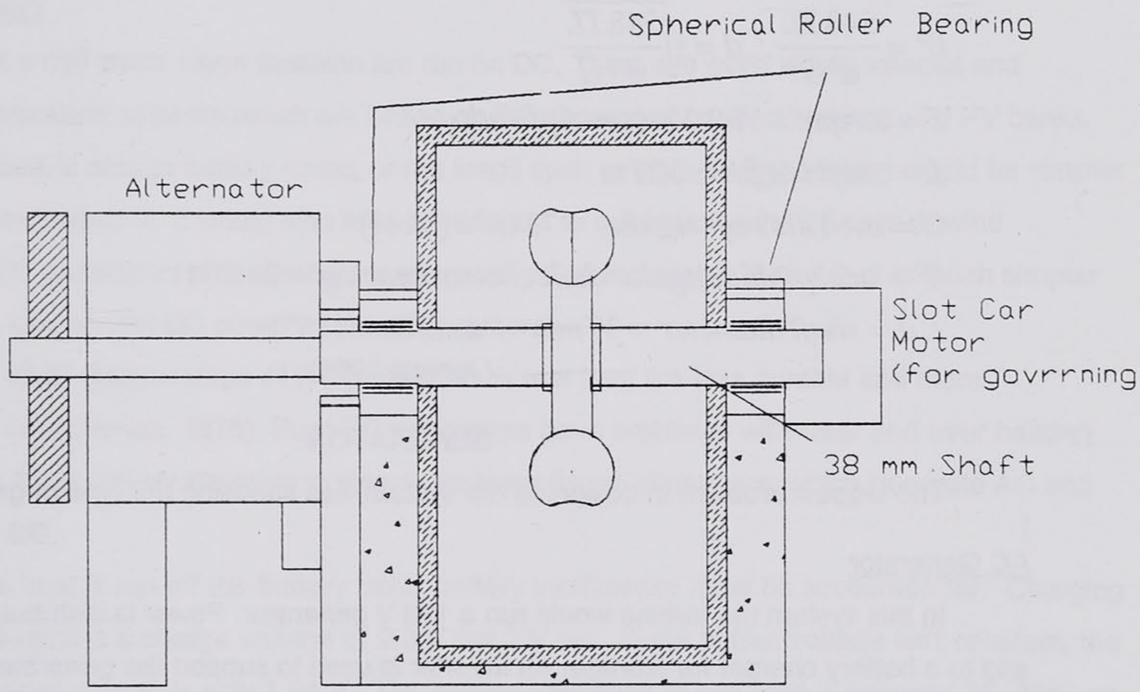


Figure 9. Microhydro Set-Up: Front View



The shaft should be supported on spherical roller bearings, for best durability. Because little or no axial load is a expected, thrust bearings are not used. The appropriate shaft size is about 38 mm (1.5 "), based on a maximum permissible angular deflection of 0.04°.Using a safety factor of 2:

$$\theta^\circ = \frac{548\,TL}{d^4G} \therefore d = \sqrt[4]{\frac{548\,TL}{\theta^\circ G}}$$

$$T = torque = 18.9\,Nm\,(see\ Appendix)$$

$$L = shaft\ length = 0.27\,m$$

$$G = \mathrm{mod}\,ulus\ of\ rigidity = 73\,GPa\,(steel)$$

$$\theta^\circ = acceptable\ angular\ deflection\ at\ bearing = 2x0.04$$

$$\therefore d = shaft\ diameter = 37\,mm \rightarrow use\ 38mm\,(1.5")$$

(Junival,1991)

GENERATOR

The biggest problem in designing the system was choosing the type of generation

]

AC Generator

In this system the turbine would run a 120 V generator. Power is distributed to the load and to a battery charger for storage. An inverter is used to support the generator during peak loads higher than the hydro capacity. Since the remaining appliances calculated as DC loads would constitute a small amount of the load, it would be easier to run the whole system on AC, as opposed to having extra wiring for DC circuits.

One advantage of running an AC generator is that it offers the option of running 120 or 240V with three phase and of stepping up or stepping down voltage for various applications.

AC generation requires running the generator at synchronous speed, as most AC equipment is rated for 60 Hz. Speed fluctuation is not tolerated and must be controlled. This could entail redesigning the turbine with a larger pitch diameter to achieve 1800 RPM, or with a smaller one for 3600 RPM. Another possibility is to use a gearing transmission system which uses V-belts or gears to change the rotational speed at the generator. This would also introduce some inefficiency- between 2-5%. An alternative to mechanical regulation is electronic. Solid state speed governors, which adjust loading to the armature winding to vary torque and control speed, are available for microhydro units. One such unit is used for an Independent Power Developers system.(energyguy) Unfortunately, there was not enough time nor information to assess the performance of this system.

One main drawback of this system is that storage is less efficient due to losses associated with rectification of AC to DC for charging. The other problem is that the freezer compressor may have starting wattage's of up to 6 kW, so that it could not be run directly off the hydro generator, and would have to draw off the inverter.

DC Generator

Most small stand alone systems are run on DC. There are even whole villages and telecommunication systems which are based on DC generated by wind turbines and PV banks. Power is used to charge battery banks or run loads such as pumps. The system would be simpler to control and regulate. It would also lend itself better to expansion with PV cells or wind chargers. DC generators and alternators are usually less expensive than AC. It is much simpler to regulate and control DC power in charging systems.

The main disadvantage of DC generators is that they are less durable and more inefficient. (Hackleman, 1978) Pure DC generators have problems with wear and over heating of brushes. Most battery charging systems use large frame alternators, which generate AC and rectify it to DC.

If the load is run off the battery bank, battery inefficiency must be accounted for. Charging of batteries require a charge voltage of 2.3 V per 2 V cell. Since output voltage isn't constant, the average output voltage is only 1.94 V. The charge efficiency of batteries is between 75- 85%, or it takes 125-115 A of input for 100 A of charge. This makes for a charge/ discharge watt hour efficiency of 100/115 x 1.94/2.30=73% .If DC loads were run directly off the alternator, the alternator couldn't be used for direct charging, as charging demands regulation and tapering of voltage not appropriate for motors and other loads.

DC electricity is less efficient to transmit due to lower voltages and higher currents. If a typical 24 V bank is used, peak loads of 4-6 kW could draw current of 166-250 A, resulting in high resistance losses. Though there is 48 V DC equipment, it is more expensive.

It was decided to use DC generation, mostly due to the simplicity in control. It would use a 24 V AC large frame alternator . The alternator is about 50% efficient.Smead, 1991) The alternator must be rated for at least 2010 W/24 V=84 A; a 90 A alternator would be chosen rated for 2 kW (2.7 HP) continuous duty. It is hooked up directly to the turbine shaft .

STORAGE

One aspect of stand alone systems, especially those utilizing renewable sources of energy, is that power supply is not always equal to the load demand, and unlike grid systems, there is no alternative for routing in outside power or rerouting excess power. Therefore in order to better exploit the power source, some form of storage is desired. Storage can add considerable capital cost and complexity to the system. On the other hand it offers a means of storing off peak power so it can be used to supply peak loads when generation is insufficient. this is particularly useful in this situation where the hydro plant is running 24 hours a day, and is not always able to meet peak loads.

There are various means of storing energy. The ones considered were pumped hydro, hydrogen generation, thermal storage and batteries.

Pumped hydro uses excess energy to pump water to a reservoir, which can be allowed to flow back through the generator during peak loads. It is clean, theoretically simple system, and would appear to be the most suitable if hydro is already the main power supply. The efficiency, from the power source to regeneration is the combined efficiency of the pump (~80%) and the generator using the pumped water(~75%), for a liberal estimate of 60%. However it would mean more land disturbance in order to build a suitable reservoir. It would take about 260 m^3 to store a day's worth of energy. It would also complicate the piping system, involving special controls to regulate and activate the flow.

Hydrogen generation uses excess energy to generate hydrogen gas by electrolysis of water. Hydrogen gas has a high energy value (34.777 kWh/kg). With minor modifications gas engines can be made to operate on hydrogen, and can be used for power generation or running an all terrain vehicle. It could also be used to supply fuel for cooking and water and space heating. The efficiency of hydrogen generation is about 50%. (Peavey,1993) The main problems are involved in storage of the gas. Hydrogen gas is quite volatile and can be dangerous if not properly regulated. Maintenance could prove time consuming. Though hydrogen generation has some potential for remote energy storage, there still needs to be more research.

Thermal storage uses electrical resistance coils to heat some medium such as water, rocks or phase change salts. The medium is stored in a well insulated container. heat can be used for space or water heating using a heat exchanger running through the container. (In the case of using water, the hot water can be used directly). Thermal storage also offers a means to divert excess current when there is no load on the system. the drawback of thermal storage is that the energy can also be used for heating purposes. Also, even with very good insulation, energy leaks out of the store. An alternative to storing heat would be to incorporate a cold store in the freezer system. Since the freezer is the largest load, this could significantly reduce peak loads. Unfortunately this option was considered too late. It would involve more detailed design of the freezer system itself which is outside the scope of the project.

Battery Bank

The most conventional means of storage with stand alone systems is the use of electrochemical batteries. There are many types of batteries available, the most readily available being lead acid batteries. It is a well known technology, relatively simple to manage and easy to incorporate due to the availability of equipment. It is also the most direct means of storing electrical energy. Battery storage has an efficiency of about 70-75%. The problem with battery storage is that battery banks can be quite expensive. There is also a problem from the environmental point of view with disposal of used cells, due to lead acid wastes. In spite of these problems, it was decided to go with battery storage.

Battery banks have their own inefficiencies. The actual capacity of the battery be effected by a number of factors including temperature and rate of discharge. At lower temperatures and higher than rated discharge rates, capacity will be diminished.

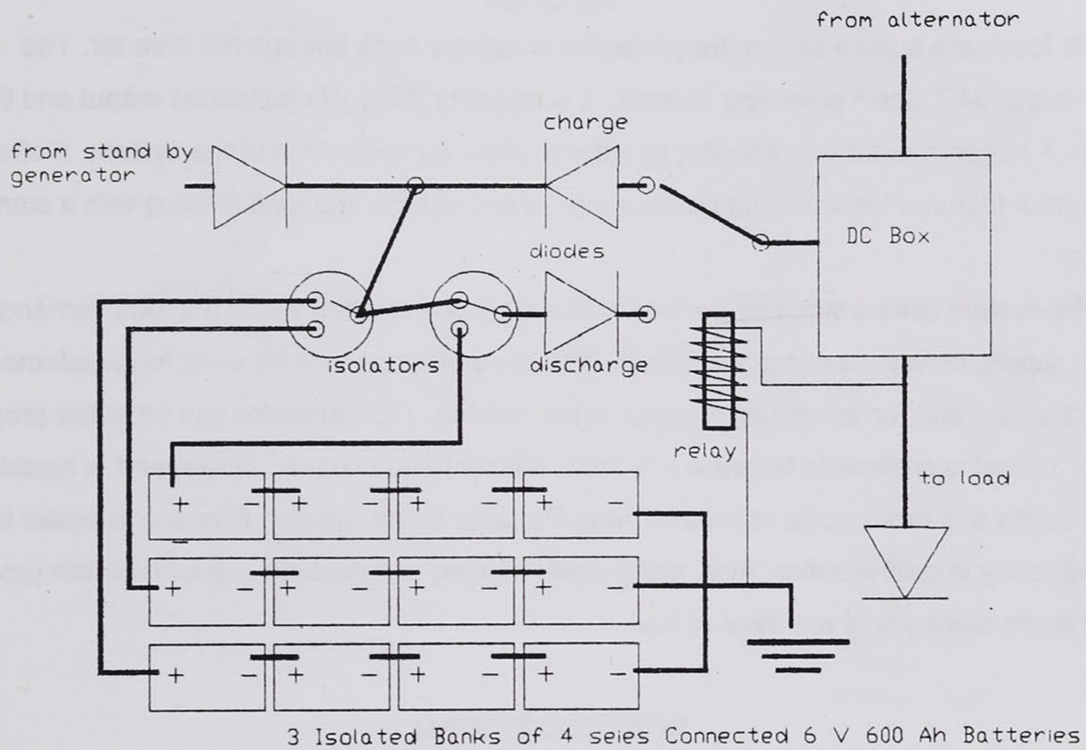
The usual philosophy in designing battery banks for remote systems is to size them to provide at least two days of storage. Though desirable, for such a high load it would require a large, expensive bank. Since the hydro-generator is expected to run all day long, at a fairly constant rate, there is not the no-supply condition typical of wind or PV systems. For emergency back up it is more practical to depend on the fuel generator than a large battery bank. A more feasible approach is to use the batteries for peak load supplement, when the load exceeds the microhydro output. The peak possible load, with everything turned on is 6.8 kW. It is unlikely that all the loads should be running simultaneously for an appreciable length of time. Assuming that the total load is distributed over 8 hours a day, the average load (on the demand side of the storage, including inverter losses) is 4.44 kW. The generator supplies 2.01 kW, directly to the load. This means the battery bank may be expected to supply the deficit. Assuming an energy recovery efficiency of 90%, and a nominal voltage of 24V, the batteries must be sized to supply $\frac{(4440-2010)W}{0.90x\,24V}x8h = 900\,Ah$. Assuming a maximum 50% permissible discharge cycle, this would require a 1800 Ah capacity bank.

The size of the battery bank is limited by the current of the charger. The rule of thumb is to size the charger current to five times the Ah capacity of the bank . If the generator put out 2.01 kW, with a charge efficiency of 85%, and a a charge voltage of 28.8 V for a 24 V bank, the maximum charge attainable is 70 A. Therefore the bank capacity should not be more than 350 Ah. If the bank is only to be discharged to 50%, then the bank can be 700 Ah.

To solve the problem it is possible to use isolators, so in effect there would be three separate banks of 600 Ah. (A lower capacity was chosen for cost effectiveness and simplicity). The isolators can be set to chose the bank to charge or discharge, by sensing the voltage level of each bank. It also allows the banks to go through rest periods.

Heavy duty deep cycle lead acid batteries were chosen . The bank consists of three sets of four series connected 6V 600 Ah L-16 Deep Cycle cells arranged in parallel, with isolators in between each set. The batteries are maintained with a float charge when fully charged. They

Figure 11. Battery Bank



are rated at a 10 hour discharge. They have an 80% discharge capacity. For short periods of very heavy loads will , they can stand deeper discharge than the design 50%. The batteries are stored in a well insulated shack, close but separated from the rest of the system. A fan is provided for ventilation, and a small space heater for emergency heating.

AC Power

AC loads are supplied from the generator or battery bank through the inverter. The inverter is a 2624 Trace™ pure sine inverter. It is rated for 2500 W continuous output and 6000 W surge. A larger inverter was chosen, in order to allow for expansion of the system. It offers many control features for switching power supplies and charge and load sharing with a stand-by generator.

The system uses a stand by generator to supply power when either the load demand exceeds supply, or in case of system failure. The generator can also be used for supplementary battery charging and for equalizing charges when needed. The generator can be either propane or diesel. Diesel is preferable because it is more efficient and cheaper. However it is noisier, more polluting and more prone to break down,. Propane burns cleaner. Propane is easier to start, especially in cold weather. Also, since water heating and cooking is provided with propane, it would mean storing only one type of fuel.

CONTROL SYSTEM

The control system serves to regulate and distribute energy. It consists of current and voltage control, battery chargers, an inverter and a distribution panel. The control system functions to protect the system components. The flow chart of the system is shown in Figure 12.

Table 8. Control Requirements

Hazard	Cause
1)Generator burn out	-Turbine overspeed (change in flow) -low load and batteries fully charged
2)Battery undercharge	-insufficient charge current
3)Battery overcharge	-excessive charge current
4)Battery drainage	-reverse flow to unloaded inverter, or non-spinning turbine

Figure 11. Control and Energy Flow

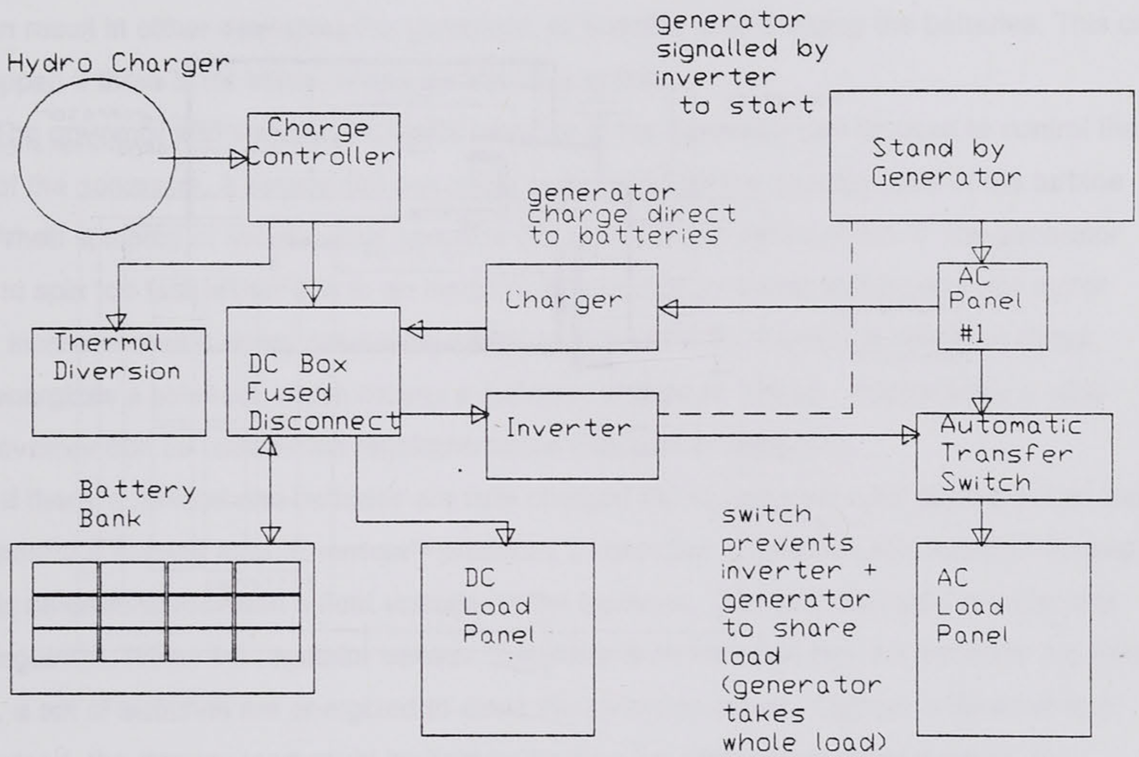
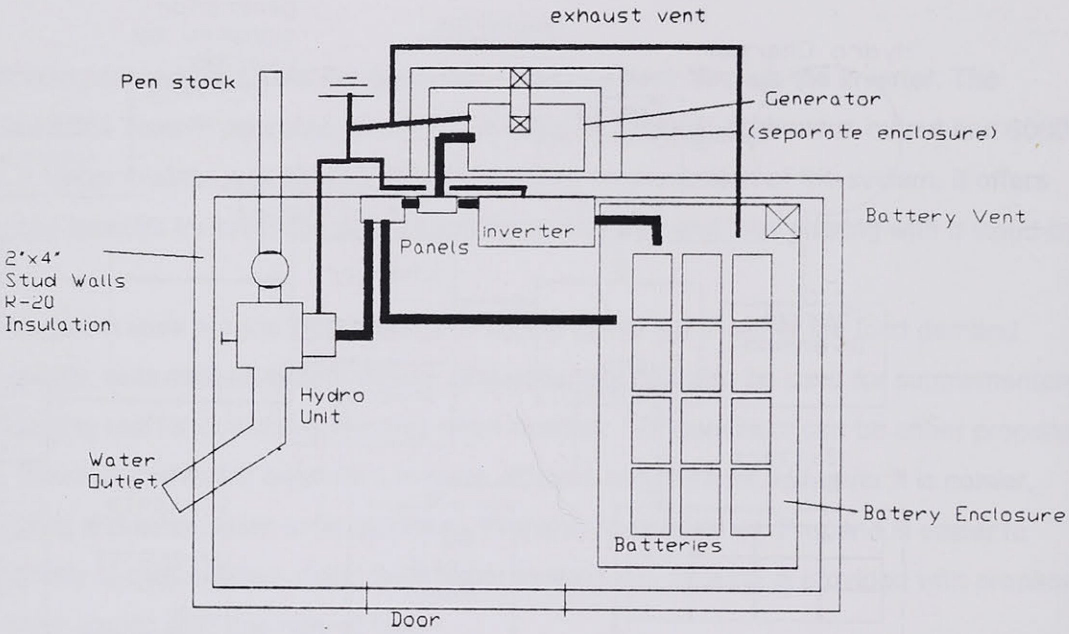


Figure 12. Energy Shed Layout



The alternator has it's own current regulation, which limits current to the maximum rating no matter how much the load tries to draw. A voltage regulator is used to maintain constant voltage level.

If the generator continues spinning without a load, it will spin faster as voltage level rises. This can result in either damaging the generator, or possibly overcharging the batteries. This can also happen if there is for some reason an increase in flow.

The governor and voltage regulation circuitry of the generator can be used to control the speed of the generator. A simple slot car motor is mounted on the opposite side of the turbine shaft. When spinning at synchronous speed, it generates a specified current. If the generator begins to spin too fast, either due to an increase in flow or a reduction of load, the slot motor current increases and it energizes a relay which closes a circuit. Current flows into a circuit which energizes a solenoid, which moves a deflector in front of the jet. Alternatively a solid state governor can be used which regulates speed with field modification.

If there is no load and batteries are fully charged the charge controller diverts power from the source to a dummy load. Enermax™ produces a controller to perform this function. Enough power is diverted to maintain a float voltage on the batteries. The controller acts as a parallel shunt regulator. When the regulator senses that there is no load and that the batteries are fully loaded, a set of switches are energized to close the diversion circuit. Current is diverted to a dummy load. the dummy load could be light bulbs, heating elements or even a motor. For simplicity, heating elements were chosen. Heat is used to heat up a thermal store. The heating elements must be able to divert at least the system supply, 2.01 kW. The heat store is simply a well insulated hot water tank with three 24 V 25 A heating elements.

Current flows from the alternator into a DC load center panel. This panel consists of a breaker box which distributes power to the freezer unit, to a battery charger and to an inverter. Current is allowed to flow only one direction from the alternator to the load and from the DC panel to the inverter by means of diodes.

1. During off load times the alternator is charging the battery bank.
2. When the load is small, current flows from the generator to the load or inverter, and any left over is floated across the batteries.
3. When current levels rise, a switch is energized to allow battery current to flow into the panel.

4. If supply is insufficient, a switch is engaged to switch on the stand by generator. With an auto transfer switch, all AC loads are switched over from the inverter to the generator, which also can be charging batteries.

COSTS

The costs of the system are itemized in Table 9.

Table 9. Component Costs

Item	Cost
PVC Pen stock and Fittings	$1,531.25
Turbine	$1,500.00
Ampex Alternator	$150.00
L-16 Batteries	$4056.00
Enermax Control	$375.00
Heating Elements	$351.00
Trace 2624 Inverter	$1755.00
Relays	$136.00
Automatic transfer switch	$55.00
Load Center	$189.00
Total	$10098.00
+ 6% shipping costs	$10703.00
Cost/ kWh over 10 years	**$0.075**

The site owner operates a cabin construction business. Costs for materials to build the enclosures are not included as the site owner already has access to construction materials. Installation costs were also not included as the site owner is able to do that on his own. It should be noted that costs for items such as conductors and lead batteries are subject to metal market prices.

As can be seen the total cost is larger than anticipated. It should be noted that it is assumed that the system is being paid for in the first year, and is not being financed. With all the components, it's cost is comparable to a fuel generating system over a ten year period. If calculating the pay back period in terms of savings in fuel, based on a diesel fuel cost of $0.09, the payback period works out to about 8.75 years. Inflation has not been accounted for when calculating the fuel equivalent. If escalation of fuel prices were accounted for, it would compare even more favorably. The results would be more favourable over a twenty year period , though the battery banks would have to be replaced after about 8-10 years, depending on how they are maintained, though high quality batteries can last longer.

CONCLUSIONS

As was seen the, capacity of the system after taking into account inefficiencies was lower than anticipated, at around 40%. Literature does cite higher values for micro hydro sites. Cost of energy was also higher than anticipated , though still competitive with fuel over the long run.

There are a few questionable parts of this project.

1. Flow data- more comprehensive hydrological; analysis would need to be undertaken, before implementing any plans

2. Institutional- the legal aspect of obtaining permits was overlooked; it could prove a significant deterrent.

3. Load-More detail should done to assess the appropriateness of the load elements such as the freezer unit. More detailed design or expected operating performance would be in order.

4. Control System-more work and research of control systems needs to be undertaken-it may be possible to better utilize the available power with a better understanding of solid state controls.

5. Other Options There are other possibilities not explored. One example that was suggested is using wood fire to generate steam. Perhaps some heat and electricity cogeneration plant could be set up. The problem would be in preserving the wood lots, and the labour invbolved in cutting wood. It also would create more air pollution.

The system as designed is relatively economical and environment friendly. It should prove to be durable. Though it theoretically will supply the 33 kWh daily load demand, at 39.2 kWh/day (after storage availibility) it is very close and does not leave much margin for error. Overall it will save the consumption of 5470 L of diesel per year; this is a saving in it's cost of $1700. and it's associated pollution emissions.

Appendix A: Load Calculation Spreadsheet

Load	Wattage	Hours/day	Days/week	Watt Hours	AC	DC		Peak Wattage
								40
Lighting								20
Kitchen	40	4	7	1120	1120			15
Bedroom	20	2	7	280	280			30
Bathroom	15	2	7	210	210			20
Living Room	30	3	7	630	630			58
Bunk house	20	4	7	560	560			36
Refrigerator/F	1	540	7	3780		3780		30
Ceiling Fan	36	6	7	1512		1512		30
Stereo	30	3	6	540	540			170
VCR	30	2	5	300	300			25
TV	170	2	5	1700	1700			1150
Short wave	25	12	7	2100		2100		500
Washer	1	250	2	500		500		300
Dryer	1	500	2	1000		1000		0
Food Processor	300	0.1	4	120	120			0
								50
Business								1500
Lighting	50	4	4	800	800			750
Freezer	1500	12	7	126000		126000		0
Hoist	750	0.5	5	1875		1875		0
				0				1500
Greenhouse				0				18
Lighting	1500	8	7	84000	84000			0
Fans	18	24	7	3024		3024		
				0				
			Total kWh/we	230	90	140		
			Per Year	11963	4694	7269		6.24
			Per day	32.86	12.89	19.97		
			Total (Supply Side)		19.29	27.16	##	
Av Power Demand	4.11	kW			15.12	20.37	##	
Average Power Su	4.44	kW						

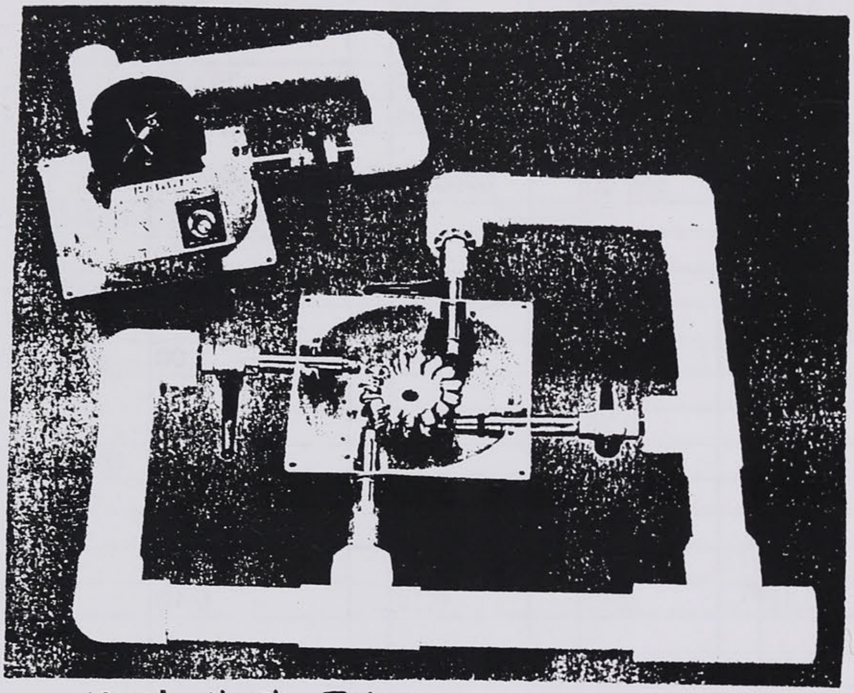
APPENDIX B: Hydro Design Spreadsheet

	100 gpm, 4"pipe, 6"turbine, 1 jets			100 gpm, 4"pipe, 4turbine, 2 jets		
Head (Ht)	78.64	m		78.64	m	
Flow (Q)	0.00631	cum/s		0.00631	cum/s	
Theo Total Power	4.87	kW		4.87	kW	
	6.52	HP		6.52	HP	
Res. Head (Hr)	0.50	m		0.50	m	
Entrance Area (Ae)	0.0034	sqm		0.0034	sqm	
Ent. Diameter (de)	0.065	m		0.065	m	
H. Distance (Lh)	232.50	232.50		232.50	232.50	
Length (L)	245.44	m		245.44	m	
Pipe Diameter (dp)	0.105	m		0.105	m	
Velocity (Vd)	0.73	m/s		0.73	m/s	
Re	76475.21			76475.21		
f	0.019			0.019		
entance loss (ke)	0.78			0.78		
elbows (kb)	0.80			0.80		
T (kt)	0.00	1.10		0.00	1.10	
exit loss (kx)	1.00			1.00		
Valve Losses (kv)	2.00			2.00		
Head Loss (Hf)	1.32			1.32		
Effective (Ha)	77.31	m		77.31	m	
# Jets	1			2		
Jet Velocity (Vj)	38.01	m/s		38.01	m/s	
Jet Area (Aj)	0.000166	sqm		0.000083	sqm	
Jet Diameter (dj)	0.0145	m	0.1889	0.0103	m	
	0.57	in		0.40	in	
Vt/Vj	0.45			0.45		
Turbine Rim Speed (Vt)	17.11	m/s	D/Dj	17.11	m/s	D/Dj
Turbine Pitch Diameter (dt)	0.152	m	10.486	0.102	m	9.886
	6.00			4.00		
Speed (N)	2143.66	rpm		3215.50	rpm	
theta	10.00	degrees		10.00	degrees	
Torque (T)	18.90	Nm		12.60	Nm	
Hydraulic Efficiency (n)	0.87			0.87		
Theoretical Power (Pt)	4.24	kW		4.24	kW	
	5.69	HP		5.69	HP	
Shaft Loss	0.95			0.98		
Transmission Loss	1.00			0.98		
Generator Efficiency	0.50			0.55		
Electric Power	2.02	kW		2.24	kW	
	2.70	HP		3.00	HP	
Energy	48.36	kWh/day		53.78	kWh/day	
Tolerable Line Loss	0.02			0.02		

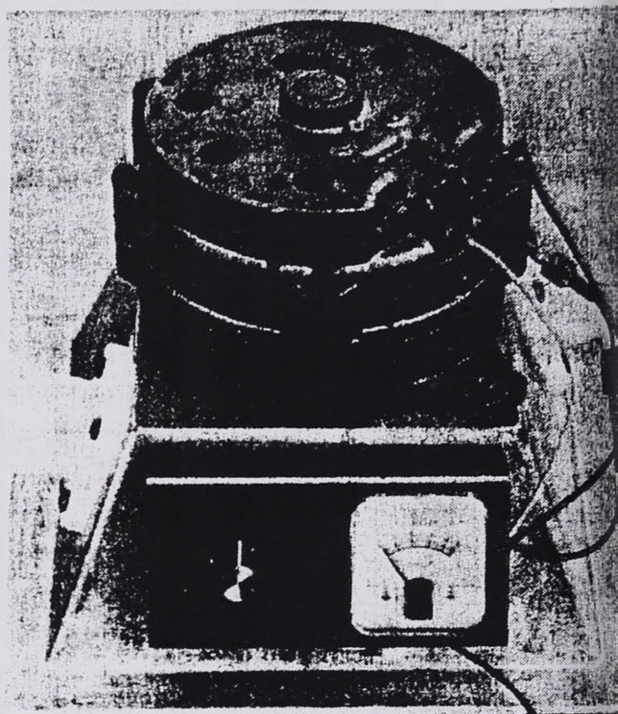
Transmitted Power	1.97	kW		2.20	kW	
Charge efficiency	0.73			0.73		
Inverter Efficiency	0.90			0.90		
Recovered Power	1.55	kW		1.44	kW	
	2.08	HP		1.93	HP	
	37.26	kWh/day		34.63	kWh/day	
	13598.80	kWh/y		12638.41	kWh/y	
Cost						
$/kWh (for 10 years)	$5,000.00			########		
	$0.04			$0.04		
Dimensions						
Nsj	19.26			20.43		
D/dj	0.09	11.22		0.10	10.48	
D	0.163			0.108		
Do/D	1.29			1.31		
Do	0.21			0.14		
w	0.055	2.17		0.039	1.55	
l	0.04	1.70		0.03	1.19	

	Harris	Small Hydroelectric :Peltech 9.75"	Peltech 6"	Basset Home Built	LVS (turgo)	Independant Developers
Flow(cum)	0.01	0.05	0.03	0.02	0.00	0.01
Head (ft)	192.40	200.00	200.00	60.00	200.00	393.70
(m)	58.64	60.96	60.96	18.29	60.96	120.00
Speed (RPM)	2969.85	1212.00	1903.49	550.00	3250.50	3600.00
Power (HP)	2.58	29.50		3.75	0.89	6.70
(kW)	1.92	22.01	15.67	2.80	0.67	5.00
Nozzles	4.00	2.00	2.00	1.00	1.00	1.00
Efficiency	0.53	0.79	0.77	0.75	0.71	0.52
Nsj	12.69	23.60	31.28	24.32	15.58	20.27
D (in)	5.00	9.75	6.00	12.84	4.00	4.00
(m)	0.13	0.25	0.15	0.33	0.10	0.10
Dj/D2	0.06	0.11	0.16	0.12	0.07	0.09
Dj(in)	0.28	1.10	0.96	1.51	0.28	0.38
(m)	0.01	0.03	0.02	0.04	0.01	0.01
Do/D	1.20	1.35	1.46	1.36	1.24	1.31
Do(in)	6.01	13.18	8.74	17.48	4.97	5.22
(m)	0.15	0.33	0.22	0.44	0.13	0.13
For Site Values						
Q	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063
H	77.31	77.31	77.31	77.31	77.31	77.31
i	1.00	1.00	2.00	1.00	1.00	1.00
power	2.53	3.77	3.66	3.61	3.37	2.48
speed	1829.60	2787.95	5298.03	2935.88	1945.15	2952.00

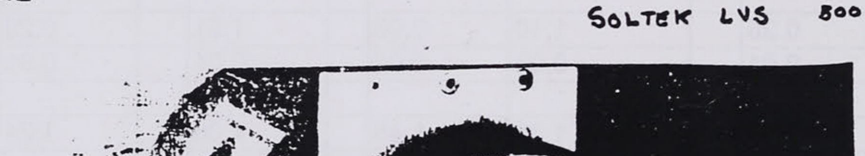
APPENDIX E: Commercial Components



1500 W Harris Turbine



SOLTEK LVS 800 W Turgo Turbine



5 kW 120V AC - Independant Power Developers

APPENDIX D: Pictures of Site

CABIN SITE
(BEFORE
CONSTRUCTION)

SITE
WITH
CABIN

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