Water Service System Concept Design Generation and Evaluation for a Remote Village in Nepal

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Improved access to clean drinking water greatly benefits impoverished communities.
Source: Zahnd (2007).

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Kris Robinson
15 September 2007

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I have been very fortunate to be given a great opportunity to be involved in an extremely rewarding and satisfying project which contributes to the continual development of a remote and impoverished community in Nepal. It has been a very challenging project and I have learnt a great deal from this experience. Probably the most important thing I can take away from this project is an appreciation of the hardships and difficulties some people have to face in the world to maintain a sustainable livelihood. I would like to give thanks to many people who made the following work possible.

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ABSTRACT

Pamlatum, a remote and impoverished village located in the Humla district of Nepal, is in need of improved access to clean water. A village assessment and field survey was conducted in April 2007 by Rural Integrated Development Services Nepal, in collaboration with Engineers Without Borders. This provided the groundwork for the formulation of a number of customer requirements for an improved water service system. The Quality Functional Deployment process was used to translate the customer requirements into measurable engineering targets which provided the framework to generate, develop and evaluate a range of concept designs for developing a suitable water service system for Pamlatum. This lead to the development of a solar-powered water pump concept design incorporating a slow sand water filtration and purification system. This system has the capability to be robust, reliable, efficient and long lasting with the potential to supply adequate supplies of clean water to Pamlatum, providing immeasurable benefits to the village community and the local environment. However, further research, design development and refinement of the analysis and results will need to be undertaken to develop a system that can be maintained by the local village community. Problems associated with the transportation and installation of the concept design, due to the large equipment and material loads required, also need to be overcome. It is also questionable whether the Pamlatum community can afford the water services over an extended period of time. Without addressing these issues, it is unlikely that the village community will endorse and take ownership of the water service system.

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List of Acronyms

AC	Alternating Current
ADB	Asian Development Bank
AIT	Asian Institute of Technology
ANU	Australian National University
AS	Australian Standard
DC	Direct Current
EWB	Engineers Without Borders
FMEA	Failure Mode and Effects Analysis
HARS	High Altitude Research Station
IAM	Incidence Angle Modifier
MDG	Millennium Development Goal
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
NASA	National Aeronautics and Space Administration
NGO	Non-Government Organization
NTU	Nephelometric Turbidity Units
NZS	New Zealand Standard
O&M	Operation and Maintenance
PE	Polyethylene
PSH	Peak Sun Hours
PV	Photovoltaic
QFD	Quality Functional Deployment
RIDS	Rural Integrated Development Services
SPWP	Solar-Powered Water-Pump
STC	Standard Testing Conditions
TDH	Total Dynamic Head
UN	United Nations
UNDP	United Nations Development Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNICEF	United Nations Children’s Fund
UV	Ultraviolet Radiation
WHO	World Health Organization

Aims & Contributions

The overall aim of this project is to contribute to improving the accessibility of safe drinking water for a remote and impoverished mountain village called Pamlatum, located in the Humla district of north-western Nepal. This project was developed in collaboration with Rural Integrated Development Services Nepal and Engineers Without Borders. The specific aims and contributions of this project are to:

- Understand how this project fits into the broader context of the world water situation.
- Understand the parameters which define the accessibility to water.
- Understand the parameters which define safe drinking water.
- Conduct a village assessment of Pamlatum and surrounding villages to identify population and migration movements, skills and education, current community development projects in operation, current water supply situation and local natural resources.
- Use the Quality Functional Deployment process to develop a framework for generating and evaluating water service system concept designs for Pamlatum.
- Develop customer water service system requirements based on the village assessment and conducted research.
- Compare the existing water service system against the village water service requirements to serve as a benchmark for future designs.
- Translate the village water service requirements into specific and measurable engineering targets for generating concept designs.
- Generate and describe a solar-powered water-pump concept design for increasing Pamlatum's accessibility to safe drinking water.
- Model and simulate the performance of the concept design using the software package PVSyst v4.1.
- Analyse and discuss the potential performance results of the concept design including the general installation, maintenance, costs, safety, social, environmental and standards compliance issues.
- Critically evaluate the potential of the concept design in relation to the customer water service system requirements.
- Summarise the technical, social, economical and environmental sustainability of the design.
- Provide conclusions for this project including recommended further work.

The scope of this project does not include:

- Understanding or analysing the village, local and regional level capabilities and capacities for affording, manufacturing, supplying, installing and maintaining the concept design.
- Providing a cost estimation based on Nepalese currency and prices. All costs are based on Australian dollars and retail prices.
- A detailed design of the concept design and its components.

Chapter 1 Introduction

The water is not good in this pond. We collect it because we have no alternative. All the animals drink from the pond as well as the community. Because of the water we are also getting different diseases. Zenebech Jemel, Chobare Meno, Ethiopia

They [the factories] use so much water while we barely have enough for our basic needs, let alone to water our crops. Gopal Gujur, farmer, Rajasthan, India

Two voices from two countries united by a single theme: deprivation in access to water (UNDP 2006).

1.1 WORLD WATER & SANITATION SITUATION

Access to clean potable water is essential for human health and survival. Water is required for our everyday basic needs such as drinking, personal hygiene and food preparation. Without water, life cannot be sustained beyond a few days and the lack of access to adequate supplies leads to the spread of disease (WHO 2003). Access to improved sources of water such as piped water into a dwelling, public standpipe, borehole, protected spring or rainwater collector are readily accessible to the developed world. However, many people in developing countries are only able to access water from unimproved sources of water such as surface water from a river or dam and unprotected springs. Water from unimproved water sources is often difficult to access and unsafe to drink. The World Health Organization (WHO) and The United Nations Childrens Fund (UNICEF) (2006) estimate that 1.1 billion people in the world have no access to improved sources of water, and 2.6 billion have no access to any form of improved sanitation services. As a consequence, 1.8 million children under the age of five die every year from preventable diseases associated with the lack of safe drinking water and poor sanitation (UNDP 2006). Most of these deaths occur in undeveloped rural communities (WHO and UNICEF 2005).

International commitment to improving access to safe drinking water and sanitation services are reflected in a broad vision set out by the Millennium Development Goals (MDGs). The MDGs are an internationally agreed set of time-bound goals for reducing extreme poverty, extending gender equality and advancing opportunities for health and education. MDG Target 10 calls for the world to halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation (ADB *et al.* 2006). When taking into account population growth, an additional 1.6 billion people will need access to improved sanitation and safe drinking water over the period 2005 to 2015. If trends since 1990 continue, the world is likely to miss the target by almost 600 million people (UN 2007).

1.2 DOMESTIC WATER QUANTITY, SERVICE LEVEL & HEALTH

WHO (2003) covers the impacts water accessibility has on domestic water consumption, health and hygiene. The supply of water for basic needs have direct consequences for health, both in relation to physiological needs and in the control of diverse water-related disease. For poor rural and urban communities, the basic need for water may extend further to include water for productive uses in growing food so that livelihoods can be sustained. Estimates of the volume of water needed for basic needs vary widely. For instance, WHO (2003) summarises the water quantity recommendations produced by three different papers. Sobsey (2002 cited WHO 2003) sets out 15 litres of water used per capita per day as being a key indicator in meeting minimum standards for disaster relief. WELL (1998 cited WHO 2003) suggested that a minimum criterion for water supply should be 20 litres per capita per day. Gleick (1996 cited WHO 2003) suggested that the international community adopt a figure of 50 litres per capita per day as a basic water requirement for domestic water supply.

The volume of water used by a household depends on accessibility as determined primarily by distance and time in accessing the water source, but also includes reliability and potentially cost (WHO 2003). Reliability depends on the continual supply of water, whether it be river water, groundwater or rainwater. Reliability also depends on the performance of any infrastructure used in the delivery of water. The cost of water can also potentially impact the accessibility of water. If the cost per unit of water is too expensive, disadvantaged households with low incomes may not be able to afford an adequate volume of water for basic needs. The cost of operation and maintenance of any water supply infrastructure is also a limiting factor for water accessibility. If a community cannot access skilled technicians, materials and spare parts to keep the water supply infrastructure maintained at a reasonable cost, it is likely that the community will abandon the required maintenance activities. System failure will eventuate and thereby disrupt the access to water supplies.

A lack of sufficient access to domestic water supplies may result in poor hygiene (WHO 2003). Poor hygiene is linked to diarrhoeal disease which is a major health concern throughout the world, especially in young children. Despite the evidence pointing to the health benefits of increased quantities of water, the relationship is not simple. Most research has made significant assumptions about water use (WHO 2003). Hygiene is not solely related to availability of water, but also to specific hygiene behaviours such as hand washing at critical times (WHO 2003).

1.3 WATER QUALITY

Diseases related to contamination of drinking water constitute a major burden on human health. WHO (2006) describes the reasonable minimum requirements for safe practice to protect the health of consumers, as well as deriving numerical "guideline values" for constituents of water or indicators of water quality. The great majority of evident water-related health problems are the result of microbial contamination (WHO 2006). The greatest risk from microbes in water is associated with consumption of drinking water that is contaminated with human and animal excreta (WHO 2006). The usual practice for evaluating water quality is to measure the critical parameters which are normally *Escherichia Coli* (*E.coli*), chlorine, turbidity and pH (WHO 2003).

1.4 PROJECT BACKGROUND

My project is focused on improving the accessibility to safe drinking water for a remote village in Nepal called Pamlatum. Pamlatum is one of four villages within a 600m radius that have been identified by Rural Integrated Development Services Nepal (RIDS-Nepal) to have poor access to a clean and safe water supply. My project is in collaboration with RIDS-Nepal and Engineers Without Borders (EWB). It has been envisioned by RIDS-Nepal to install an upgraded water service system for Pamlatum and thereby improving the accessibility to safe drinking water for the village community. A set of customer requirements and design specifications will be formulated which will be used to generate a solar-powered water-pump (SPWP) concept design for the water service system. Only one design concept will be generated due to the scope of this project, however a framework will be developed for the generation of additional future concept designs. The framework will also allow future concept designs to be evaluated against each other to aid in the selection of a final design. When a final design is selected and funding is granted for the project, the detailed design phase of the project will be initiated and expected to start during 2008. If funding is granted, installation of the water service system is planned to commence at the end of 2008. This project is part of a wider long-term holistic community development program operated by RIDS-Nepal.

1.5 RURAL INTEGRATED DEVELOPMENT SERVICES – NEPAL

RIDS-Nepal is a social (non-profitable) Non-Government Organization (NGO). Its projects are financed in partnership with *The ISIS Foundation* as well as by donations from individuals, charities, communities and International NGOs. The vision of RIDS-Nepal is to enable individuals and communities to improve their living conditions and livelihood through long-term Holistic Community Development (HCD) projects (Zahnd 2007). RIDS-Nepal's current working area is mainly focused on the Humla district of north-west Nepal, which is the least developed area of Nepal. Alex Zahnd is the project director for RIDS-Nepal. He is also Assistant Professor at the Mechanical Engineering Department at Kathmandu University in the field of renewable energy and HCD. Alex Zahnd is at the forefront of HCD in the Humla district. The HCD projects are implemented by harnessing local renewable energy resources through applied renewable energy technologies, utilising local resources and skills, and developing close partnerships with local communities.

Alex Zahnd has written a number of papers in HCD for the Humla region. One in particular is his case study for a solar photovoltaic elementary lighting system for a poor and remote mountain village in Nepal. In his paper, Zahnd (2004) provides an in depth view into the energy and poverty scenario of the Humla region, electrification in Nepal, lighting technologies and a design for a household solar lighting system that was installed in the village of Chauganphaya. He concludes that bringing light to households has improved the livelihood and advancement of the village community. He also stresses the importance of a grass-roots holistic approach to community development by implementing appropriate and sustainable smokeless stoves, pit latrines and clean drinking water projects. Zahnd has named these services along with lighting the '*Family of Four*'. These services have provided impoverished communities of Humla with some basic life essentials. The *Family of Four* has been extended to include nutrition for mal nourished children (under five years of age), greenhouses for increased crop yield, solar driers for extended food storage and education programs. The synergetic effect of all these projects outweighs many times over the effect and benefit of each individual project (Zahnd 2004).

Chapter 2 Water Accessibility & Quality Parameters

The following sections introduce the reader to the parameters that affect water accessibility and quality which provide some groundwork in establishing the customer requirements.

2.1 WATER ACCESSIBILITY

WHO (2003 p.22) categorises water accessibility in terms of service level shown in Table 1.

Table 1: Summary of water access requirements to promote health.

Service level	Access measure	Needs met	Health Concern
No access (0-5 l/c/d)	> 1000m or > 30 minutes	Consumption cannot be assured. Hygiene only practiced at source	Very high
Basic (5-20 l/c/d)	100-1000m or 5-30 minutes	Consumption should be assured. Hand washing/basic food hygiene possible.	High
Intermediate (~50 l/c/d)	<100m or <5 minutes	Consumption assured. Personal/food hygiene assured; laundry/bathing should be assured.	Low
Optimal (>100 l/c/d)	Instant Access	All consumption needs met. All hygiene needs should be met.	Very low

2.2 WATER QUALITY

A summary of the parameters that WHO (2006) uses to define water acceptable for drinking are presented in Table 2. The indicator organism of choice for faecal pollution is *E.coli* as it is an important parameter for verification of microbial quality. Infection from microbial organisms is associated with person-to-person transmission, contact with animals, food and consumption with water that is contaminated with human and animal waste. Water turbidity is another important parameter for assessing suitable drinking water quality. Turbidity in water is caused by suspended particulate matter washed into or stirred up by the river system. Water with a turbidity level of less than 5 NTU is usually acceptable to consumers. The other water quality parameters that should be measured include the pH and chlorine levels. The quality of the water sources surrounding Pamlatum have been measured and are presented in Chapter 3. Only *E.coli* and turbidity parameters have been discussed in detail throughout this paper and there will be no further discussion of pH or chlorine. The Nepalese standard for *E.coli* concentrations are less than 10 colonies per 100ml (Hiller 2007).

Table 2: Acceptable water quality parameters recommended for drinking.

Water Quality Parameter	Acceptable Limits for Drinking
E. coli (colonies per 100ml)	Nil – WHO (2006) <10 – Nepalese Standards (Hiller 2007)
pH	6.5 - 8.5
Chlorine (mg/l)	residual >0.5
Turbidity (NTU)	5 (acceptable for drinking) <1 (desirable for effective disinfection)

Chapter 3 Pamlatum Village Assessment

In April 2007, RIDS-Nepal and EWB collaborated on an assessment of four villages in the Humla region, namely Pamlatum, Dingha, Chauganphaya and Dharapori. These villages have poor access to a clean and safe water supply. All villages, except for Dharapori, share the same water service infrastructure which supplies fresh water to the village via a gravity-fed system which taps into a local mountain spring. Dharapori accesses fresh water from a similar system but from a different spring source. Brad Hiller from EWB, and Sujit Thakuri and Sher Bahadur Budha from RIDS-Nepal, conducted a field investigation of the region and surveyed the village members on the use of their existing water service system. In the following sections I provide an introduction into the Humla district followed by a summary of the village assessment with particular attention to Pamlatum village. The information in the following sections is a summary of the village assessment report produced by Hiller (2007) and personal communications with Alex Zahnd. Some of the photos taken during the village assessment are presented in *Appendix A, p.57*.

3.1 INTRODUCTION TO THE HUMLA DISTRICT OF NEPAL

The Humla district is located in north-western Nepal with the town of Simikot (Figure 1) as the regional headquarters. Humla is an extremely remote and mountainous area of Nepal and there are no roads or rail into Humla and Simikot. The main access route into Humla starts from the city of Nepalganj in the country's south-west.

Figure 1: Map of Nepal. Source: Zahnd (2007).

Because of the remoteness and difficult access into the Humla district, 99% of the population live by subsistence farming with little or no cash economy in small village communities (A. Zahnd, personal communication, 2007). These villages generally have no access to urban infrastructure such as electricity, piped water into dwellings, sewage and waste disposal and other basic urban services. Life for the people of Humla is extremely challenging. The annual growing season is only 3-4 months and is bracketed by a long and fairly severe, cold and snowy winter. Villagers are perennially affected by food shortages, and people survive the winters only with the assistance of the Government rice provision program. Because families are so focused on food production, children must help and can rarely be spared to go to school. In addition, a day's walk to remote health clinics cannot be afforded. Public health and sanitation in this area is largely unknown, and water and latrine projects have only recently been introduced and are not yet widely distributed (A. Zahnd, personal communication, 2007).

3.2 PAMLATUM VILLAGE

3.2.1 Location

To reach Pamlatum village (Figure 2), one has to either walk a 17 day trek through the Himalayan mountain range, or take a one hour adventurous flight over and through the mountain valleys to Simikot, followed by a day's walk. Pamlatum is located at an altitude of 2611m, a latitude of N 30˚ 00′ 49.16″ and longitude of E 81˚ 46′ 14.57″.

Figure 2: Pamlatum, Dingha, Chauganphaya and Dharapori villages. Source: Google (2007).

3.2.2 Population, Education & Skills

Pamlatum village has 26 households and a population of 178 people. Pamlatum has 371 head of livestock which is predominately goats and sheep. The villages studied are considered poverty-stricken, with Pamlatum the poorest of the four. While the villages of Dharapori and Dingha contain both literate community members and some skilled tradespeople, the capacity of Pamlatum village seems more limited. Twenty to twenty-five children within Pamlatum attend school and one village member is skilled in house construction. The presence of a regional school located in Chauganphaya would suggest the presence of some educated community members. This school contains 300 students aged 7 to 18 years old from the upper Humla valley.

3.2.3 Community Participation Record

Many village members are already actively involved in a number of community development projects. RIDS-Nepal has helped facilitate HCD projects in all villages under study except for Dingha. Pamlatum village has been fitted with smokeless metal stoves for cooking and heating, pit latrines and solar powered indoor lighting. Greenhouses for increased crop yield, household-level slow sand water filters, nutrition and education programs are planned for implementation during 2007. The record of involvement of villagers in past schemes may provide an insight into the village's capacity to welcome new technologies and also their record of maintenance of previously installed systems.

3.2.4 Seasonal Migration

During the months from April/May to September/October, a significant proportion of the village population migrates from the village into higher altitude mountain regions with their livestock (Figure 3). In Chauganphaya village for example, where the total population is approximately 320, it is estimated that approximately 200 people would remain in the village during summer while the remaining 120 people would live in the hills. Village members migrate due to the food shortage that exists during the summer months for both humans and livestock in the areas around the village and the fact that the temperature is milder at higher altitudes during the hot summer months. During their time at altitude, people graze their larger livestock on the more plentiful pastures and some people will cut logs for transport and trade. In June and July, many people will make the three to five day walk (depending on weight of trading goods) from their highland outposts to the Chinese (Tibetan) border. The trade of animals and logs in China is a crucial source of income for the Humla people and probably represents the bulk of their annual income.

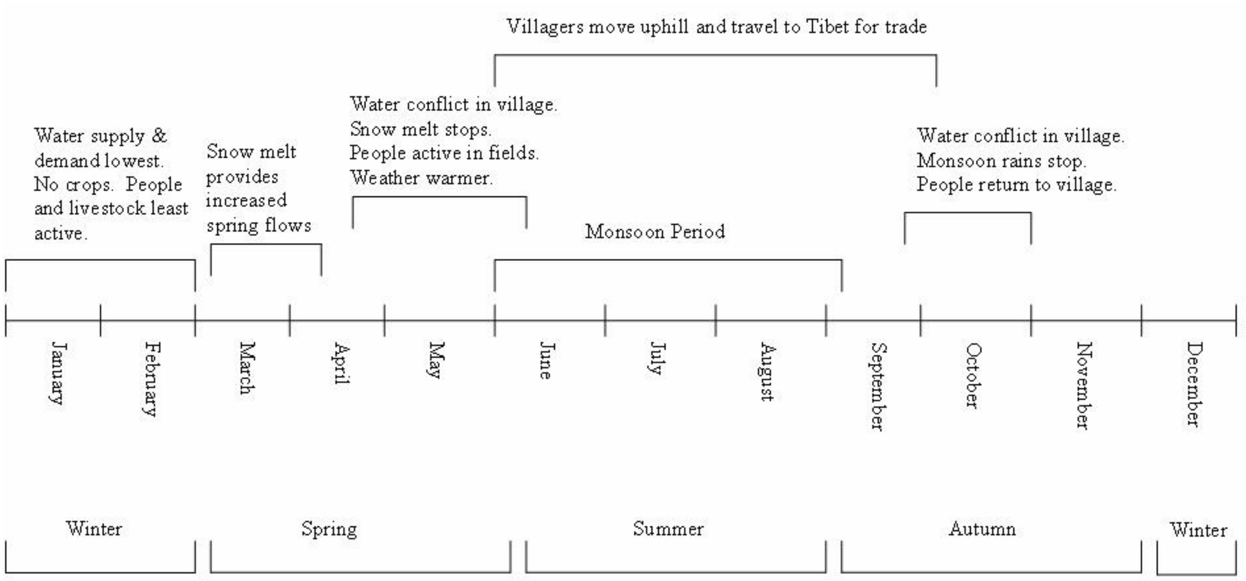


Figure 3: Annual calendar for Humli households in relation to water demand.

3.2.5 Terrain

Pamlatum is situated on a south-facing mountain side, which is ideal for northern hemisphere solar applications. The slope of the village towards the Hepka River is very steep and treacherous with an average slope of 33˚. Figure 4 shows the cross-section of the mountainside terrain along with the locations of some of the existing gravity-fed water service system infrastructure.

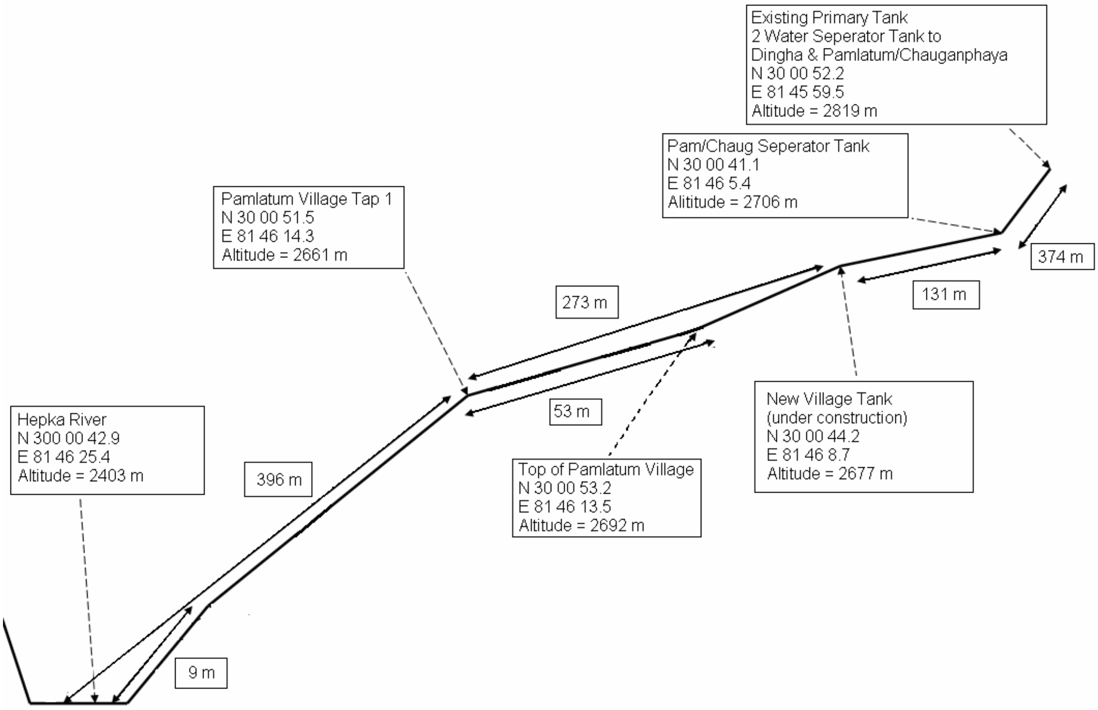


Figure 4: Cross-section of the terrain leading up to Pamlatum village from the Hepka River

3.2.6 Hepka River

The local river for Pamlatum is the Hepka River, which is located approximately 400m on a diagonal slope from Pamlatum Tap 1 (approximately 260m altitude difference). The Hepka River feeds into the larger Karnali River near Dharapori village (Figure 2). Both rivers serve as a valuable water resource for the region. Table 3 summarises the quality and geomorphology of the Hepka River water measured as part of the field investigations during April 2007 (spring). River discharge measurements were taken when flow rates were high due to the winter snow melt. Summer flow rates are also high due to the monsoon rains. Flow rates are at their lowest during winter.

Table 3: Hepka River quality and geomorphology measurements for April 2007.

Coordinates of measurements taken:		N 30˚ 00′ 2.9″; E 81˚ 46′ 5.4″	
Hepka River Geomorphology		**Hepka River Water Quality**	
Width (m)	8	*E.coli* sample (colonies per 100ml)	34-38
Avg. Depth (m)	0.7	Turbidity (NTU)	12
Cross-Sectional Area (m^2)	5.6	pH	7.2
Velocity (m/s)	0.9	Total CI (chlorine)	0.1
Discharge (m^3/s)	5	Free/Residual CI (chlorine)	0.1
Daily Discharge (l/day)	432,000,000	Water temperature (˚C)	5-14

Although seasonal turbidity data is not available, it is anticipated that turbidity levels will be highest in the summer monsoon months and least during winter. Turbidity levels in summer are expected to be twice the level in spring (A. Zahnd, personal communication, 2007). Anecdotal evidence (A. Zahnd, personal communication, 2007) suggests that the concentrations of *E.coli* measured in the Hepka River during spring would be equivalent to concentrations expected in autumn. Winter levels would be lowest (perhaps 50% of spring values) while summer concentrations may be two or three times higher than those measured in spring. In either case, concentrations of *E.coli* render the water unsuitable for drinking.

It is important to note that the Hepka River was sampled near the bridge leading up to Dharapori village. It is anticipated that if the Hepka River was sampled for *E. coli* further upstream, the concentrations would be somewhat reduced. Beyond Dingha and Pamlatum villages, only two other small villages lie further up the Hepka River valley. Both villages are significant distances away from the river and thus do not pose a direct danger to the river's water quality (A. Zahnd, personal communication, 2007).

3.2.7 Local Climate

The hourly temperature for the entire year during 2006 was measured at the High Altitude Research Station (HARS) in Simikot. Simikot is at a similar altitude and experiences similar weather patterns to Pamlatum. The seasonal temperature range for 2006 was -6.72˚C to 31.14˚C. On average, over 700mm of precipitation throughout the year falls on the Humla region (Stakhouse *et al*. 2007). The monthly total precipitation is shown in Figure 5.

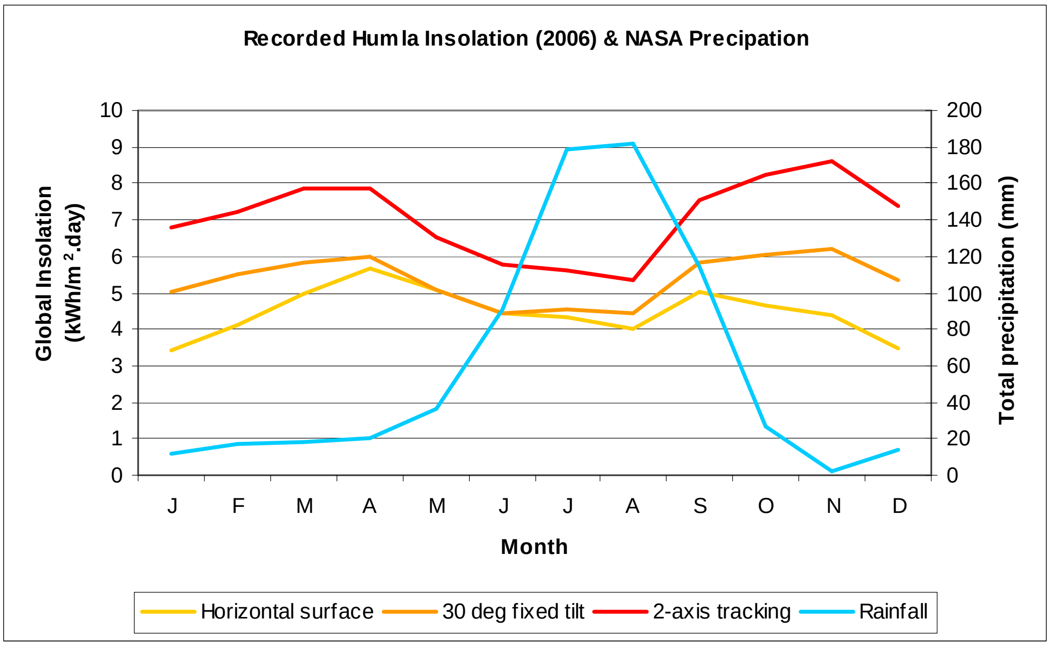


Figure 5: Averaged solar insolation and total precipitation for Humla.

The Humla region enjoys around 300 sunny days per year. On average throughout the year, Humla receives 4.5 kWh/m^2.d or 4.5 Peak Sun Hours (PSH) of energy from the sun on a horizontal surface. For a 30˚ fixed-tilted surface, the year average solar insolation is increased by over 20% to 5.4 kWh/m^2.d per day (5.4 PSH), and for a two-axis tracking surface the year average is further increased by over 31% to 7.1 kWh/m^2.d per day (7.1 PSH). Figure 5 presents the average daily solar insolation for horizontal, fixed 30˚ fixed-tilted and two-axis tracking surface available for each month. The warmer months of May to August correspond with the monsoon season and hence increased cloud cover and decreased solar insolation, as opposed to an expected increase in solar insolation due to more daylight hours and increased intensity in solar irradiation. Recorded climate figures are shown in *Appendix B, p.60.*

3.3 EXISTING WATER SERVICE SYSTEM

3.3.1 Gravity-Fed Water Service System Layout

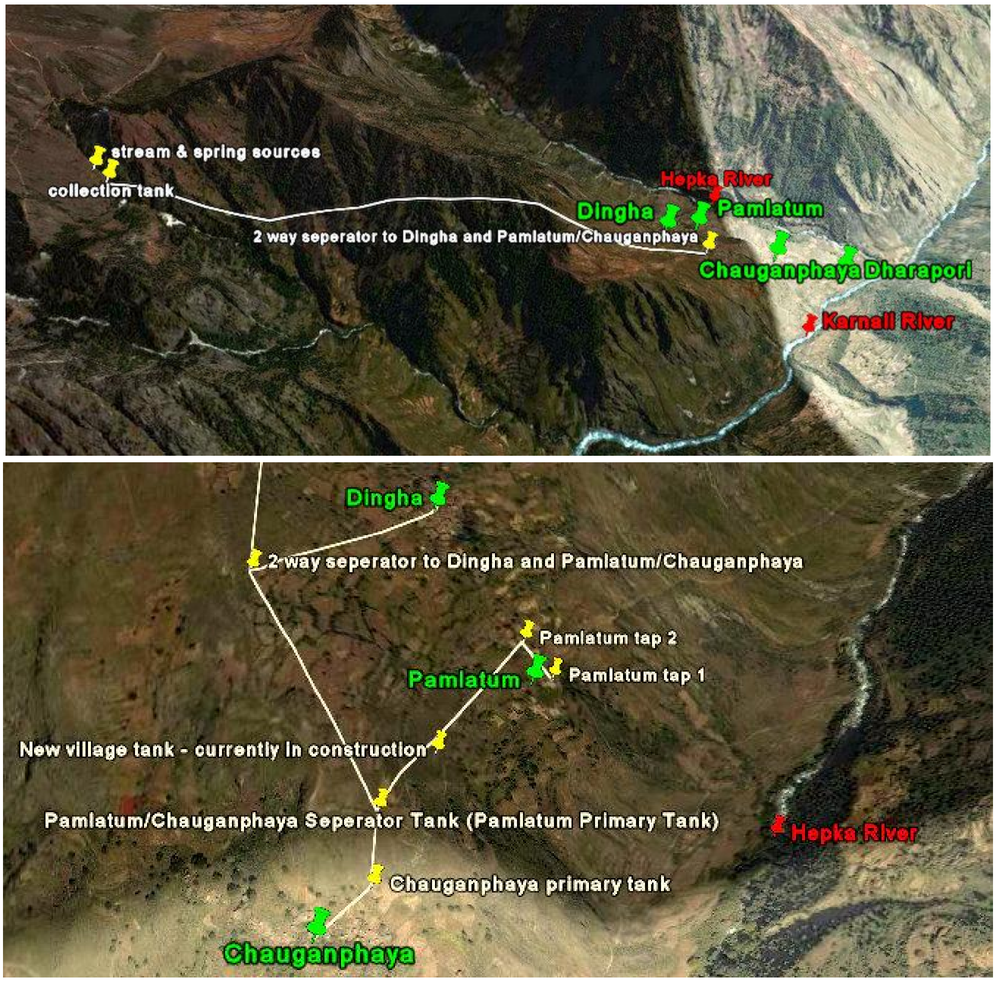


Figure 6: Layout of existing water service system infrastructure. Source: Google (2007).

Pamlatum, Chauganphaya and Dingha currently source their water from a natural spring source located approximately 4km (4 hour walk) upstream from Pamlatum village (Figure 6). The spring water is fed into a collection tank and distributed to a separator tank via polyethylene (PE) pipe. This separator tank diverts water between Dingha, Pamlatum and Chauganphaya villages. Water diverted to Chauganphaya and Pamlatum is fed into another separator tank located further down the hill. This separator tank diverts water between Chauganphaya and Pamlatum villages. Water diverted to Pamlatum travels to two tap outlets located within the village (only Pamlatum's water taps are shown in Figure 6).

3.3.2 Water Flow Rates

Figure 7 presents the water flow rates supplied to Pamlatum by the gravity-fed system. Water flows into Pamlatum at a rate of 0.2 litres per second. There are two taps within Pamlatum village that flow continuously 24 hours a day at flow rates of 0.125 (tap 1) and 0.012 (tap 2) litres per second. There are distribution losses within the system which are caused by leaks from pipes and tanks. Table 4 summarises Pamlatum's water supply including the quantity of water supplied and lost over the course of the day. Water flows out of taps at a relatively constant rate throughout the year.

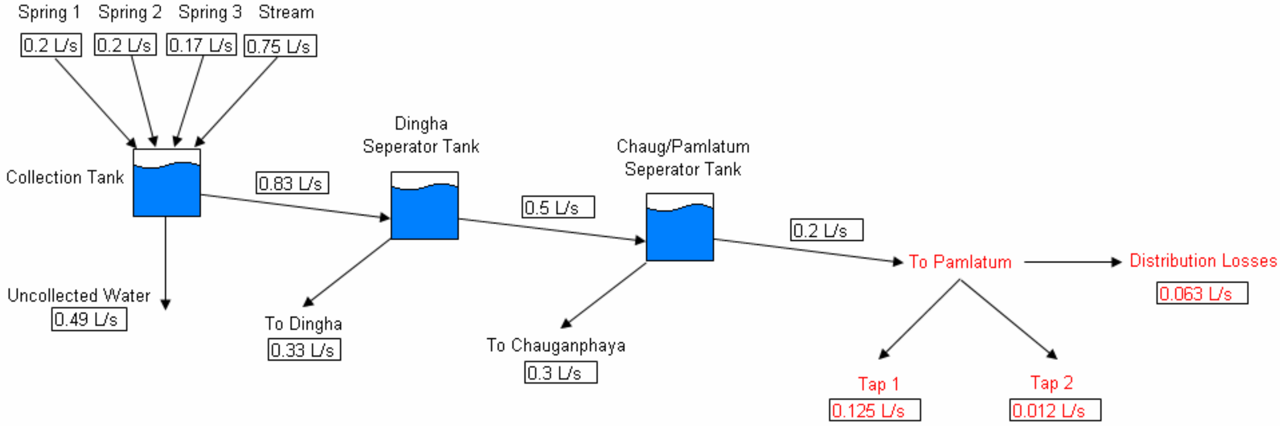


Figure 7: Existing water service system flow rates into Pamlatum village and tap outlets.

Table 4: Accumulative water supplied to Pamlatum including distribution losses.

Water Flow	Quantity of water supplied in given time period (Litres)				
	1 hour	3 hours	6 hours	12 hours	24 hours
Water supply from taps	493	1,480	2,959	5,918	11,837
Distribution losses	227	680	1,361	2,722	5,443
Total	**720**	**2,160**	**4,320**	**8,640**	**17,280**

Because there are no controllable head works (i.e. on/off taps), water flows continuously from the tap stands. In many cases, excess water (wastewater) flows into depressions (either formalized structures or informal pools) where it can be accessed by livestock as drinking water. If functioning effectively, this can limit the need to take livestock down to river areas for drinking. However in some cases, livestock were observed to intermingle with villagers to use the primary outlet as a source of drinking water. Additionally, stagnant livestock pools may promote the breeding of insects which may transmit disease. Water eventually flows down paths or other slopes and ultimately discharges into fields close by.

3.3.3 Water Quality

The water flowing out of village taps across all villages is of acceptable drinking quality (Table 5) in Nepal, demonstrating the cleanliness of the spring sources. All taps have *E.coli* levels below the Nepalese standard of 10 colonies per 100ml sample. The water flowing out of Pamlatum's taps measure 3-4 colonies per 100ml sample. Turbidity levels out of Pamlatum's taps are also under the recommended acceptable limit of 5 NTU.

Table 5: Water quality measurements of existing water service infrastructure.

Location	E. Coli (per 100ml)	Turbidity	pH	Free CI	Total CI
Spring 1, 2 & 3	-	<5	7.2	0.1	0.1
Stream	-	28	7.0	0.1	0.1
Collection Tank	-	<5	7.2	0.1	0.1
Pamlatum Tap 1	3-4	<5	7.4	0.1	0.1
Pamlatum Tap 2	-	-	-	-	-

3.3.4 System Maintenance

The gravity-fed system is poorly constructed. According to village members, people (unsure who) travel once a week to the spring sources and collection tank to check the pipe and conduct maintenance as required. The walk to the collection tank is difficult and dangerous, with steep terrain and potential for rock falls especially during the winter caused by the freezing and melting of water. The system fails frequently due to the following reasons:

- Water pipes in many areas are exposed above ground and are vulnerable to damage from stock trampling, vandalism and minor landslides.
- During the winter months, water in pipes near or above the ground surface often freeze over night and do no defrost until mid morning when temperatures rise above zero.
- Debris such as grass, twigs and small animals (such as frogs, snakes and rodents) can become stuck in tanks and pipe connections. This can block and contaminate water flow.

If flows cease, community members inspect the tanks, pipes and other components for obvious problems and make the appropriate repairs with the materials and skills available. It is often the case that villages do not have sufficient tools or materials to effectively repair cracks, leaks or breakages in tanks and pipes.

3.3.5 Water Collection & Consumption

There is no doubt that current rates of water consumption in Humla villages are far below global standards such as those set by WHO. Often water supplies are not even sufficient for basic needs such as drinking and cooking, let alone bathing and washing. The main reason is the difficulty in accessing water supplies for water collection. The task of fetching water is often carried out by women and children (mainly girls). The distance travelled to a tap within Pamlatum ranges from a few metres to over 100m. Fetching water is a repetitious task that is done several times daily. Around 10 to 30 litres of water are commonly carried in one trip. Additionally, village members find that the water outlets within the village provide miniscule flow rates. Filling a 30 litre vessel from tap 1 will take approximately 4 minutes; filling it from tap 2 will take approximately 42 minutes. Due to the long collection times, it is common for village members to wait for an hour before they can even access water from tap stands.

A survey of a family in Chauganphaya village suggested that their household would use 35 to 40 litres a day between six people (2 adults and 4 children). This equates to an average of just 6 to 7 litres per person per day. This scenario in water consumption is typical for all households and surrounding villages. The amount of water collected is only sufficient for basic cooking and drinking purposes. Due to the lack of water in the majority of villages, people and animals of Pamlatum are forced to travel to the Hepka River to meet additional water needs. Families in Chauganphaya and Pamlatum suggested that if a new system were to be installed, they would desire approximately double their current allocation. Any additional water supply could be used for washing hands, bathing, washing clothes and flushing pit latrines. Furthermore, additional water supplies could also be used for productive uses in irrigating greenhouses, thereby increasing available food supplies. A calculation on Pamlatum's average specified daily water demand is provided in *Appendix C, p.63*. For Pamlatum, a daily water consumption of 7 litres per person (1,246 litres for the entire village) indicates a water collection efficiency of just 7.2% (17,280 litres is supplied to Pamlatum from the separator tank) due to distribution losses and continually flowing taps.

3.3.6 Summary of Major Limitations & Consequences

The major limitations of the existing water service system include:

- Too few tap outlets with insufficient flow rates (Pamlatum tap 2 in particular).
- Inadequate water storage and uncontrollable head works.
- Poor construction requiring frequent maintenance and repairs.
- No trained people to maintain the system appropriately and no access to spare parts.
- No money to buy spare parts for operation and maintenance as there is no fund collection among families.
- Difficult and potentially dangerous access to spring sources and collection tank.
- Exposed water pipes freeze overnight and are also vulnerable to damage.
- Adequate materials, tools and skills for maintenance and repair are difficult to access.
- It is hard to located system faults due to the very large water distribution lengths.
- Excess water from the continual tap flows of taps is, in some cases, not properly managed.

The consequences of the major limitations include:

- Village conflicts over water are common due to long waits for village tap access.
- Water collected from taps is barely sufficient for drinking and cooking purposes.
- Village members and animals are forced to travel to the Hepka River for additional water.
- Not enough water for irrigation to grow food, resulting in food shortages.
- Not enough water for adequate personal hygiene.
- Due to the frequent breakdowns, village members lose faith and are less likely to maintain or take adequate care of the water service system.
- Excess water can create stagnant pools and promote insect breeding which may transmit diseases. Excess water can also cause erosion to land and slipping hazards on paths.

3.4 RIVER WATER COLLECTION

Because of the lack of accessibility to clean water from village tap stands, Pamlatum village members (typically women and children) are forced to travel to the Hepka River to complete their water needs. These additional needs include washing, bathing and stock watering.

The steep slope of the mountain-side village makes journeys to the river both treacherous and exhausting, especially when considering 10 to 30 litres of water are often carried at one time.

As mentioned previously, the quality of the river water is not acceptable for drinking. The strong presence of *E.coli* in the Hepka River would be due to a combination of human bathing and washing in these waters, as well as serving as a livestock drinking and ultimately a livestock defecating source. The health of children in the village is greatly affected by the poor accessibility to safe drinking water, especially when forced to use river water for drinking. Women are then burdened with caring for family members who contract waterborne diseases. The women also bear the main responsibility for fetching firewood (for up to 40 hours per week), cleaning, cooking and some agricultural activities, leaving them with little time for education and economic advancement (A. Zahnd, personal communication, 2007).

In addition, the health of the river and surrounding riverbanks are affected through livestock and human use. Livestock trample and destroy vegetation on the river bank and mountain slopes leading to potential erosion of mountain sides and increased water turbidity. Not only does the presence turbidity and *E.coli* affect the immediate villages under investigation, but it also affects the health and livelihood of villages further downstream.

Chapter 4 Customer Requirements

4.1 QUALITY FUNCTIONAL DEPLOYMENT PROCESS

The following customer requirements have been developed from my conducted personal research and the village assessment and field survey. Most of the limitations and problems associated with the gravity-fed system have been translated into customer requirements using the QFD process (*Appendix D.1, p.65*). Engineering judgement has been used to create some requirements in the case where there is a clear and obvious need for the requirement, but has not been specifically expressed by village members. The bulk of the customer requirements affect people who have direct contact with the system such as end-users, system maintainers, transporters and installers. There are many more customers and project stakeholders which are presented in *Appendix D.2, p.68*). The customer requirements have been broken into two groups: essential requirements and desirable requirements.

Essential requirements are critical for the success of the project and design. Only if all essential requirements are met will the concept design be deemed valid for selection.

Desirable requirements are not critical and are used as a tool to distinguish the most appropriate concept design based on the importance of the requirements and a scoring system. The list of all requirements, including their importance, can be found in *Appendix D.3, p.69*. These requirements apply to all concept designs generated.

A benchmark evaluation of the existing water service system against the requirements is presented in *Appendix D.4, p.70*. The benchmark evaluation allows the strengths and weaknesses of the existing water service system to be revealed in a formalised process which can aid the concept design generation phase of the QFD process. The requirements generated have been translated into engineering specifications and measurable design targets which were used in the formulation and evaluation of the SPWP concept design. These engineering specifications and targets are presented in *Appendix D.5, p.74*.

4.2 ESSENTIAL REQUIREMENTS

4.2.1 Autonomy

Water shall be collected into water storage within the village to provide autonomy for days when water from the source is not available due to maintenance, repair, water shortage or unavailable hydraulic energy (in the case of the SPWP system, – nights and cloudy days). At least three days autonomy shall be provided for the water service system.

4.2.2 Robust

The water service system shall withstand all environments experienced by the local region such as wind, rain, ice, snow, frost, sun, dirt, extreme temperatures and water turbidity. The water service system shall be robust and secure to prevent any damage, theft or vandalism from livestock, wildlife, vegetation, children or unwarranted people.

4.2.3 Easily Accessible

Water from village outlets shall be easily accessible by the local village people by ensuring short distances to taps and adequate tap flow rates. The water service level shall be at least *intermediate access* as defined in section *2.1 Water Accessibility, p.4*. The water service system shall also be easily accessible for routine maintenance.

4.2.4 Reliable

The water service system shall be reliable and operate continually and consistently with minimal breakdowns and downtime.

4.2.5 Long Lifetime

The water service system shall have an operating lifetime of at least 20 years.

4.2.6 Low Life-Cycle Cost

The unit cost of water shall be minimal. The water service system needs to be economically sustainable and, most importantly, affordable by the end-users with jeopardising the quality or sustainability of the whole system.

4.2.7 Transportable

The materials and equipment needed for installing the water service system shall be lightweight, easily transportable via foot or animal and obtained from local suppliers where possible.

4.2.8 Maintainable

Maintenance and repairs on the water service system shall be quick and easy and completed by local village members using local materials and supplies where possible. In addition, the cause of system failures shall be easily identified to aid in timely repairs.

4.2.9 Nepalese Standards & Local Authorities

The design, installation and operation of the water service system shall comply with all Nepalese government and local authorities' standards, regulations and legal framework.

4.2.10 Safe Drinking Water

The water supplied to Pamlatum by the water service system shall be safe for drinking as defined in section *2.2 Water Quality, p.4*.

4.2.11 Local Renewable Energy

The water service system shall be powered by renewable forms of energy such as solar, wind, hydro, gravity, etc. It is simply not sustainable to regularly transport fossil fuels into the village to operate the water service system due to Pamlatum's remoteness and difficult access.

4.2.12 Village Ownership & Acceptance

A sense of ownership of the water service system infrastructure shall be instilled within the community to promote interest in the project, including the proper operation and maintenance of the water service system.

4.2.13 Children & Women Friendly

Since most of the daily water collection is performed by children and women, the water service system shall be easily operated by them. The water service system shall contribute to the safety, wellbeing and productivity of children and women.

4.3 DESIRABLE REQUIREMENTS

4.3.1 Water Demand

The village water demand shall be met by supplying water from the water service system to the village for drinking, personal hygiene, cooking, washing, pit latrines, livestock and crop irrigation. Water demand shall be met consistently year round and seasonal variations in water demand shall be taken into account along with designing for village population growth. A minimum daily average of 4,320 litres (24.3 litres per person) shall be supplied to the village (this does not take into account population growth). See *Appendix C, p.63*.

4.3.2 Excess Water Management

Any excess water supply from the water service system shall be prevented or managed properly by diverting the water into crop fields, livestock watering pools or channels that flow into the river system. Excess water shall not cause any hazards on walking paths or soil erosion and shall not be left to stagnate in pools to allow insects to breed and transmit disease.

4.3.3 Efficient

The water service system shall be efficient in utilizing the available local energy resource to minimise the size and cost of components. The water service system shall also allow the village community to maximise the utilization of the water supplied with minimal excess water.

4.3.4 Low Capital Cost

Total capital costs of the water service system shall be kept to a minimum without jeopardising the quality and sustainability of the system.

4.3.5 Low Operating Cost

The operating costs of the water service system due to routine maintenance, system failure and the replacement of parts shall be kept to a minimum without jeopardising the quality and sustainability of the system. The operating cost must be affordable to the village.

4.3.6 Simple to Install

The water service system shall be quick and simple to install. Local labour from the village shall be utilized effectively for the installation.

4.3.7 Low Maintenance Frequency

The frequency of routine maintenance required on the water service system shall be minimal without jeopardising the quality and sustainability of the system.

4.3.8 Australian Standards

The water service system shall comply with Australian standards where applicable.

4.3.9 Injury Prevention

The water service system shall not risk injury to people during the installation and operation of the system including routine maintenance and repairs.

4.3.10 Pollution Free

The installation and operation of the water service system shall not impact the environment.

Chapter 5 Design Concept Generation

The following concept design was generated using the methodology detailed in *Appendix E.1 & E.2, p.80.*

5.1 SOLAR POWERED WATER PUMP SYSTEM OVERVIEW

Figure 8 presents a conceptualised overview of the SPWP design. For a more graphical view of the overall system using Google Earth, go to *Appendix E.5, p.84*. Water is pumped from a shallow well located next to the Hepka River through a series of three identical pump-station systems where it is then fed into the village filtration, storage and supply system. The pump-station systems are powered by solar energy, whereas the water supplied to village water access points is gravity fed from storage.

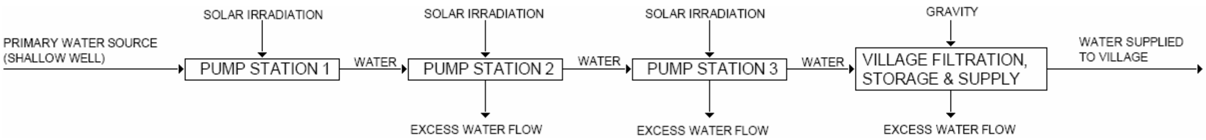


Figure 8: Solar powered water pump system conceptual block diagram.

5.2 PUMP STATION CONCEPTUAL DESIGN

Figure 9 represents a more detailed conceptual block diagram showing the components that make up a pump-station system.

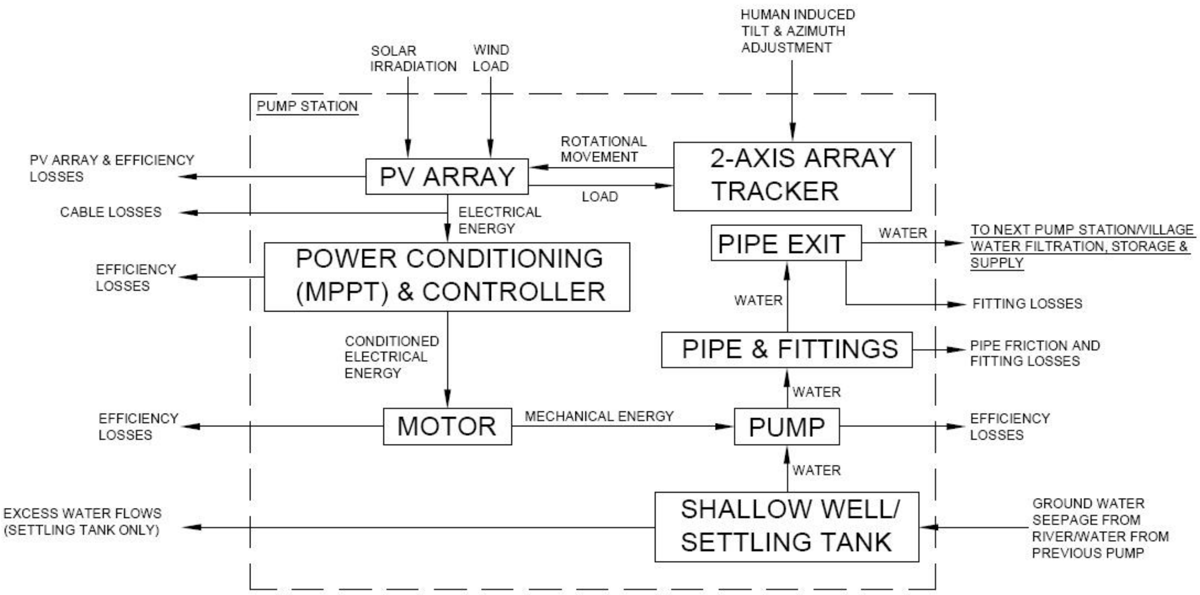


Figure 9: Pump station conceptual block diagram.

Since all pump-station systems are identical (with the exception of different source collection points), only one diagram is shown. The pump is powered by a photovoltaic (PV) array which is attached to a manually adjusted two-axis tracking frame to maximize the energy collected. The PV array supplies electrical energy to a Maximum Power Point Tracker (MPPT) and controller which converts the power into a suitable voltage and current required by the motor.

The motor then converts the electrical energy into mechanical energy to drive the pump. The pump then imparts hydraulic energy onto the water where it is pumped from the water collection point (shallow well or intermittent settling tank) through PE distributing piping. The water exits into the next pump station system or the village filtration, storage and supply system.

5.3 VILLAGE FILTRATION, STORAGE & SUPPLY CONCEPTUAL DESIGN

Figure 10 represents a more detailed conceptual block diagram showing the components that make up the village filtration, storage and supply system. Water from Pump Station 3 is fed into a settling tank where it is then gravity-fed into a slow sand water filter and then finally into storage. Water is then accessed by village members via seven water tap outlet points which has been gravity-fed from the village storage tank.

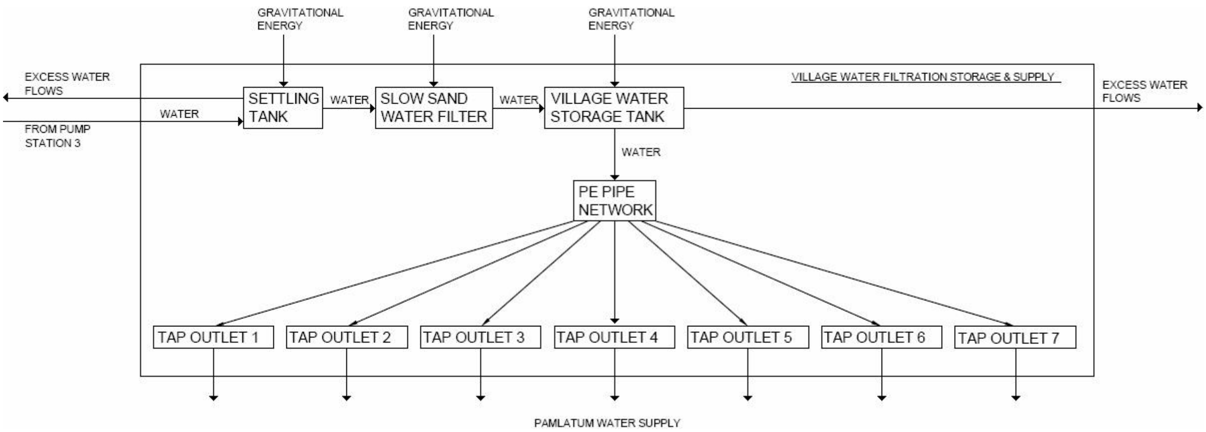


Figure 10: Village filtration, storage and supply conceptual block diagram.

The conceptual diagrams presented in this chapter show the main system components including the main inputs and outputs of each component. One input that was not included in the block diagrams, but affects nearly every component, is ambient air temperature (especially with the overheating of PV arrays and freezing of water pipes).

Proper excess water management is a customer requirement; however the excess water system is not shown on the above concept design. It was decided to only provide a description of the excess water design which is presented in the following chapter.

Drawings showing the complete concept design in the form of a water schematic and an electrical schematic are presented in *Appendix E.3, p.82* and *Appendix E.4, p.83* respectively

Chapter 6 Design Concept Components

6.1 Pump Station Water Collection

6.1.1 Riverbank Shallow Well

The following description of the shallow well has been adapted from Morgan (1990, p.23). The shallow well is capable of supplying approximately 6,000 litres per day, which shall be adequate for the water supply of Pamlatum village. A picture of what the well may look like is shown in Figure 11. This method for water collection shall allow the water in the ground from the Hepka River to seep into the well, and the sediments will be filtered out by the ground soil before the water is pumped up the hill. This is a good way for improving the quality of water and preparing it for sand filtration. This method also improves the microbial quality of the water, as pathogenic bacteria are trapped in the soil before entering the well. The water quality from the well may even be at a standard suitable for drinking, however this should be verified once the well is constructed. In such a case, a slow sand water filter may not be required to further treat the water. For now, it shall be assumed that a slow sand water filter is required for completeness of the concept design.

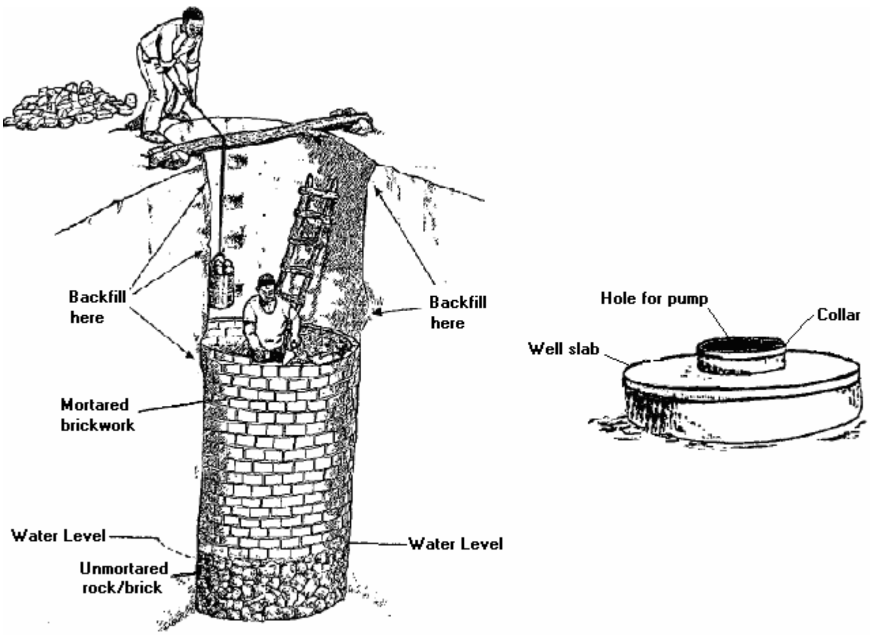


Figure 11: (left) Shallow well construction and (right) the well cover (Morgan 1990, p.23).

6.1.1.1 Well Location

The shallow well shall be built close to the Hepka River at the proposed pump location but above the high water mark. The ground should be firm and not erode easily when excavated. The ground should be built up in soil and not rock.

6.1.1.2 Excavating the Well

The well shall be built during the dry season when the water table is at its lowest. A 1.5m diameter ring shall be excavated into the hillside next to the river and in a straight line down to the water table. Once the water table is reached, excavation of solid material should continue as far as possible (2-3m below the water table) until the point where the water inflow into the well is too high and further digging is impossible.

6.1.1.3 Lining the Well

The well shall be lined with bricks to form a tube structure which will protect the well from erosion and ensure suitable water quality. The bricks shall be well-fired to prevent crumbling when under water. Below the water level, the bricks shall be carefully stacked without mortar. Gravel shall be packed between the brickwork and the wall of the well to offer support. Brick mortar should be used with the brickwork as soon as it is technically feasible and certainly above the level of the water. The mortared brickwork shall be built up to 300mm above ground level. Clay slurry shall be packed between the excavation and the brickwork to form a sanitary seal. This helps to prevent contaminated water leaking into the well from the surface.

6.1.1.4 Well Cover (optional)

A concrete cover shall be built and placed on top of the well to provide protection. The cover slab helps to prevent polluted waste water and other objects from falling into the well. It also makes the well safer for children and animals. The cover is optional, as a well house shall be constructed around the well to offer further protection and security.

The cover shall be built from a concrete mixture of small stones (3 parts), river sand (2 parts), and cement (1 part) and reinforced with 3mm wire mesh (150mm distance between wires) in the middle of the slab. This method for concrete slab construction can also be applied to the foundations of the water storage/settling tanks and the slow sand water filter (however a thickness of 100-150mm is recommended). The final thickness of the slab cover shall be 75mm and have a diameter 100mm more than the diameter of the outer lining of the well. An appropriately sized hole is needed to allow a pump to be fitted to the well. A collar shall be built around the hole in the cover to aid in protection of the water source.

6.1.1.5 Well Housing

A house for the shallow well and pumping equipment shall be built using local housing materials from the area. The house will protect the well from unauthorised people and animals as well as provide protection for the pumping equipment. Power from the PV array shall be supplied via underground armoured cabling into the well house and connected electronic equipment. The well house shall also protect the equipment from the harsh environment. The well house shall be large enough to accommodate all the required equipment, including the required maintenance supplies for the equipment. The well house shall also be large enough for extracting the pumping equipment to perform routine maintenance. It shall also be necessary to install a proper locking device to the entrance door of the well house (i.e. padlock and key).

6.1.2 Settling Tanks

Water shall be transferred from the shallow well to Pamlatum village through a series of three pump stations. Each pump station shall pump water up the hill into an intermittent settling tank as shown in Figure 12. The settling tank at the end of Pump Station 1 shall provide the water collection point for Pump Station 2, likewise for Pump Station 2 and 3. Finally, the settling tank for Pump Station 3 shall be part of the water filtration and collection facility for Pamlatum's water supply.

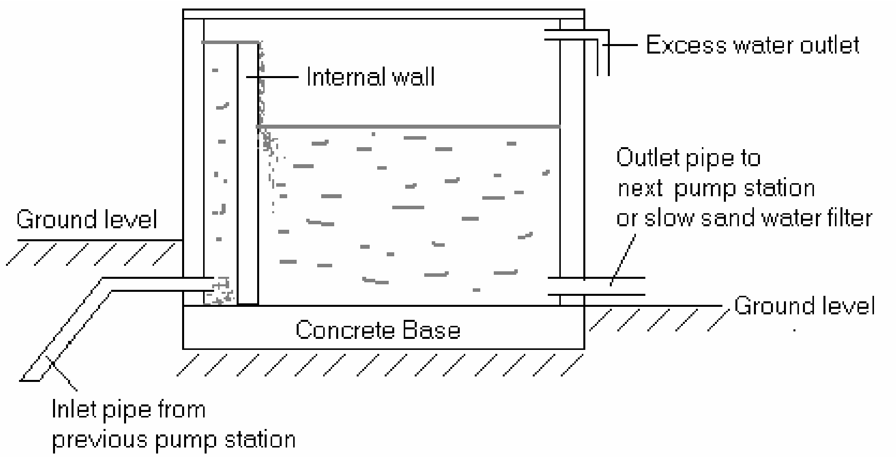


Figure 12: Settling tank.

The settling tank shall be constructed from the same bricks, mortar and cement as the shallow well. When the settling tank fills to capacity, an outlet pipe shall be installed at the top of the tank to relieve the water into properly managed excess water flows.

The main purpose of the settling tank is to allow any sediment particles in the water to settle to the bottom of the tank before the water is fed into the next pump station and finally into the slow sand water filter. In order for the settling tank to operate effectively, it is necessary to avoid turbulence caused by water being pumped into the tank and stirring up sediment. One way to achieve this is to section off a small volume of the tank by an internal wall of bricks. Water is pumped into the bottom of the small tank section and then rises to the top of the internal wall and spills over into the larger tank section. Any heavy sediment pumped into the tank should remain stuck on the bottom of the small tank section. An outlet pipe can then be positioned in the external wall of the larger tank section close to the tank floor.

6.1.2.1 Pump Stations 1 & 2 Settling Tank

The settling tank for Pump Station 1 and 2 shall be small. All pump stations are identical with the same equipment. Therefore, all pump stations shall operate at the same flow rates throughout the day. The settling tanks for Pumps Stations 1 and 2 shall have a water storage capacity of approximately 1,500 litres (assumption). A tank 1.0m high and 1.5m in diameter shall be sufficient. The outlet of the settling tank shall be connected to the pump of the next pump station. The settling tanks and associated pumping equipment shall be protected by a simple housing structure identical to the one described for the shallow well housing.

6.1.2.2 Village Water Supply Settling Tank

The settling tank at the end of Pump Station 3 shall be situated above the slow sand water filter so water from the settling tank can be gravity-fed into the filter. This settling tank also serves as an intermittent water storage facility, which is required because the slow sand water filter proposed in this design can only accommodate flow rates of up to 300 litres per hour as opposed to the pumping system's maximum flow rate (*Appendix H.2, p.109*) of approximately 800 litres per hour. The maximum flow rate is based on the average daily flow rate for November, the sunniest month. In November, the pump operates for approximately 7.73 hours per day (*Appendix H.2*, *p.109*). Therefore, the settling tank shall require a water storage capacity of at least 3,865 litres ((800 – 300 L/h) x 7.73 hrs). A settling tank 1.5m high and 2.0m in diameter shall be sufficient.

6.2 PUMP STATIONS & WATER DISTRIBUTION

The following hydraulic calculations, pipe selection and pump station design have been completed with the aid of Burton and Monsour (2003), Potter and Wiggert (2002), APMA (1987) and Wenham (*et al*. [no date]).

6.2.1 Total Dynamic Head & Distribution Piping

The total dynamic head (TDH) of the pumping system is the sum of the pressures required to overcome the height difference through which the water is lifted plus the friction losses through pipes and fittings. These pressures are converted into equivalent metres of head according to the following formula;

$$TDH = StaticHead + FrictionHead \qquad (m)$$

The height difference between the shallow well and proposed water storage site is approximately 295m. Since the system shall operate using three pump stations, approximately 1.2m of static head shall be added to each pump station to overcome the height of the water level in the settling tanks. Therefore the static head of the entire system will be approximately 300m.

The length of pipe required for transferring the water between source and destination is approximately 470m. An additional 10m of piping will be assumed to account for pipe bends. The required pipe length for the system shall therefore be 480m.

The pipe length, pipe material, pipe inside diameter and the water velocity through the pipe will determine the amount of pipe friction head. Valve and pipe fittings will also cause friction losses. It is often the practice to express the friction loss associated with fittings as an equivalent length of pipe (L_e) according to the following formula; (Potter and Wiggert 2003, p.317).

$$L_e = K\frac{V^2}{2g}$$

Where K is the minor loss coefficient of the fitting, V is the water velocity through the pipe and g is the acceleration due to gravity at 9.81m/s^2. A table showing some minor loss coefficients of a number of valves and pipe fittings is shown in *Appendix F.1, p.85*. In most solar-powered water-pump systems, the water velocity inside the pipe should not exceed 1.0m/s (Burton and Monsour 2003, p.8). Assuming the sum of minor loss coefficients in the entire system is 60 and a water velocity of 1.0m/s, the equivalent length of pipe will be approximately 3.0m. This is added to give a total equivalent pipe length of 483m.

The nominal flow rate needs to be calculated in order to find the friction head. The nominal flow rate is calculated by dividing the average daily water supply by average daily PSH. The average daily PSH is equivalent to the average daily kilowatt-hours of sunshine for the site. The proposed design shall use a two-axis PV array tracking system and therefore an average 7.0 kWh/m^2.d is collected by the PV panels. Assuming on average 4.32 m^3 of water is to be pumped per day, then this is equivalent to the entire 4.32 m^3 being pumped at the nominal flow rate over a period of 7 hours according to the following formula; (Burton and Monsour 2003, p.43)

$$NomFlowRate(L/h) = \frac{DailyFlow(L)}{PSH}$$

Therefore, the nominal flow rate will be approximately 620l/hr or 0.17l/s. Polyethylene (PE) pipe shall be selected to distribute water due to its superior endurance and physical qualities (*Appendix F.2, p.85*). Where possible, any distribution piping shall be buried underground at a depth of 50 to 100cm to prevent the water in pipes from freezing. Any exposed pipes shall be insulated with black polyethylene tubular foam wrap. All the information is now obtained for selecting the appropriate sized pipe as shown in Table 6. Values of friction head which are used to select the appropriate pipe size are obtained from head loss charts shown in Figure 13.

Table 6: Pump station system parameters.

Parameter	Entire System	Per Pump Stage
Static Head	300 m	100 m
Total Equivalent Pipe Length	483 m	161 m
Nominal Flow Rate	0.17l/s (620 l/hr)	0.17 l/s (620 l/hr)
Pipe Outside Diameter	20 mm	20 mm
Friction Loss	5.5 m per 100 m of pipe	5.5 m per 100 m of pipe
Total Friction Loss	27 m	9 m
Friction Loss as % of Static Head	9 %	9 %
Total Dynamic Head (TDH)	327 m	109 m

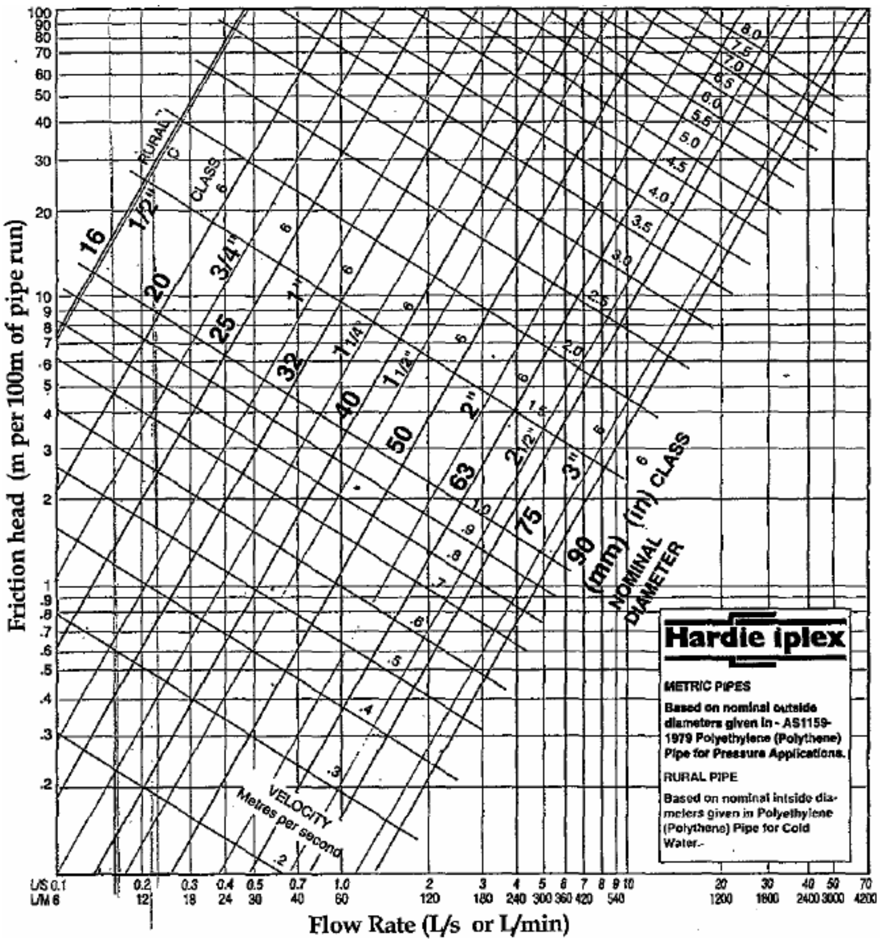


Figure 13: PE pipe friction loss chart (Burton and Monsour 2003, p.7).

As a rule of thumb, a friction loss figure of 5-10% of static head is commonly used (Burton and Monsour 2003, p.8). If the pipe selected by the system designer is too small, then the pump will require excessive power to drive it, which increases costs. Equally, for long pipe lengths, the selection of too large a pipe diameter could result in low friction loss but high cost for the larger than necessary pipe and its fittings. An outer pipe diameter of 20mm shall be selected resulting in a total friction head of 27m and a total dynamic head of 327m. The system shall be divided into three pumping stages. Therefore the pumping equipment for each station shall be selected based on 109m TDH with a nominal flow rate of 620l/hr.

6.2.2 Pumping Equipment

Identical equipment, including the PV array, will be selected for each pump station. The following shall describe the pump, motor and power conditioning equipment for one pump station.

6.2.2.1 Pump

The pump shall be a Grundfos SQF 1.2-2 submergible progressive cavity pump. This pump is suited for high heads and low flow rates. It comes with a DC MSF-3 permanent magnet motor, MPPT and controller. Complete specifications on the package are provided in *Appendix F.3, p.86.* Figure 14 presents the operating curves and its group efficiency (combined pump and motor efficiency) for a range of flow rates and heads.

At the nominal flow rate and total dynamic head of 620l/hr and 109m respectively, the group efficiency is approximately 46% with a required electric power input from the power conditioning equipment of 400W. This will mean that 184W out of the 400W supplied to the pump motor will be converted to hydraulic power imparted onto the water. The pump weight and dimensions are presented in Table 7.

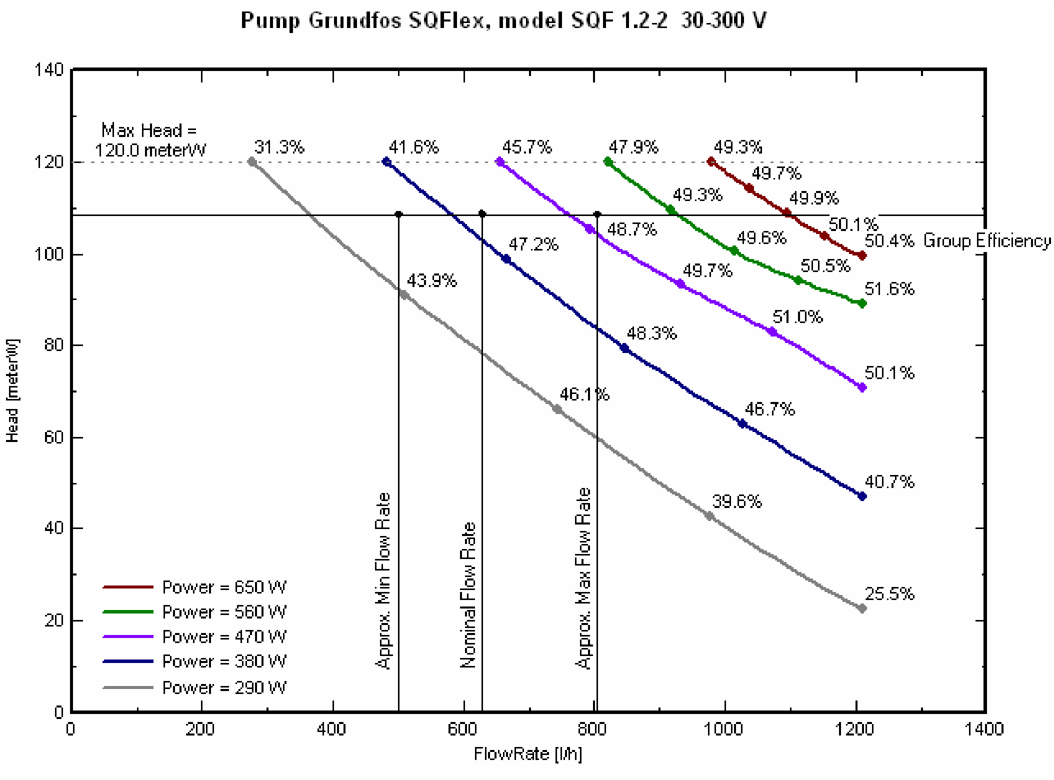


Figure 14: Grundfos SQF 1.2-2 pump operating curves (source: PVSyst software package).

Table 7: Grundfos SQF 1.2-2 pump dimensions and weight.

Pump package weight	9.7 kg
Pump Length	1225 mm
Pump Diameter	74 mm

6.2.2.2 Permanent Magnet DC Motor

Permanent magnet direct-current (DC) motors produce a constant flux which is independent of the armature current and light intensity. This greatly improves the starting torque of the motor, particularly at low light levels and gives them excellent performance under reduced load. DC motors are typically expensive when they are compared with AC motors however they have high efficiencies. The big advantage of DC pumping system is that an inverter is not required to convert the DC power to AC. Inverters are expensive electronic equipment that are typically unreliable and are usually the weakest link in the system (Wenham *et al.* [no date]). However, the big downfall for permanent magnet DC motors is that they require brushes which need periodic replacement every one to five years. If the brushes and motor are not kept in good condition, the carbon dust from wearing brushes may cause arcing, overheating and considerable power loss (Wenham *et al.* [no date]).

6.2.2.3 Maximum Power Point Tracking

Positive displacement pumps cannot be directly coupled to a motor and PV array as these types of pumps require constant current to operate effectively. Therefore a MPPT shall be used to condition the PV power into a suitable form for the pump motor. A MPPT aims to find and electronically track the array MPP over a range of module voltages (which vary with temperature) and module current (which vary with irradiance). The PV array power is converted into a voltage and current suitable for the pump motor. For a positive displacement pump, the pump motor then 'sees' a relatively constant current and a varying but optimum voltage, which allows instantaneous output to fluctuate with irradiance. The maximum possible PV array power is supplied to the motor and the daily pump water is maximised.

6.2.2.4 Controller

A controller shall be required to operate the system safely. The following controls shall be incorporated as part of the controller:

Table 8: Pump controls

Control	Description
Main Switch	Manually operated main switch to shut down and turn on system.
Pump inlet sensor	Inlet level sensor/switch inside tank/well to prevent dry pump operation.
Pump and motor temperature protection	Shuts down pump and motor when running at too high a temperature. Pump and motor may be operating at too high a temperature due to pipe blockages, dry operation, faults, wear and tear, etc.
Max. Power Protection	A limitation control device to protect the pump and motor from surges in power. This shall also include maximum voltage and current protection.

The system shall also log important data parameters to aid in error and failure detection so repairs can be completed quickly. Data logging shall also help the verification of the design which will assist future SPWP installations. Data that may be logged include:

- Solar irradiation
- Ambient air temperature
- Module cell, motor and pump temperature
- Power inputs into MTTP/controller, motor and pump
- Water flow rates
- Pipe pressures for determining pumping head (i.e. to determine clogged filters, pipe blockages, leaks, etc).

The MPPT and controller would typically have an efficiency of around 95% (Burton and Monsour 2003, p.34). Since 400W of electrical power is required by the pump motor, the PV array will be required to supply a maximum power input to the MPPT of:

$$P_{MPPT,in} = \frac{400}{0.95} = 421 \quad W$$

6.2.3 PV Array Power Generator

Ideally, one would want to place the PV array as close to the pump and motor as possible. However, since the pumps and motors will be located down on the river bank and at stages on the hillside, there will be large horizon shading losses due to the deep valley and mountain slopes. The horizon model (*Appendix B*.3, *p.62*) used for the calculations was taken from within Pamlatum. Due to the large distance from Pamlatum village to the Hepka River (~480m), it may not be feasible to place the PV array within the village. It is likely that the PV array will be placed on the hillside between Hepka River and Pamlatum village, using armoured underground cables to run power from the PV arrays to the pump motors. The armoured cables should be an adequate size and thickness to minimize cabling losses, however there will be a trade-off associated with cost. Peak power from the PV array must be above the required power input to the MPPT of 421W to account for cable losses. Cable losses in most systems are usually below 2% (Burton and Monsour 2003, p.49). However, due to likelihood of long cable lengths, 10% loss associated with cabling shall be assumed in the calculation.

Allowance must be made for de-rating the PV array due to the effects of cell operating temperature and dirt. As a rule of thumb, Burton and Monsour (2003, p.49) de-rate the output of the PV array by 80%. Therefore the array must have a peak power at STC of:

$$P_{peak,array} = \frac{421}{0.9 \times 0.8} = 585 \quad W$$

The PV modules for the array shall be the model BP 5170 170 W_p as presented in Table 9. Complete specifications are presented in *Appendix F.4, p.90*. The pump motor has a nominal voltage of 120V and a nominal current of 4.0A. The PV array shall contain four modules arranged in series. The PV array at STC shall therefore operate at 144V and 4.7A. The peak power of the PV array at STC is 680W, which is greater than the required 585W. This shall provide a safety factor (~16%) to compensate for days with low levels of sunshine. The PV array shall also be enclosed in a fenced area to provide protection.

Table 9: PV module characteristics

Manufacturer	BP Solar	**Max. Power @ STC**	170 W_p
Model	BP 5170	**Warranted Min. P_{max}**	161.5 W
Technology	Si-poly	**V_{mpp}**	36 V
Module weight	12.4 kg	**I_{mpp}**	4.7 A
Module Height x Width	1580 x 783 mm	**Module Efficiency**	13.71 %

6.2.4 Two-Axis Tracking Frame

The PV array shall be attached to a two-axis tracking frame such that the PV array continually faces the sun at a perpendicular angle to maximise the sunshine collected. The two-axis tracking frame shall adjust the tilt and azimuth of the PV array as shown in Figure 15. The tracking frame shall be manually adjusted two or more times per day for azimuth and once every one to three months for tilt. This a simple method for increasing the yearly output of the array without any complicated tracking machinery and control gear (which would just increase the maintenance requirements and likelihood of failure). However there is a stronger burden on the system operators to continually track the sun. Table 10 shows the optimum PV array tilt angles for each month based on PVSyst v4.1 generated meteo file (see *Appendix G.2, p.93*).

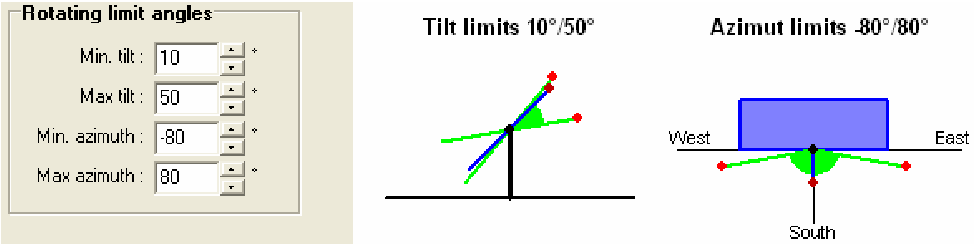


Figure 15: PV array tilt and azimuth limits (source: PVSyst software package).

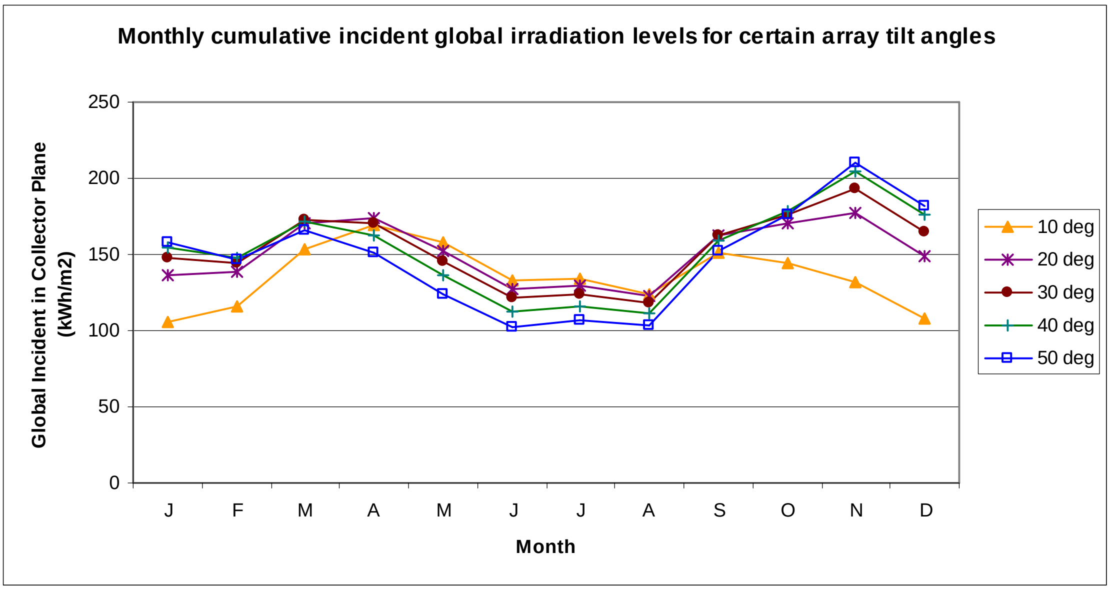


Figure 16: Monthly cumulative incident global insolation levels for PV array tilt angles.

Table 10: Optimal PV array tilt angles for each month.

January	50˚	May	10˚	September	30˚
February	40˚	June	10˚	October	40˚
March	30˚	July	10˚	November	50˚
April	20˚	August	20˚	December	50˚

6.3 WATER FILTRATION & VILLAGE WATER SUPPLY

The following description of the slow sand water filter has been adapted from Morgan (1990, p.260). The village water collection and filtration system is presented in Figure 17. The system consists of a settling tank (not shown in picture) to remove the larger sediment particles as described in section *6.1.2.2 Village Water Supply Settling Tank, p.24*. After the settling tank, water is fed into a slow sand water filter to remove the fine sediment particles and to help purify the water from pathogenic bacteria. Finally, clean and purified water is stored in a village water tank above Pamlatum. Water is gravity-fed from storage to water outlets throughout the village.

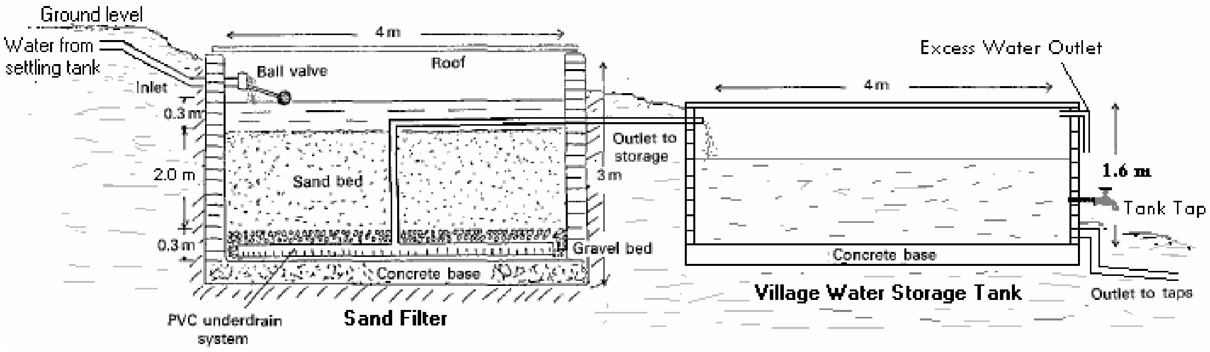


Figure 17: Water filtration and storage system (adapted from Morgan 1990, p.260).

6.3.1 Slow Sand Water Filter

The slow sand water filter shall filter out most of the remaining sediment in the water, resulting in low turbid water. The water shall also be purified as pathogenic bacteria do not find either sand or soil a good medium in which to multiply and therefore tend to die off.

The slow sand water filter shall be 4m in diameter and 3m high, which will hold approximately 36 cubic metres of water. The size of the filter shall allow 300 litres of water to pass through it per hour. The filter shall be constructed with bricks and rendered on the inside to keep it watertight. A low pressure ball valve shall be fitted to the inlet inside the tank to shut off the water supply when the filter reaches capacity. Thick-walled water collector pipes shall be positioned along the base of the filter. The water collector pipes shall have a series of saw cuts along the bottom of the pipe to allow the filtered water to enter. The collector pipes shall be connected to a common riser pipe which passes up through the centre of the filter and exits through the external wall 500mm below the top of the filter.

Granite chips (6mm) are then thoroughly washed and laid over the collector pipes to a depth of 300mm. This will require about $4m^3$ of granite chips. Thoroughly washed sharp river sand is then added on top of the granite chips so the final depth of the sand after flooding is approximately 2m. This equates to approximately $24m^3$ of sand. It is important that good quality river sand is used with all organic matter removed. The outlet pipe through the external wall of the filter shall sit just above the sand, thereby ensuring the sand does not dry out.

Once construction is complete, water can be passed through the system to allow the sand to settle. The water shall be passed through the system for at least a week to flush out sediments and waste matter. Water will enter the top of the filter and seep through the layers of sand to the granite chips. Water will then enter through the saw cuts of the collection pipe. Because of the height difference between the filter water level and collection pipes, water will be forced up the central riser pipe and through the filter outlet. When running at capacity, approximately 30 to 40cm of water should lie above the sand.

Over an extended period of time, the filter will start to become clogged with the collected sediment and water will not pass through it as effectively. When this occurs, the water flow rate through the filter will reduce and the settling tank will fill up. Excessive amounts of water flowing out of the overflow pipe in the settling tank will trigger the action for cleaning the filter. This is an easy way to identify when the filter is clogged and requires maintenance. Filter cleaning is required after an extended period of service, ranging from a few weeks to a few months (Jaksirinont 1972).

6.3.2 Village Water Storage Tank

The village water storage tank must be built below the slow sand water filter so the water can gravitate into it. The storage tank shall be built to provide at least three days worth of water supply based on the specified daily water demand of 4,320 litres per day. This equates to a tank size of approximately 13m^3 (13,000 litres). It was found that when the capacity of the tank was increased to 20m^3 (20,000), the number of PV modules could be reduced from five to four for each pump station with little effect on the average daily water supplied to the village (these results have not been included in this paper). This seemed a more appropriate solution as PV modules are more expensive, require more maintenance and are more likely to fail when compared to increasing the size of the village water storage tank. The storage tank shall be built from burnt bricks approximately 4m in diameter and 1.6m high (20,000 litre capacity). Water shall be gravity-fed from the slow sand water filter through an inlet pipe at the top of the tank. The tank should also have a water relief outlet at the top of the tank to allow water to trickle out when the tank is at capacity and the pump is still operating. The village water storage tank shall have a tap outlet located at the bottom of the tank. It shall also have a pipe outlet at the bottom of the tank which distributes water to tap outlets throughout the village via a gravity-fed piped network.

6.3.3 Village Tap Outlets

There shall be a total of seven water tap outlets (one located on the village water storage tank and six water outlet points throughout the village). Water from the village storage tank shall be gravity-fed throughout Pamlatum village via water pipe to the six water outlet points. The water pipe shall be buried underground at a depth of 50-100cm so the pipes do not freeze. Any exposed pipes shall be insulated with black polyethylene tubular foam wrap to prevent freezing. The water outlet point will consist of a tap stand set in concrete, to which the water pipe outlet is connected together with a heavy-duty screw (Figure 18). Proper drainage for the tap shall be provided by installing an apron around the tap. The apron shall be made from concrete with raised edges, thereby diverting any spilled water into a drainage channel.

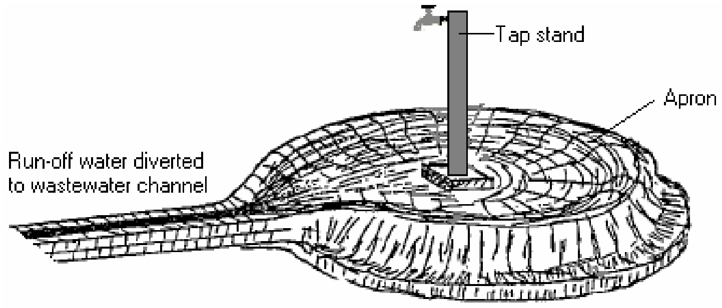


Figure 18: Tap stand with apron (adapted from Morgan 1990, p.241)

The altitude variation from the proposed village storage tank to the lowest point in the village is approximately 80m. It is assumed that this static head, with the correct sized piping, will be able to pressurize the water tap outlet system to ensure adequate tap flow rates. Figure 19 presents the possible layout of water distribution piping and water tap outlets for Pamlatum village. The average household distance to a tap outlet shall be less than 100m.

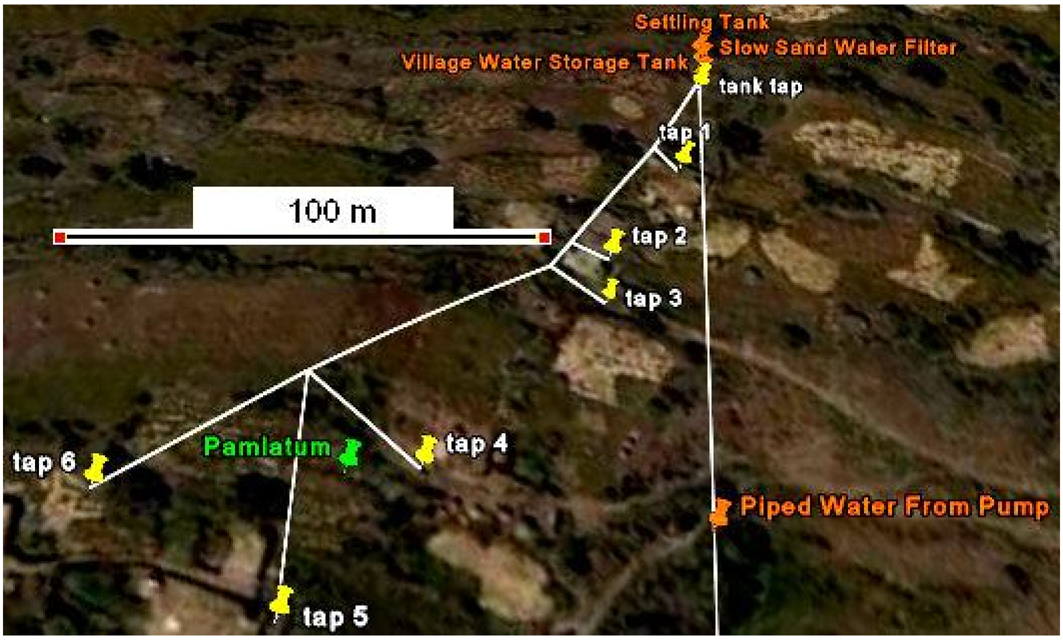


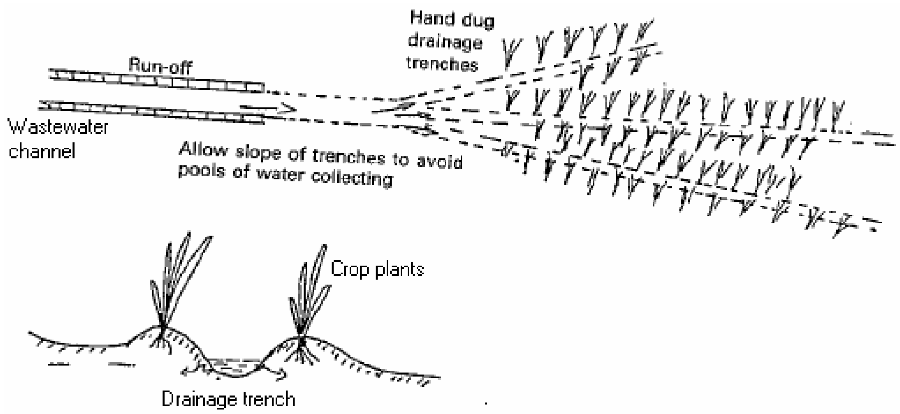
Figure 19: Possible layout of Pamlatum's water point outlets.

6.4 EXCESS WATER FLOWS

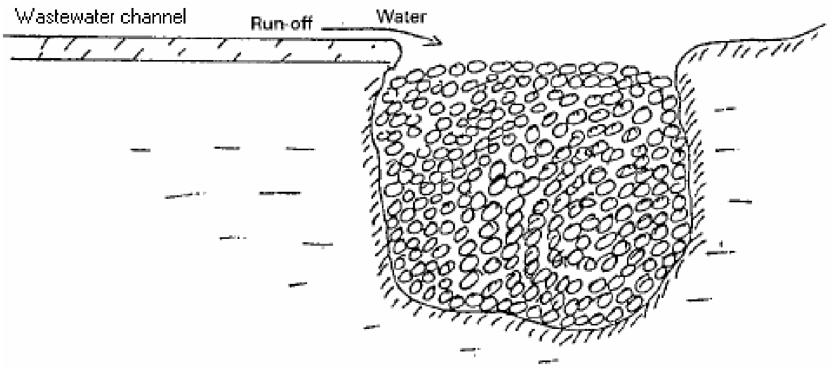
In most water pumping systems, a sensor to shut down the pump when the storage is at capacity would be used to prevent excess water flows. For this design, the pump shall operate continuously, even when the tank is full. Any excess water shall be relieved into drains and disposal systems which divert the water into either formalized livestock watering pools, crop fields or back into the ground water and river system. This was decided for the following reasons:

- Excess water from the existing gravity-fed system, when managed properly, provided water in productive ways for livestock watering pools and informal crop irrigation.
- The SPWP system is likely to be expensive and one would want to have the pump operating continuously to get most value out of the system in terms of water supply.
- Village members will know when the tank is full from the excess water trickling out of the tank outlet, and therefore, village members could increase their water consumption for that day and use is productively.
- The pump controller at each pump station will be located a long way from the storage tank (approximately 160m). It would not be feasible to connect a sensor to indicate when the tank is full. It would be expensive and there will be issues involved with installation, reliability and maintenance.

Excess or spilled water from storage tanks and tap outlets shall be diverted into open channels. Where appropriate, the water in the channel shall flow into formalized livestock watering pools. This will help remove the need for livestock having to travel to the Hepka River for water. The riverbanks and mountain slopes will then be kept in a better condition. Alternatively, the excess water channels shall divert water into crop fields where the water is soaked into the ground and evaporated into the air (Figure 20a). If none of these solutions are appropriate, excess shall be diverted into a soak-away filled with stones outside Pamlatum village where the water will seep into the ground and eventually flow back into the groundwater and river system (Figure 20b).



(a)



(b)

Figure 20: (a) Crop irrigation and (b) soak-away drainage (Morgan 1990, p.238).

Chapter 7 Design Analysis & Discussion of Results

7.1 PERFORMANCE

The solar powered water pumping system design concept was simulated using the PC software package called PVSyst v4.1. This software package is used for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transport) PV systems, and includes extensive meteorology and PV systems components databases, as well as solar energy tools. A step by step guide on how the SPWP design was modelled and simulated using PVSyst v4.1 is presented in *Appendix G, p.93*.

7.1.1 General Performance Results

The following performance results are for a single pump station. Since the pump stations are identical, these results apply to all three pump stations. Table 11 summarises the main performance results. The main results to point out are the missing water, percentage of unused water that is lost to excess water flows, the group efficiency and system efficiency. Detailed performance results can be found in *Appendix H, p.106*.

The results showed 4.3% of the allowed daily water consumption of 4,360 litres is missing (can not be supplied by the system). This equates to just over 1 litre less per person per day than the nominated (allowed) demand. Since the specified minimum average daily demand is actually 4,320 litres per day, this is assumed acceptable. 3.8% of the daily water pumped (163 l/day) is lost to excess water flows and 96.2% of the water pumped is collected and utilized effectively. However in reality, excess water flows may even be less, as village members will be able to tell when the village storage tank is at capacity and therefore they can potentially increase their water consumption for that day and reduce excess water flows. The efficiency of the motor and pump combined (group efficiency) is 48.5%. Typical group efficiencies for a high voltage DC system like these range from 60% to 70% (Burton and Monsour 2003, p.34) so there is definitely room for improvement. The system efficiency is defined as the amount of solar irradiation energy collected by the PV array that is effectively converted to hydraulic energy that is imparted onto the water. The system efficiency of 4.86% takes into account the efficiency of the PV array, cabling losses, power conditioning efficiencies, group efficiency and any other loss between the PV array and pump. Typical system efficiency for a system like this range from 4% to 6% (Burton and Monsour 2003, p.34) so this is acceptable.

Table 11: Summary of main performance results of the SPWP system.

Avg. Head	102.8 m	**Water Pumped**	1582 m^3/yr
Avg. Flow Rate	627 L/h	**Excess Water (lost)**	59 m^3/yr
Specific Energy	2.10 kWh/m^3	**Excess Water Flows**	3.8 %
Group Efficiency	48.5 %	**Nominal Water Needs**	1591 m^3/yr
System Efficiency	4.86 %	**Missing Water**	4.3 %

Avg. Water Pumped	4.334 m^3/day	**Avg. Nom. Water Demand**	4.360 m^3/day	**Avg. Excess Water**	0.163 m^3/day

7.1.2 System Losses

Figure 21 presents all the losses associated with converting the solar irradiation collected by the PV array into hydraulic energy to lift the water from the water collection point into the intermittent settling tank (applies to all pump stations). The explanation of each loss is detailed in *Appendix H.3, p.111*.

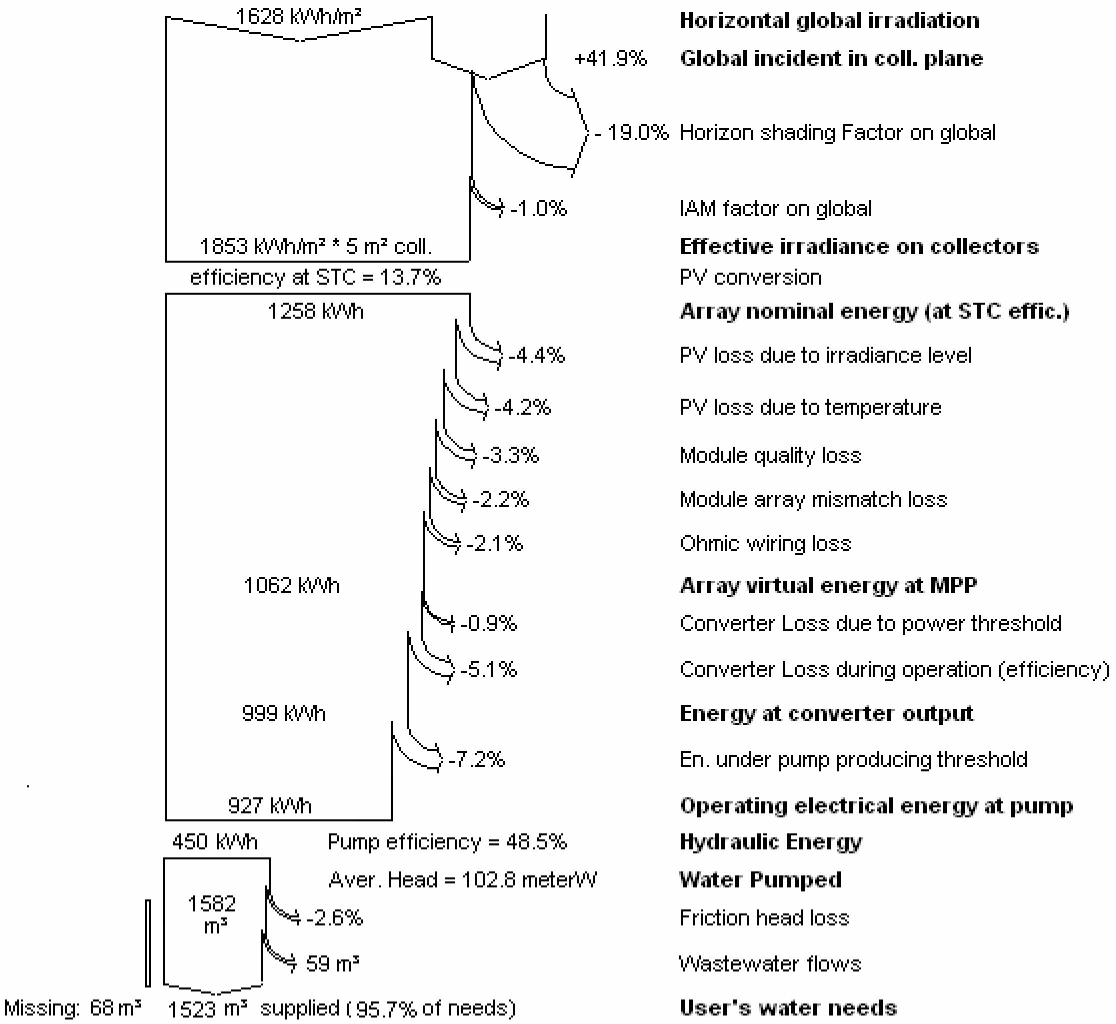


Figure 21: Annual system losses.

7.1.3 Pamlatum Village Water Supply

7.1.3.1 Nominal Water Demand

Table 12 presents the monthly nominated water demand (allowable consumption) for Pamlatum village used during the simulation of the system. The average nominal daily demand is 4,360 litres or 24.5 litres per person. The values in brackets show the percentage increase or decrease from the minimum specified average daily village demand of 4,320 litres per day. The average nominal water demand is above the specified demand and therefore meets this requirement. However, the problem arises when considering the seasonal variations in the water supplied and village population growth. Figure 22 presents the monthly water pumped and consumed by Pamlatum village with the high and low water demands and seasonal migration overlaid on the graph (from Figure 3).

Table 12: Nominal (allowed) water demand for Pamlatum village.

Month	Allowance		Month	Allowance	
	l/day	l/pers.d		l/day	l/pers.d
January	3,770	21.2 (-12.7%)	July	2,910	16.4 (- 32.6%)
February	4,520	25.4 (+ 4.6%)	August	2,720	15.3 (- 37.0%)
March	5,700	32.0 (+ 31.9%)	September	4,010	22.5 (- 7.2%)
April	5,020	28.2 (+ 16.2%)	October	5,890	33.1 (+ 36.3%)
May	4,200	23.6 (- 2.8%)	November	5,870	33.0 (+ 35.9%)
June	2,320	13.0 (- 46.3%)	December	5,390	30.3 (+ 24.8%)
Average Allowance	**4,360 litres/day**		**24.5 litres/person.day**		
Avg. Specified Demand	**4,320 litres/day**		**24.3 litres/person.day**		

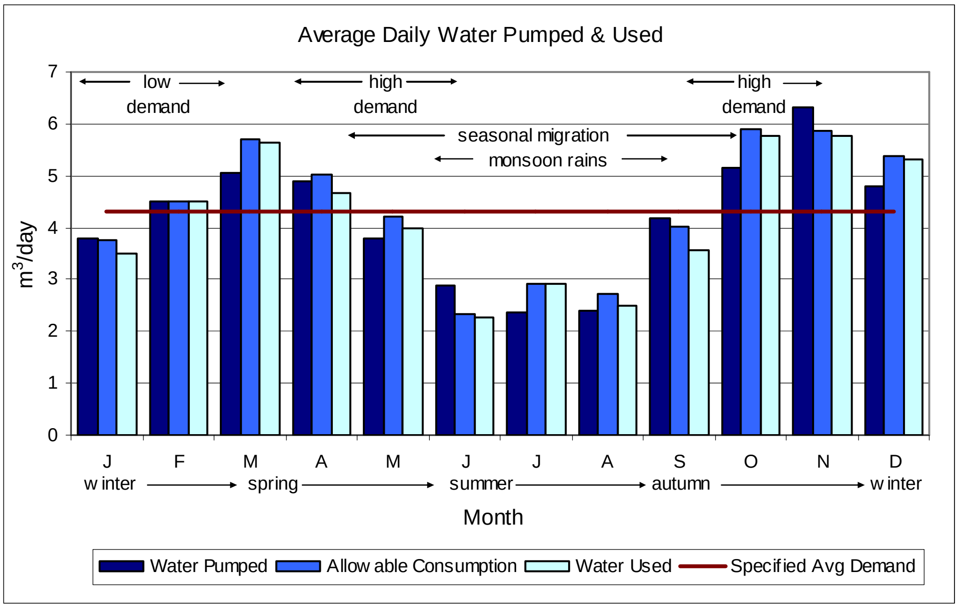


Figure 22: Water pumped and used, including the specified average village water demand.

As can be seen, the water supply problem arises during January, May, September and especially June through to August. The nominated water demand for these months is under the minimum specified demand of 4,320 litres per day. During the month of June, the nominal water demand for Pamlatum is only 2,320 litres per day. This nominal demand is 46.3% lower than the specified average. It is known that seasonal migrations of the village people into higher mountain areas occur from May/April to September/October. In Chauganphaya village for example, the village population reduces by up to 40% during the summer. Since Pamlatum village is located next to Chauganphaya and both villages adopt similar lifestyles, it is likely that the population of Pamlatum is also reduced from April through the October through seasonal migration. This will need to be confirmed through future village assessments.

The other thing to point out from Figure 22 is the high and low village water demands. During the winter months from December through to February, water demand is at its lowest as people and livestock are less active and crop production is minimal. There is a peak in water demand from April to June as the weather is warmer, springs flows from snow melt is reduced and people are more active in growing crops. There is another peak in water demand from the end of September to November as people return from the seasonal migration and the monsoon rains stop. The monsoon rains occur during the summer months of June to September. This additional rainfall during summer will help compensate the low water supply from the pumping system during these months. Overall, the peaks and troughs in village water demand, along with the seasonal migration and monsoon rains, correlate well with the amount of water supplied by the pumping system. If population growth was taken into account, after ten years the average specified village water demand would rise to 5,270 litres per day (*Appendix C, p.63*). For this point in time, it shall be assumed the water supply is acceptable until more information is obtained about seasonal variations in water demand and the impacts of population growth.

7.1.3.2 Missing Water & Excess Water Flows

Missing water is defined as the difference between the nominal water demand and the water actually consumed by the village. Figure 23 presents the average daily missing water and excess water flows for each month. Both the daily missing water and excess water are variable throughout the year. Approximately 4.3% of the water is missing and approximately 3.8% of the water pumped is lost by excess water flows. The peaks on the graph occur during months when the allowable water consumption and daily water pumped are relatively large. It is also likely that these months have more consecutive days of cloudy weather and/or more consecutive days of sunny weather. Consecutive cloudy days will cause the village storage tank to empty (quicker with larger consumption rates) and the missing water percentage will rise. Likewise, consecutive sunny days will cause the village storage tank to fill up (quicker with larger pump rates) and the excess water will flow out from the top of the tank.

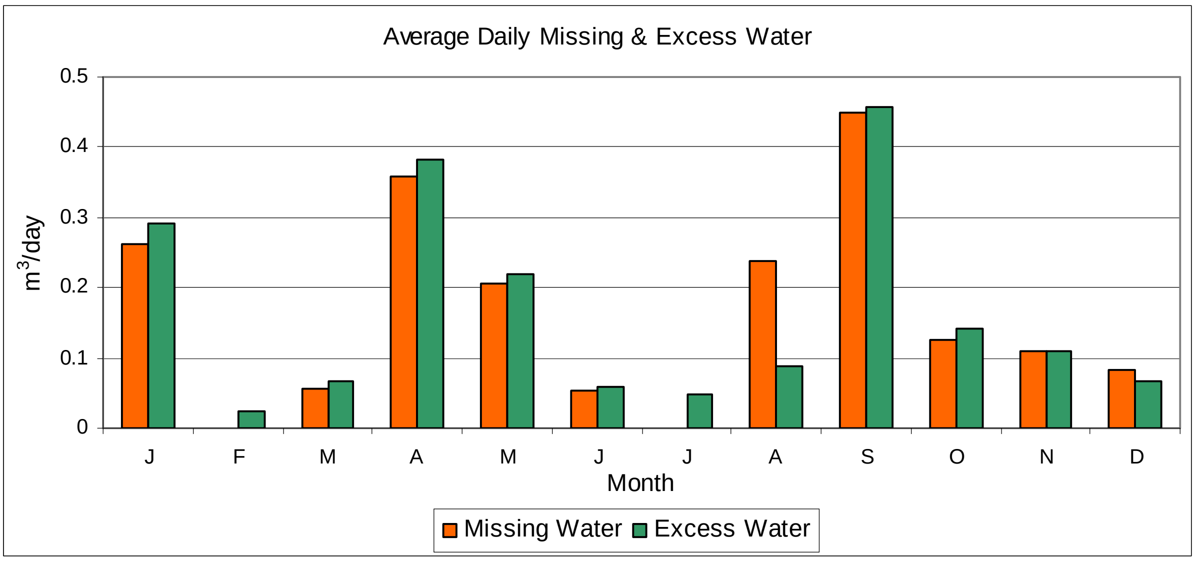


Figure 23: Average daily missing and excess water.

7.2 Transportation & Installation

The following sections provide a brief estimation on the total equipment weight, the requirements on transportation and a brief installation schedule. While many assumptions (see *Appendix I, p.113*) have been made, the analysis does provide insight into the transportation and installation requirements.

7.2.1 Transportation

The weight of materials and equipment (Table 13) has either been specified from catalogues or has been obtained from assumptions based on brief Internet searches and telephone calls with suppliers. Sources of material and equipment information, assumptions and calculations on units and weight are presented in *Appendix I.2, p.114*. The total estimated equipment weight is 61.2 tonnes which includes a 10% safety factor for unspecified material and equipment supplies.

Table 13: Weight of materials and equipment.

Item	Unit Weight (kg)	Units (qty.)	Total (kg)
Grundfos Pump & Motor	9.7	3	29.1
BP PV Module	12.4	12	148.8
MPPT/Controller	6	3	18
2-axis tracking frame	30	3	90
20 mm PE pipe	15	6	90
Pipe fittings	0.1	50	5
Valves	1	10	10
Taps	1	7	7
Armoured Cable	20	3	60
Burned Bricks	**2.8**	**5250**	**14,700**
Washed River Sand	**1000**	**28**	**28,000**
Gravel	1000	6.2	6,200
Cement	20	210	4,200
Pump House	500	3	1,500
PV Array Perimeter Fencing	500	1	500
Installation Equipment and Tools	100	1	100
		Total	55,658
		Add 10% Safety Factor - **Total Weight**	**61,224**

Table 14 presents the time required to transport all materials and equipment including the required number of people and animals. Non-village members include project managers, engineers, technicians and volunteers. The human weight carrying capacity has been assumed based on personal experience and judgement. The weight carrying capacity for animals (i.e. pack mules) is based on a brief Internet search (Barnett 2005).

Table 14: Human and animal resources required for transportation

Human weight carrying capacity per day (assumption)	40 kg
Animal weight carrying capacity per day (Barnett 2005)	100 kg
Days for transportation (assumption)	**14**
Number of village members for daily transportation (assumption)	26
Number of non-village members for daily transportation (assumption)	10
Total number of people required for transportation per day	**36**
Total number of animals required for transportation per day	**30**

7.2.2 Installation

Figure 24 presents a brief installation schedule based on utilizing 10 non-village members and 26 members from Pamlatum (assuming one person per household is able to help with installation). This schedule is based on my personal assumptions and engineering judgement.

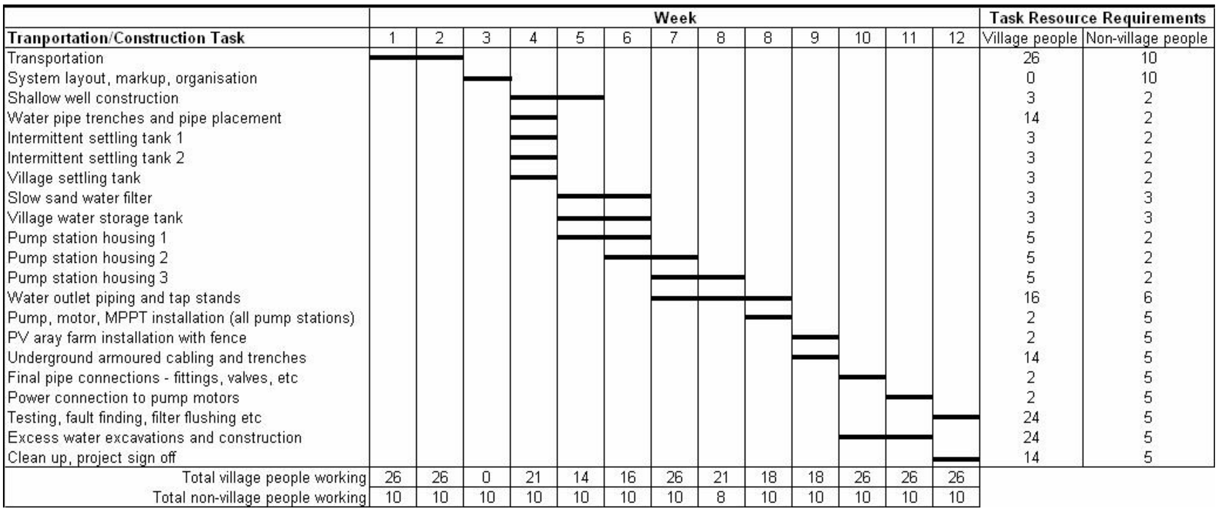


Figure 24: 12-week installation schedule and human resources.

7.3 OPERATION & MAINTENANCE

7.3.1 Operation & Maintenance

Keeping the system well maintained is important for ensuring reliability and continual operation. Equipment with moving mechanical parts will have the most maintenance requirements to ensure reliability. Both pumps and motors have mechanically moving parts. Other equipment such as the two-axis array tracker and water taps have moving parts, however they are manually operated and should require less maintenance to ensure reliability. The slow sand water filter will require regular cleaning maintenance to remove trapped sediment. The remaining equipment will require much lower levels of maintenance. For instance, PV modules will require occasional cleaning of dust and bird droppings.

There are many factors besides routine maintenance that influence the smooth operation of a solar powered water pumping system. Undertaking preventative measures even before the system is in operation by performing good quality engineering design and installation is a major factor in the smooth operation of a solar water pumping system.

Sondalini ([no date]) provides a thorough checklist of the important engineering design and installation factors one must have in a helical rotor pump and motor to get a long, failure-free, low maintenance operating life. It is out of the scope of this project to go into great detail on engineering design and installation. Due to the scope of this project, I have only provided a brief outline of the types of routine maintenance activities that may be required for the system, including the required maintenance frequency and skill level (Table 15). This is based on my own judgement. Mike Sondalini (2007), an industrial maintenance and quality management consultant at Lifetime Reliability, has noted the maintenance schedule as "on the right track". Table 16 summarises the maintenance requirements from Table 15. The frequency of routine maintenance activities (excluding PV array azimuth adjustments), is within the target of twelve times per year (*Appendix D.5, p.74*).

Table 15: Maintenance schedule.

Component	**Frequency**	**Duration**	**Skill/ Difficulty**
2-axis trackers			
Adjust array azimuth.	3 times per day	15 min	Very Low
Adjust array tilt.	every 1 to 3 months	15 min	Very Low
Lubricate joints and bearings.	once per year	60 min	Low
PV Modules			
Clean dirt/bird droppings.	once per month	30 min	Very Low
Electrical Cable/Sensors			
Check electrical connections.	once per month	60 min	Low
DC Motors			
Replace brushes.	every 5 years	1 day	Medium
Ensure brushes are clean from dust.	once per month	60 min	Low
Ensure good connection with pump.	once per month	60 min	Medium
Pumps			
Ensure pumps are firmly mounted.	once per month	60 min	Low
Remove pumps from well. Check pump drive shaft, bearings, seals, etc. Check condition, lubricate, clean, tighten, etc.	once per year	1 day	High
Slow Sand Water Filter			
Remove 150 mm thick layer of sand from top of the filter, wash and replace.	When filter is clogged. (~ Every 4 months).	1 day	Medium
Pipes and fittings			
Check pipes/tanks/valves for blocks, leaks and proper fitting.	once per month	120 min	Low

Table 16: Annual maintenance requirements summary.

O&M Occurrence	Duration	Skill/Difficulty
Daily	45 min	Very Low
Monthly	7 hours	Very Low - Medium
Quarterly	1 day	Very Low - Medium
Yearly	1-2 days	Low - High

7.3.2 Local Materials & Spare Parts

It is critical for the long-term operation of the system that village members are able to gain access to local materials and spare parts needed for maintenance and repairs at an affordable price. Pamlatum is in a remote location with Simikot, the regional headquarters, a day's walk from the village. Ideally, any maintenance and repair supplies required for the system should be accessible from Simikot. Identifying the regional capability and capacity in supplying materials and spare parts for the system is out of scope of this project.

7.3.3 Breakdown Frequency

It is hard to determine how often the SPWP system is likely to fail without knowing the detailed design. A paper by Chowdhury (*et al.* 1993) researched the operational performance of seven installed solar powered water pumping systems in the state of Wyoming, US. The pump systems were a mix of AC and DC powered, positive displacement and centrifugal pumps, fixed tilt and one-axis tracking. Static heads ranged between 3 to 100m with water flow rates between 1,800 and 30,000 litres per day. The systems were in operation between 1991 and 1992 (1-2 years) and a total 6 failures occurred between five of the systems. These failures included two pipe blockages due to sand in the well, one collapsed water-well, problems with the shock absorber in one array tracker due to high wind loading and one freezing of an electrical float. With better design, all these failures could have been prevented. Even though this paper is a little out of date and the pumping systems were in operation for only two years, it does give a ball-park figure on the failure rates of solar-powered water-pumping systems. On average, preventable failures occurred in the pumping systems every 1 to 2 years. The concept design for Pamlatum is more likely to fail as it contains three pump stations. Contingency plans to repair the system and to deal with the impact of unavailable water should be developed in the case of failure.

7.3.4 Failure Modes & Effects Analysis

It is recommended by Sondalini (2007) to perform a Failure Mode and Effects Analysis (FMEA). FMEA is a risk assessment technique for systematically identifying potential failures in a system. Ideally, FMEA should begin during the earliest conceptual stages of design and continue throughout the life of the pumping system. In FMEA, *failure mode* means the ways in which something might fail and *effects analysis* refers to studying the consequences of those failures. The purpose of the FMEA is to take actions to eliminate or reduce failures in the design, starting with the highest-priority ones. It is also used for developing routine maintenance schedules to eliminate or reduce failures during operation.

7.4 Cost Estimation

All assumptions and sources of capital costs are presented in *Appendix I.2, p.114*. The following cost estimation provides an insight to the associated costs of the SPWP system. Further analysis is needed to ensure the accuracy of these estimates. It must me noted that costs are hard to ascertain at this point in time. All costs are based on Australian dollars and retail prices. *Appendix D.5, p.74* contains all the cost design targets for the SPWP system.

7.4.1 Hardware & Installed Capital Cost

Installation costs include importation, transportation and installation of the SPWP system. Table 17 presents the total installed cost which includes a 10% safety factor for unidentified hardware cost, and a 20% factor to compensate the cost of installation. The total installed cost has been estimated at AUD $60,000, which is above the target value of AUD $50,000. This target is not confirmed and could just as easily be AUD $100,000. It depends on the available funding, including the quality and standard required to ensure long-term sustainability.

For a cost comparison, three separate solar water pumping companies were consulted for a price quote on the specified pumping system (*Appendix J, p.116*). The quotes range from AUD $21,248 to AUD $41,000. None of the quotes included cost for transportation, installation, water filtration/purification or water storage.

Table 17: Hardware and installed capital costs.

Component	Unit Price	Units	Total (AUD)
Grundfos Pump & Motor	$3,150	3	$9,450
BP PV Module	$1,400	12	$16,800
MPPT/Controller	$600	3	$1,800
2-axis tracking frame	$800	3	$2,400
20mm PE pipe	$100/100m	6	$600
Pipe fittings	$2	50	$100
Valves	$20	10	$200
Taps	$20	7	$140
Armoured Cable	$500/100	3	$1,500
Burned Bricks	$0.80	5250	$4,200
Washed River Sand	$50/m^3	28	$1,400
Gravel	$75/m^3	6.2	$465
Cement	$6/bag	210	$1,260
Pump House	$1000	3	$3,000
PV Array Perimeter Fencing	$500	1	$5,00
Installation Equipment and Tools	$1000	1	$1,000
		Hardware Costs	$44,815
		Add 10% safety factor	$4,482
		Total Hardware Costs (rounded up)	$50,000
		Installation Costs (20% of hardware costs)	$10,000
		Total Installed Costs	**$60,000**

7.4.2 Operation & Maintenance Cost

The routine maintenance costs (excluding replacement costs) were assumed to be 3% of total capital costs, which equates to AUD $1,800 per year. The replacement of motor brushes were assumed to take place every five years at a cost of AUD $50 per replacement for all motors. The replacement of the pumps was assumed to take place once after ten years at total cost of AUD $9,450. Assuming a 20-year operating lifetime, a discounted rate of 10% and nil inflation, the present cost of all the replacements is AUD $3,748. Therefore the total replacement cost equates to AUD $190 per year. Adding routine maintenance costs, the total annual operating cost is thereby approximately AUD $2,000 per year. The target annual operating cost is AUD $1,500.

7.4.3 Life-Cycle Cost Analysis

Table 18: Life-cycle cost analysis

System description:	*2.05 kW Stand-alone solar powered water pump system*				
Parameters					
Period of Analysis:	*20 years*		Excess Inflation:		*i = 0*
Discount Rate:	*d = 10%*		Annualisation Factor (Pa):		*8.51*
Annual water collected:	*1,523,000 litres*		Number of Households:		*26*
Capital Cost					
Hardware:		$..............	$50,000	…………......	
Installation:		$..............	$10,000	…………......	
Total Installed Costs:		$..............	$60,000	…………......	
Operation and Maintenance					
Annual Cost:		$..............	$1,800	…………......	
Discount Factor (Pa):		…………......	8.51	…………......	
Life-cycle O&M:		$..............	$15,318	…………......	
Replacements					
Item	*Year*	*Cost*	*Pr*	*PW*	
Motor brushes	5	$50	0.62	$31.00	
Motor brushes	10	$50	0.39	$19.50	
Pumps	10	$9,450	0.39	$3,685.50	
Motor brushes	15	$50	0.24	$12.00	
		Total Life-cycle Replacements:		$3,748.00	
Total Life-cycle Cost		$79,066			
Annualisation Factor (Pa)		8.51			
Annualised Life-cycle Costs		$9,291			
Unit Water Costs		**0.00610**	**$/litre**	**0.610**	**¢/litre**
Avg. household water consumption		5,877	litres/yr		
Yearly household water cost		$357	per year		

Table 18 (above) presents the life-cycle cost analysis based on a system operating lifetime of 20 years, discount rate of 10% and no inflation. The method for analysing the life-cycle costs was taken from Markvart (2000, p.148). The unit cost of water is calculated at AUD 0.61¢ per litre, which is above the target cost of AUD 0.41¢ per litre. The average household water expense for Pamlatum, based on Australian dollars is estimated at AUD $357 per year.

7.5 SAFETY

7.5.1 Water Quality

The turbidity of Hepka River during spring is 12 NTU and is relatively low (turbidity levels can exceed 300 NTU (Jaksirinont 1972)). Slow sand water filters require influent turbidity less than 20 NTU and preferably below 10 NTU (WHO [no date]). In this concept design, water seeps from the Hepka River through the ground soil and into the shallow well. The ground soil acts as a filter and helps to remove sediments and pathogenic bacteria from the water. Water is pumped from the shallow well through a series of three settling tanks where further sediment is removed from the water. Whether the water turbidity, before it reaches the slow sand water filter, is below the recommended 10 NTU throughout the year is unknown without further analysis of ground water and the filtration process. The size of the suspended particles contained in the water will also influence the effectiveness of the filtration process. Using the Wentworth Grade Scale, suspended particles are classified into groups ranging from cobble to silts and clays (256mm to 0.00024mm in particle diameter respectively) (Ongley 1996). Field tests to verify particle sizes should be completed, with the filtration process designed accordingly to tolerate and remove these particles.

After entering the filter, sediment and micro-organisms are removed in the top few centimetres of the sand (WHO 2006). Nearly all the remaining turbidity will be removed from the feed water into the filter (Ellis 1987). The fine sand and slow filtration rate facilitate the establishment of a biological community known as the "schmutzdecke" on the surface of the filter. The majority of the biological community will be predatory bacteria who feed on water-borne microbes passing through the filter. If the slow sand water filter is maintained appropriately, microbiologically "clean" water at the filter outlet should be produced which should not require disinfection to inactivate any bacteria (WHO [no date]). When working ideally, the filter should reduce *E.coli* by 99% to 99.9% (Jaksirinont 1972). This process is also effective for the removal of organics, including certain pesticides and ammonia (WHO 2006).

7.5.2 Injury Prevention

There are several issues surrounding the safety of village members during the installation and operation of the SPWP system. The steep mountain slopes pose a risk to safety during installation. Prior to installation, workers should be briefed about possible workplace dangers and how to avoid injury. They should also be trained in the correct operation and installation of equipment.

Another potential safety risk is the high voltages produced by the three PV arrays. The nominal voltage for each array is 144V and once again, workers and system operators need to be briefed and trained in the proper installation and handling of high voltage equipment. As mentioned in previous sections, the safety risk to the general village community from the pumping system shall be reduced by the following measures:

- Secure pump housing for pumps, motors, electronic equipment and settling tanks.
- Perimeter fence for the PV array farm.
- Underground pipes and armoured cable where possible.
- Proper management of excess water flows.

In addition, proper paths, steps, railings, etc, should be constructed to allow safe access to pumping stations, PV array farm and other associated equipment. Appropriate and easy to understand warning signs should also be installed where necessary.

7.6 SOCIAL

The social issues associated with introducing a SPWP system for Pamlatum are complex and cover a broad range of topics for discussion. The main indicators used in this project for meeting the social requirements are village ownership, village acceptance and women and children friendly. It is out of the scope of this project to go into detail about the social issues. The main purpose of this section is to raise some key questions associated with meeting the social requirements. The questions asked are based on my overall understanding of the social issues involved through conducted research into a number of papers including Zahnd (2004), Short and Oldach (2003), Briscoe and Ferranti (1988) and other non-referenced material.

7.6.1 Village Ownership

- Has the village community been involved in all phases of the project such as village assessments and initial consultation, project management, system design and layout, installation and operation?
- Is there a financial cost structure put in place so that the pumping system can be handed over to the village community who will then pay for the water services over the operating lifetime of the system?
- Are there dedicated village community members who can be trained and paid in the proper operation and maintenance of the system so that operating independence can be achieved?

7.6.2 Village Acceptance

- Is the technology culturally appropriate and acceptable to the end users?
- Do village members value and take pride in the proposed water service system.
- Has the design including the layout of taps and flow rates been accepted by the village?
- Do village members accept their allowable water consumption and seasonal variations?
- Do village members accept the colour, taste and odour of the water supplied to the village?
- Do village members accept their roles in operating and maintaining the system? Do village members accept how and where they will get maintenance materials and spare parts?
- Is the system affordable for the village community and does the entire community accept the cost of the water services over the life-cycle of the system?

- Does the village community understand and accept the possible implications of system failure, including the immediate lack of water, and is there a contingency plan in place for repairing the system and providing backup water supplies?

7.6.3 Women & Children Friendly

- Does the design reflect the requirements of women? Have women been involved in all phases of the project?
- Are water tap outlets easily accessible and operable by women and children?
- Is system maintenance by women possible? Are women village members trained in the proper operation and maintenance of the system?
- Do women understand the possible implications of having more available time? (i.e. an increase in time available can simply result in a change of use of that time or even an increased burden on women).
- Do women understand the possible implications of increased water supplies? (i.e. an improved water supply may also be used for irrigation, with the greater crop yield requiring more work).
- Are children properly protected from the pumping system?

7.7 ENVIRONMENTAL

The solar powered water pumping system does not produce any greenhouse gases as it is powered entirely by the sun. It does not produce any toxic or harmful substances. If the system is designed properly, it will allow livestock to access water from watering pools within or near the village rather than being forced to travel to the river. This will prevent vegetation along riverbanks from being destroyed and soil erosion. Preventing soil eroding into river waters will provide a cleaner and less turbid water source. The river water will also be safer to drink as there will be less faecal pollution from animals. The only environmental degradation caused will be from the installation of the system and excavations of soil. However the environmental degradation is minimal, and over time the vegetation will re-establish itself and there will be a net benefit for the local environment.

The other environmental issue revolves around the manufacturing of the equipment. It is out of scope of this project to examine this issue. Some questions that are worth considering include:

- Does the equipment contain any harmful materials that could cause potential environmental damage when its operating lifetime is over and the equipment is disposed?
- Does the manufacturing of the equipment itself cause any environmental damage?
- How many years will it take the PV array to provide enough useful pumping energy to offset the energy required to manufacture and install the entire pumping system?

7.8 STANDARDS, REGULATIONS & LAW

7.8.1 Nepalese Standards & Local Authorities

All Nepalese standards and local authorities that require compliance shall be dealt with during the detailed design and planning phase of the project. At this point in time, it is assumed that all regulative bodies will be complied with.

7.8.2 Australian Standards

Australian standards that are deemed appropriate for compliance shall be dealt with during the detailed design and planning phase of the project. At this point in time, it is assumed that the solar powered water pump system will be compliant under Australian Standards. The relevant Australian Standards include:

AS 4059	Stand Alone Power Systems
AS/NZS 3000	Wiring Rules
AS 2368	Test pumping of water wells
AS 2200	Design charts for water supply and sewerage
AS 2492	Crosslinked polyethylene pipe for hot and cold water applications
AS 2537	Mechanical jointing fittings for use with crossed-linked PE pipe for hot and cold water applications.
AS 3778	Measurement of water flow in open channels
AS 4726	Water microbiology
AS/NZS 5667	Water quality – Sampling

Chapter 8 Concept Design Evaluation

The following is an evaluation of the SPWP system based on all requirements that were developed as part of the QFD process (*Appendix D.1, p.65*). Whether or not a requirement has been met is based on meeting the targets of the engineering specifications (*Appendix D.5, p.74*) that relate to that requirement (as shown in the House of Quality in *Appendix D.7, p.78*). The engineering specification values reached by the SPWP concept design are presented in *Appendix D.6, p.77* alongside the engineering targets.

8.1 ESSENTIAL REQUIREMENTS

Table 19 critically evaluates the potential that the SPWP concept design will satisfy the essential requirements during ideal operation. If a requirement is not met, a description of the actions to be taken is provided to verify whether or not that requirement can be met. Before a design is selected, all essential requirements should be met.

Table 19: Evaluation of essential requirements.

Essential Requirement	Meets Requirement
Autonomy	**Y**
The water storage capacity is 20,000 litres, which is 4.6 times the average daily specified water demand of 4,320 litres per day. The target was three days worth of water storage (12,960 litres or 15,800 litres when accounting for population growth after 10 years).	
Robust	**Y**
Pump housing and PV array fencing will help protect the system from the environment, livestock, children and unauthorised people to some degree. All pipes are buried underground or properly insulated to prevent freezing. Power cabling is also buried underground for protection. The system is tolerant of high river turbidity levels due to the ground filtration process before the water enters the shallow well. The system is tolerant of UV radiation and ground soil due to the pump housing and types of materials used (i.e. PE pipe, armoured cabling designed for underground).	
Easily Accessible	**Y**
Average household distance to village water outlets is less than 100m and total collection time is less than 5 minutes. The locations of the water tap outlets are spread throughout the entire village. Components are easily accessible via access paths to pump stations, PV array and the filtration system. Power isolating switches and pipe valves (not discussed) allow the system to be isolated and accessed for maintenance.	
Reliable	**Y**
The system is reliable providing it is designed and engineered to a high standard, the FMEA process is used to reduce risk and the system is maintained on a regular basis by the village community.	
Lifetime	**Y**
The system has a potential operating lifetime of over 20 years with the replacement of motor brushes every 1 to 5 years and replacement of pumps every 7 to 10 years.	
Low Life-Cycle Cost	**?**

The life-cycle cost of the water was calculated to be AUD 0.61¢ per litre which is above the target of AUD 0.40¢ per litre. This represents an annual cost for water per household of approximately AUD $357 per year. It is unknown at this stage whether this can be afforded by the end-user without further village assessments of household income capacity, the available funding for the project and the local cost of implementing the project.	
Transportable	**?**
It was estimated that the transportation of all materials and equipment will take two weeks using 36 people and 30 animals. This is above the assumed target of 20 people and 22 animals in one day. The estimated transportation results needs to be verified by refining the calculations and consulting further village assessments on availability of transportation resources. The difficulty in transportation is mainly due to the large material load, in particular, the material load of the sand and bricks. Reducing the size of the slow sand water filter will reduce the sand requirements. Reducing the size of the storage tanks, reducing the number of pump stations and designing an alternative to the shallow well will reduce the requirement on bricks.	
Maintainable	**?**
The system pumps the water in three stages with three pumps, three motors and three separate PV arrays. It is questionable whether this system is maintainable without knowing the full extent of the capability and capacity the village community has for maintaining the system. It is also questionable whether local materials and spare parts required for maintenance can be accessed within an appropriate timeframe at an affordable cost.	
Nepalese Standards and Local Authorities	**Y**
It is assumed that the design, installation and operation of the SPWP system will comply with Nepalese standards and local authorities.	
Safe Drinking Water	**Y**
There is good potential that the water supplied to the village will be safe to drink with turbidity levels under 5 NTU and *E.coli* concentrations under 10 colonies per 100ml.	
Local Renewable Energy	**Y**
The SPWP concept design is powered entirely by the sun.	
Village Ownership and Acceptance	**?**
There is potential that the village will take ownership and accept the SPWP system provided the social issues raised in this paper are addressed. However, whether or not the village takes ownership and accepts the project and SPWP system is questionable due to the uncertainties in affordability, maintainability and transportation.	
Children and Women Friendly	**Y**
There is potential for this requirement to be met provided that the social issues raised in this paper are addressed.	

8.2 DESIRABLE REQUIREMENTS

Table 20 critically evaluates the potential that the SPWP concept design will satisfy the desirable requirements, and if not, what actions need to be taken to verify whether or not that requirement can be met. Each requirement is awarded a score between 0 and 1.5 as defined below:

0.0 – does not meet requirement
0.5 – partially meets requirement
1.0 – meets requirement
1.5 – more than meets requirement

The points are awarded towards the concept design by multiplying the requirement score with the importance factor (*Appendix D.3, p.69*). At the end, all points awarded are totalled to give a final score for the design concept. The SPWP concept design totalled a score of 54.5 points out of a maximum of 82.5. Future concept designs can be evaluated using the same method and selected based on the highest score in combination with meeting all essential requirements.

Table 20: Evaluation of desirable requirements.

<table>
<tr><th>Desirable Requirement</th><th>Importance x</th><th>Score =</th><th>Points</th></tr>
<tr><td>Australian Standards</td><td>1</td><td>1.0</td><td>1.0</td></tr>
<tr><td colspan="4">It is assumed that the design, installation and operation of the SPWP system will comply with Australian standards.</td></tr>
<tr><td>Simple to Install</td><td>2</td><td>0.0</td><td>0.0</td></tr>
<tr><td colspan="4">The total equipment weight is 61,224 kg and therefore requires a lot of material handling during transportation and installation. The concept design has three pump stations with three PV arrays, thereby increasing the difficulty and complexity of installation as opposed to one or two pump stations.</td></tr>
<tr><td>Efficient</td><td>3</td><td>1.5</td><td>4.5</td></tr>
<tr><td colspan="4">The concept design achieved a system efficiency of 4.86%, a group efficiency of 48.5% and water-use efficiency of 96.3%. These results, especially the water-use efficiency, exceed the specified targets. However, there is room for improving the group and system efficiency.</td></tr>
<tr><td>Low Capital Cost</td><td>4</td><td>0.5</td><td>2.0</td></tr>
<tr><td colspan="4">The capital cost was estimated at AUD $60,000 which is above the target of AUD $50,000.</td></tr>
<tr><td>Injury Prevention</td><td>5</td><td>1.0</td><td>5.0</td></tr>
<tr><td colspan="4">The SPWP conept design shall be safe from injury providing pumps stations are contained in houses, PV arrays are fenced off, proper access paths are constructed (with steps/railings), pipes and cabling are installed underground and warning signs are installed. In addition, adequate training and education shall be provided for installation, operation and maintenance.</td></tr>
<tr><td>Excess Water Management</td><td>6</td><td>1.5</td><td>9.0</td></tr>
<tr><td colspan="4">If the SPWP system is used effectively, there will be no excess water flows. In the case where excess water does flow, the water shall be properly diverted through open channels</td></tr>
</table>

to livestock watering pools, crop fields and back into the groundwater and river system. These excess flows will provide net benefits if designed properly.			
Pollution Free	**7**	**1.5**	**10.5**
The installation of the SPWP system will have a small impact on the environment caused by excavation of soils, mixing concrete/cement and building material wastage. The operation of the SPWP system will not produce pollution such as greenhouse gases and toxic or harmful substances. When operating well, it will remove the need for humans and livestock from travelling to the Hepka River for additional water needs, thereby preventing the destruction of vegetation, soil erosion, water turbidity and animal faecal pollution. The overall condition of the river and water quality will improve.			
Water Demand	**8**	**1.0**	**8.0**
The average daily water supplied by the SPWP system throughout the year is 4,334 litres (allowable consumption is 4,360 litres per day with 4.3% of the water missing) when compared to the specified target of 4,320 litres per day. The water demand shall be met providing the variation in the water supply during the year is acceptable. Village assessments need to confirm this in regards to variations in water demand caused by seasonal migrations, monsoon season, seasonal activity levels (i.e. growing crops) and population growth. If the village population growth (2% p.a.) was taken into account, the specified water demand after 10 years would be 5,268 litres per day.			
Low Operating Cost	**9**	**0.5**	**4.5**
The annual operation and maintenance cost was estimated at AUD $2,000 when compared to the assumed target of under AUD $1,500 per year. The cost calculations need to be refined and the income capacity of the village to pay for operating the SPWP system needs to be known to verify the design targets. In addition, the available funding for operating the SPWP system and local operating costs needs to be known.			
Low Maintenance Frequency	**10**	**1.0**	**10**
A general maintenance schedule was developed to outline the frequency of maintenance and the type of maintenance required. Manual adjustment of PV array tilt takes place at least three times per day. Adjustment of azimuth is not classified as maintenance but does increase the burden on the operator. Easy to medium difficulty routine maintenance occurs every month. More difficult maintenance activities are required annually. The target maintenance frequency was at most 12 times per year and therefore is assumed acceptable for meeting the target.			
CONCEPT DESIGN TOTAL POINTS / 82.5 **82.5 = maximum score by exceeding all requirements**			**54.5** **(66.1%)**

8.3 POTENTIAL DESIGN SUSTAINABILITY

8.3.1 Technical Sustainability

Overall it is potentially technically feasible to install and operate the SPWP system. It is technically feasible for the system to provide the following:

- Water quality suitable for drinking
- Water quantity required by the village, including allowance for seasonal variations in water demand (however it is unlikely to meet higher demand due to population growth).
- Water accessibility for the entire village with household distances to tap outlets less than 100m, water collection time per trip fewer than five minutes and adequate accessibility to system components for maintenance and repairs.

Ideally, the SPWP system would be designed using one or even two pump stations to reduce complexity, maintenance requirements and likelihood of system failure. However, at the time of generating the concept design, it was not technically feasible to achieve this with the range of pumps researched. Without further design development and research into the village maintenance capability and capacity, it is questionable whether the concept design is maintainable and technically sustainable in the long term.

8.3.2 Social Sustainability

Since women and children carry the main burden of collecting water, ensuring their water service needs is important for the social sustainability of the SPWP system. The village needs to be fully supportive of the project and take ownership of the water service infrastructure. Without this support and ownership, maintenance requirements will be ignored and the system will fail needlessly (Short and Oldach 2003). The system is protected from theft and vandalism to some degree. Overall, there is potential for the health of the community to greatly improve with the combination of increased clean water supplies and adequate sanitation programs. This will ease the burden on women caring for the sick. It will also potentially free up more time that would have been otherwise used for collecting water. This free time can be used for productive uses such as education, growing food and economic advancement. There are too many social issues to cover in this paper, however, they must be dealt with to the full extent by future research, village assessments and design development to ensure social sustainability of the SPWP system.

8.3.3 Economical Sustainability

It is questionable whether the SPWP system can be afforded by the end users. Future village assessments on household income capacity to pay for the water service system and the knowledge of the available funding for the project is required to determine the economic sustainability.

8.3.4 Environmental Sustainability

The SPWP system is powered entirely from the sun without producing any pollutants. In the long term, the condition of the riverbanks and water quality will improve by removing the need for animals and humans to travel to the river. Users downstream will also benefit because of this. The operation is therefore environmentally sustainable. To determine the full extent of the environmental sustainability, analysis into component materials, manufacturing process and energy payback time is required.

Chapter 9 Conclusions & Recommended Further Work

9.1 CONCLUSIONS

Target 10 of the Millennium Development Goals is to halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation. Much work needs to be done in order to achieve this. One village in the world that requires development in water and sanitation services is Pamlatum, located in the Humla district of north-western Nepal.

A solar powered water pump concept design was generated for Pamlatum with the aim of improving the accessibility to adequate volumes of clean water supplies for basic uses such as drinking, hygiene, cooking, washing and some livestock watering and food production. The concept design presented in this paper, pumps water from a shallow well situated next to the local river through a series of three pump stations where it is finally stored in a village storage tank. Water is gravity-fed from the storage tank to a number of tap outlets located throughout the village. The design allows the water to be filtered and purified via settling tanks and through a slow sand water filter located in the village.

The design was based on the customer requirements which were developed as a result of a village assessment and field survey of Pamlatum during April 2007, and research into water accessibility and quality. The customer requirements were translated into engineering specifications with measurable design targets. This specification led to the formation of the potential design solution presented in this paper.

The concept design was modelled with a software package used for simulating and analysing the performance of photovoltaic systems, including solar water pumping designs. The results showed there was potential for the water consumption needs to be met by the design, albeit with some concern associated with the variations in the seasonal water demand and village population growth. The ease and practicability of transporting and installing the system is questionable due to the large volumes of materials and equipment needed. The long term technical feasibility of maintaining the system is a concern due to the complexity involved in using three separate pump stations. It is also questionable whether the village community can afford to pay for the improved water services due to the high cost per unit of water. These issues raised certain key questions associated with the social sustainability and appropriateness of the design. The key questions dealt with village ownership and acceptance of the system and the impacts imposed on women and children.

There is potential for developing the solar powered water pump design to the point where it is appropriate and sustainable. Further work needs to be completed by conducting further village assessments, with particular attention to the capabilities and capacities that Pamlatum has in operating such a system. The wider region also needs to be explored for its capability and capacity to support the reliable operation of the system through supplying maintenance materials and spare parts at an affordable price. It is also recommended to develop other types of concept designs and evaluate them against the requirements of the village. In any case, Pamlatum is in need of an improved water service system. An appropriate solution will greatly benefit the community through improved health and hygiene, more available time and increased economic opportunities.

9.2 RECOMMENDED FURTHER WORK

Three different but related project areas are recommended for further work. These include village assessments and field investigations, concept design generation and progression of future project stages. These recommendations are outlined below.

9.2.1 Village Assessments & Field Investigations

- Determine seasonal variations in water demand, river water quality, river water levels (high/low water mark) and gravity-fed system water flow rates.
- Present the SPWP concept design to the village members and detail their thoughts, concerns and ideas.
- Survey the thoughts of village members on the customer requirements generated, including the importance of each requirement. Modify the customer requirements and measurable engineering specifications accordingly and refine the QFD process.
- Investigate the quality of the groundwater next to Hepka River to determine the requirements for water filtration and purification.
- Determine maintenance capacities and capabilities of Pamlatum.
- Determine the type of capacities and capabilities of the local region to supply materials, spare parts and equipment for the installation, maintenance and repairs of particular types of water service systems. Develop design concepts around these capabilities.
- Determine the local costs of materials, equipment, transportation and installation.
- Determine the household income capacity to pay for a water service system.

9.2.2 Concept Design Development

- Refine and optimise the SPWP concept design. Use different pumps, motors, PV modules, tracking systems, filtration processes, etc.
- Generate other types of design concepts, such as an improved spring-source-gravity-fed-piped system, a spring-source-gravity-fed-open-channel system, a rainwater harvester system or a combination of multiple system types.
- Develop design concepts that integrate the water service requirements of Pamlatum, Chauganphaya, Dingha and Dharapori into one system.
- Evaluate the generated concept designs using the framework and method developed in this paper. Select a final concept design solution for detailed design.

9.2.3 Future Project Phases

- Develop a project plan for initiating the future project phases.
- Acquire funding and select the required personnel for the project.
- Generate a detailed design of the chosen concept design.
- Involve the village community in all phases of the project with particular attention to the needs of women and children.
- Undertake a social sustainability and environmental impact study on the manufacturing, transportation, installation and operation of the final design.
- Install the water service system and monitor the performance and impacts throughout its lifetime. Share this information with the world.

A Village Assessment Photos

The following photos were taken during the village assessment and field survey of Pamlatum, Dingha, Chauganphaya and Dharapori villages in April 2007 by Hiller (2007). All photos are in relation to Pamlatum village only.

Livestock accessing the Hepka River

People washing and bathing in the Hepka River

Poor quality pipe repairs using locally available materials such as old clothes and other waste material

Stream source

Spring source

Collection tank

Pamlatum primary tank with visible water from leakages

New Pamlatum village separation tank (under construction at the time of assessment)

Pamlatum tap 1

Pamlatum tap 2 (stock watering pool in foreground)

Tap overflow down village pathway

Excess water flow into fields is used as informal irrigation

Livestock watering pool which is stagnate and dirty due to low tap flow rate

Formalised stock watering pool which is clean and flushed regularly by good tap flow rate

View upstream Hepka River near Pamlatum

View downstream Hepka River near Pamlatum

Possible pump/shallow well site (steep bank)

Slope up to Pamlatum village

B Climate Data

B.1 HARS Simikot 2006 Recorded Data

The following insolation and temperature data provided by Alex Zahnd, was recorded during 2006 at the High Altitude Research Station (HARS) in the town of Simikot, Nepal. HARS-Simikot was built by Kathmandu University and *The ISIS Foundation* for the purpose of thoroughly testing the technologies that are applied in the village projects. This is to ensure that the technologies are optimised for the local context and environmental conditions before village level implementation. The following data are averaged hourly-recorded values for each month.

Table: Summary of the HARS Simikot global solar insolation, solar PV module and ambient temperature

Summary of the HARS Simikot Humla Global Solar Insolation, Solar PV Module and Ambient Temperature						
Month	Horiz. Radiation (kWh/m²·day)	30 Deg Radiation (kWh/m²·day)	2-axis Track.Radiation (kWh/m²·day)	PV ModTemp.(°C)	Amb. Temp.(°C)	Remark
J	3.40	5.02	6.78	8.79	5.52	Daily Average
F	4.13	5.49	7.23	11.88	8.50	Daily Average
M	4.95	5.84	7.84	12.21	8.10	Daily Average
A	5.65	5.99	7.84	15.53	11.17	Daily Average
M	5.08	5.09	6.51	19.06	15.82	Daily Average
J	4.45	4.43	5.78	19.95	16.86	Daily Average
J	4.33	4.56	5.61	21.62	18.58	Daily Average
A	4.00	4.42	5.37	21.06	17.36	Daily Average
S	5.03	5.83	7.55	20.82	17.30	Daily Average
O	4.67	6.07	8.25	16.04	11.73	Daily Average
N	4.39	6.21	8.60	10.98	8.62	Daily Average
D	3.48	5.34	7.41	8.83	7.28	Daily Average
Average per day	**4.46**	**5.36**	**7.06**	**15.56**	**12.24**	
Yearly Total kWh/m²	**1628.91**	**1955.64**	**2578.16**			
% over Horizontal		20.1	58.3			
% over 30°			31.8			

The ambient temperature is taken close to the HARS office stone wall, at a 2.5m height. Thus for even more correct ambient temperatures, one might want to subtract 2-4˚C from the present value during the non-sunshine hours (A. Zahnd, personal communication, 2007).

To obtain the P-N junction temperature of the solar PV module, one would add about 2˚C to all values of the PV module during sunshine (A. Zahnd, personal communication. 2007).

The above temperature adjustments by Alex Zahnd were not taken into account during the modelling and simulation of the SPWP system.

B.2 NASA Recorded 10-Year Average Data

As a comparison to the recorded HARS data, the NASA measured surface meteorology and solar energy satellite data was consulted. This data is accessed via a website (Stackhouse *et al.* 2007) which allows one to enter the latitude and longitude of a geographical site. A range of measured parameters can then be retrieved for that site. The following data is for comparison only and was not used for the design calculations and modelling.

Table: Geographical coordinates used to retrieve the data

Geometry Information	
Average elevation: 2960 metres	
Northern boundary 30	Latitude
Southern boundary 29	Latitude
Eastern boundary 82	Longitude
Western boundary 81	Longitude

Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:

Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m²/day)

Lat 29.999 Lon 81.774	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
NASA 10-year Average Horiz.	3.45	3.97	4.55	5.82	6.34	6.17	5.25	4.67	4.69	4.95	4.37	3.48	4.81
Humla Horiz.	3.40	4.13	4.95	5.65	5.08	4.45	4.33	4.00	5.03	4.67	4.39	3.48	4.46
Humla 30 deg til	5.02	5.49	5.84	5.99	5.09	4.43	4.56	4.42	5.83	6.07	6.21	5.34	5.36
Humla 2-axis tracking	6.78	7.23	7.84	7.84	6.51	5.78	5.61	5.37	7.55	8.25	8.60	7.41	7.06

Parameters for Tilted Solar Panels:

Monthly Averaged Peak Sun Hours Radiation Incident On An Equator-pointed Tilted Surface / Perez/Page Method (kWh/m²/day)

Lat 29.999 Lon 81.774	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE MAX	3.85	4.38	5.76	6.77	7.06	6.87	5.9	5.49	5.48	5.6	4.7	3.88	5.48
K	0.64	0.6	0.65	0.66	0.63	0.6	0.52	0.52	0.58	0.71	0.74	0.69	0.63
PAGE DIF	0.73	1.06	1.03	1.11	1.38	1.64	2.01	1.91	1.45	0.51	0.28	0.48	1.13
PAGE DNR	5.91	5.66	6.75	7.54	7.5	6.77	5.34	5.04	5.82	7.65	8.57	6.83	6.62
Tilt 0	3.77	4.35	5.69	6.62	7.03	6.83	5.87	5.46	5.4	5.56	4.58	3.82	5.42
Tilt 14	4.97	5.38	6.5	6.99	7.01	6.68	5.85	5.66	6	6.65	5.91	5.12	6.06
Tilt 29	5.95	6.16	6.97	6.99	6.59	6.12	5.49	5.55	6.29	7.43	6.98	6.21	6.39
Tilt 44	6.56	6.57	7.01	6.57	5.81	5.26	4.83	5.13	6.21	7.75	7.6	6.91	6.35
Tilt 90	5.85	5.31	4.6	3.14	2.09	1.71	1.78	2.36	3.81	5.82	6.48	6.3	4.1
OPT	6.77	6.62	7.05	7.04	7.07	6.83	5.9	5.67	6.31	7.75	7.75	7.18	6.83
OPT ANG	59	51	38	21	6	1	6	17	33	46	56	60	32.7

Parameters for Sizing Battery or other Energy-storage Systems:

Equivalent Number Of NO-SUN Or BLACK Days (days)

Lat 29.999 Lon 81.774	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Sum
1 day	0.9	0.79	0.93	0.77	0.71	0.73	0.57	0.6	0.73	0.71	0.67	0.75	8.86
3 day	2.51	1.93	1.92	1.5	1.29	1.33	1.31	1.36	1.63	1.64	1.3	1.84	19.56
7 day	3.87	2.43	3.45	2.29	1.94	2.22	2.39	2.32	3.35	3	2.5	2.67	32.43
14 day	4.46	3.7	6.67	3.26	3.24	2.91	3.49	3.77	4.2	4.96	2.88	3.59	47.13
21 day	5.53	5.72	6.93	2.7	3.3	4.06	4.38	3.65	4.43	6.39	1.97	4.17	53.23
Month	6.55	4.86	10.9	2.57	2.54	4.91	5.13	3.98	3.83	6.07	1.37	3.29	56

Meteorology (Temperature):

Monthly Averaged Air Temperature At 10 m Above The Surface Of The Earth For Indicated GMT Times (° C)

Lat 29.999 Lon 81.774	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average@2230	-9.17	-8.58	-6.7	-3.01	3.37	6.16	7.64	8.36	5.58	-2.23	-6.59	-7.86
Average@0130	-9.44	-8.81	-6.54	-2.72	3.81	7	8.25	8.59	5.37	-2.94	-7.29	-8.36
Average@0430	-4.2	-2.45	1.1	5.74	12.9	14	12.6	12.6	9.61	2.25	-1.89	-3.55
Average@0730	2.44	3.61	6.45	11	17.5	17.7	15.4	15.3	13.1	7.83	4.97	3.17
Average@1030	2.57	3.58	6.23	11.1	17.8	17.8	15.3	15.4	13.3	7.99	5.26	3.47
Average@1330	-0.55	0.43	3.17	8.19	14.8	15.1	13.2	13.7	11.3	5.51	2.58	0.7
Average@1630	-3.89	-2.89	-0.57	3.91	10	11.1	10.9	11.5	8.96	2.38	-1.1	-2.75
Average@1930	-7.53	-6.56	-4.42	-0.01	6.64	8.36	9.06	9.76	6.95	-0.51	-4.75	-6.22

Meteorology (Wind):

Monthly Averaged Wind Speed Adjusted For Height And Vegetation Type (m/s)

Height **10 meters**

Vegetation type **Tundra: 0.6-m trees/shrubs (variable %) & groundcover**

Lat 29.999 Lon 81.774	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	3.63	3.67	3.63	3.65	3.85	3.4	2.9	2.69	2.85	3.54	3.66	3.65	3.42

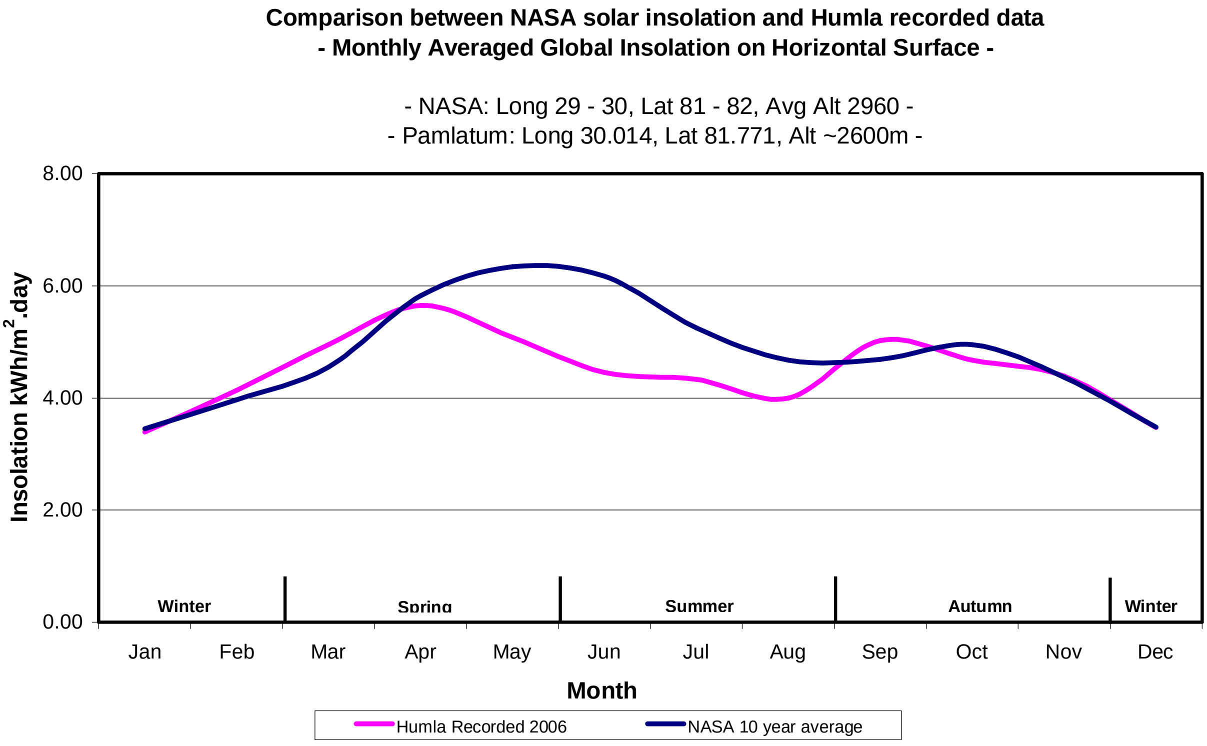
Meteorology (Other):

Monthly Averaged Total Column Precipitable Water (cm)

Lat 29.999 Lon 81.774	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	0.38	0.43	0.5	0.64	1	1.55	2.22	2.27	1.69	0.78	0.48	0.43	1.03

Monthly Averaged Precipitation (mm/day)

Lat 29.999 Lon 81.774	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	0.39	0.63	0.59	0.67	1.18	3.03	5.75	5.86	3.8	0.85	0.07	0.44	1.94



B.3 PAMLATUM HORIZON MODEL

Pamlatum is located in the Himalayan mountain ranges. Because of this, there is solar shading losses associated with the high peaks and mountain ridges that surround the village. These horizon shading losses have to be incorporated into the design model for it to be accurate. The horizon model (below) is measured by determining the angle between horizontal and the horizon for a range of points between the summer equinox sunrise and sunset positions. The below horizon model was used in the PV simulation software PVSyst v4.1 (*Appendix G, p.93*).

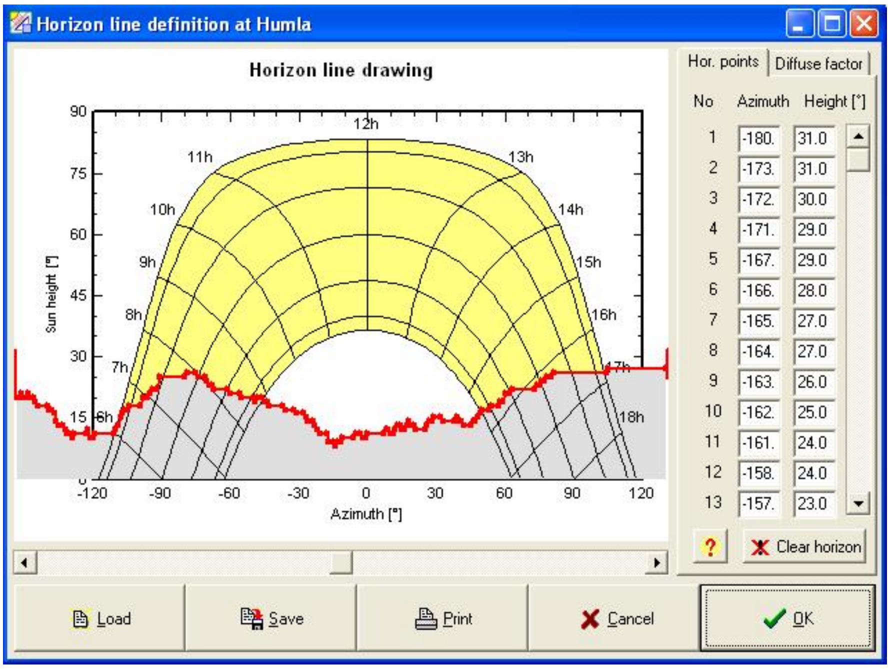


Figure: Horizon model for Pamlatum village

C Pamlatum Water Demand Calculations

The following table presents the Pamlatum village population, annual growth rate and the type and quantity of livestock. It also presents the number of households and the greenhouses based on the assumption that 1/6 of the households contain a greenhouse or vegetable patch (A. Zahnd, personal communication, 2007).

Village population and livestock

Village	Pamlatum
Annual Growth Rate	2.0%
Households	26
People	178
Vegetable Patch/Greenhouse	4
Goats	150
Sheep	150
Horses	9
Chickens	30
Donkeys	0
Cows	15
Other	17
Total	371

Village population and livestock

The following table presents the specific average daily water demand required for each activity including livestock drinking, greenhouse irrigation and lipine (mud/water solution used for washing down walls and floors of houses). These values were based on the recommendations from Alex Zahnd (personal communication, 2007).

Table: Water demand values and delegation

Activity	Demand (L/day)	Delegation
Drinking	5	per person
Cooking	3	per person
Washing Vegetables	1	per person
Bathing	5	per person
Pit Latrine	2	per person
Total	16	per person
Livestock Drinking	3	per head of livestock
Vegetable Patch/Greenhouse	25	per vege patch
Lipne	10	per household

The following table presents the total daily water demand specified for Pamlatum village. Seasonal variations in water demand have not been taken into account for these calculations. The average daily water demand has been calculated at 4,321 litres per day for the entire village. This water demand has been set as the minimum target for Pamlatum's water supply. If the village population growth (at 2% p.a.) were taken into account, the average daily water demand for Pamlatum would increase to 5,268 litres per day. The following table also presents the required storage capacity (12,963 litres) to satisfy the requirement of three days autonomy. Once again, when considering population growth, the required storage capacity will increase to 15,804 litres after 10 years.

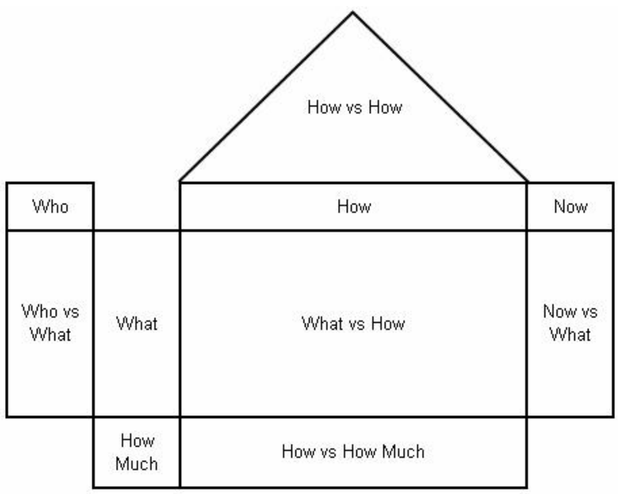
Table: Pamlatum village water demand and storage calculations

	L/day	**m³/day**
People Needs	2848	2.85
Household Needs	260	0.26
Livestock Needs	1113	1.11
Irrigation Needs	100	0.10
Total Current Village Demand	**4321**	**4.32**
5 yr Demand (2% growth)	**4771**	**4.77**
10 yr Demand (2% growth)	**5268**	**5.27**
Number of Days Autonomy	3	
Current Storage	**12963**	**12.96**
5yr Storage (2% growth)	**14313**	**14.31**
10 yr Storage (2% growth)	**15804**	**15.80**

D Quality Functional Deployment

D.1 THE QFD PROCESS

The following description of the Quality Functional Deployment (QFD) process has been taken from the 2006 ‘Systems Engineering Project’ course lecture notes at the ANU (Heslehurst 2006). The QFD process shall be used to develop design solutions for Pamlatum’s water service system. The QFD is a combination of customer specific and abstract requirements, and engineering specifications. The process develops an in-depth understanding of the design problem and forces the engineer to focus on the design problem and not the solutions. The process produces a clear set of design requirements, provides automatic documentation, simplifies the problem and ultimately enhances the design solutions. The figure below is the ‘*House of Quality’* which is part of the QFD process outlined in the following steps. The *House of Quality* developed for Pamlatum is presented in *Appendix D.7, p.78*.



House of quality as part of the QFD process

1. Identify the customers (who): The customers are the people who want or need the product. Design what the customer wants and needs. Do not assume what they want and need.

2. Determine the customer requirements (what): What does the customer want? Develop a list of all requirements and consider a customer survey (i.e. Pamlatum village assessment and field investigation April 2007). Discuss the understanding of the requirements with the customer before proceeding.

3. Determine relative importance of customer requirements (what): Evaluate the importance of each requirement. Essential requirements are not ranked but starred (*). Desirable requirements are ranked (1 the most important) using the pair wise comparison method as shown in the table below.

Table: Pair wise comparison method for ranking the importance of desirable requirements

	Req D	Req E	Req F	Total	%	Rank
Req D		1	1	2	67%	1
Req E	0		1	1	33%	2
Req F	0	0		0	0%	3
				3	100%	

Desirable requirements are then awarded a score on importance (least important requirement is awarded 1 point) as shown in the table below.

Table: Importance scores awarded to desirable requirements based on rank

Desirable Requirement	Importance Score
Req D	3
Req E	2
Req F	1

4. Evaluate design benchmarks (now vs. what): Review similar products/designs/practices and seek customer comments. What parts of existing designs/practices good? What parts of existing designs/practices needs improving? Is technology capable of improvement and will it be appropriate? Compare benchmarks against customer requirements using a 1 to 5 scale.

   - 1 = the design does not meet the requirement at all
   - 2 = the design meets the requirement slightly
   - 3 = the design meets the requirement somewhat
   - 4 = the design meets the requirement mostly
   - 5 = the design fulfils the requirements completely

5. Generate measurable engineering specifications (how): Develop the engineering specification that is measurable (i.e. size, force, weight, $, time, percentage, Y/N, etc)

6. Relate customer requirements to engineering specifications (what vs. how): Change the abstract customer requirements into measurable engineering requirements. Look at the interaction between several requirements and specifications. Review with customers and indicate the relationship between the engineering requirements to customer requirements using the following scoring values:

   - 9 = strong relationship
   - 3 = medium relationship
   - 1 = weak relationship
   - Blank = no relationship

7. Identify relationships between engineering specifications (how vs. how): Use a ‘+’ or ‘-’ sign to indicate a positive or negative relationship (i.e. is there a trade-off and optimisation decision between two engineering specifications?). Indicate the relationship between engineering specifications using the same scoring values from step 6.

8. Setting engineering targets for the design (how vs. how much): Measure existing designs against engineering specifications as a way to set targets. Targets must be realistic if they are not set by the customer. Targets can be a specific point or range of values. The combinations of steps 1 to 8 form the functional specification.

9. Generate a number of concept designs, generate many ideas - brainstorm. Test each idea against the functional specification. Generate individual concepts as well as combined concepts. Do not discard obscure or impossible solutions. Comment on how the design will be built, and provide a descriptive working model.

10. Produce design results via simulation, calculations, analysis, etc of the design and compare with the engineering targets as shown in the table below.

Table: Compare the specified engineering targets with design concept results

Engineering Specification	Units	Target	Design Concept A Results	Design Concept B Results
Spec X	kg	Target X	Result	Result
Spec Y	m/s	Target Y	Result	Result
Spec Z	%	Target Z	Result	Result

11. Compare each design with the customer requirements in relation to the engineering targets being met. Essential requirements are either met or not met by the design as shown in the table below.

Table: Evaluating essential requirements

Essential Requirement	Design Concept A	Design Concept B
Req A	N	Y
Req B	?	Y
Req C	Y	Y

Designs are scored for meeting desirable requirements based on the following values:

- 0.0 = does not meet the requirement
- 0.5 = partially meets the requirement
- 1.0 = meets requirement
- 1.5 = more than meets requirement

The scores are multiplied by the importance of the desirable requirements to calculate the points awarded to the design. All points are totalled and the design is awarded a final score as shown in the table below.

Table: Evaluating desirable requirements

Desirable Requirement	Importance	Design Concept A	Design Concept B
Req F	**1**	1.0	1.5
Req E	**2**	0.5	1.0
Req D	**3**	0.0	0.5
Total Points Awarded		**2**	**5**

12. Eliminate designs that fail to meet the essential requirements (i.e. design concept A). Detailed analysis and refining the design may be required. Change the design solution(s) if necessary to meet the essential requirements.

13. Once the designs that passed the essential criteria (assuming design concept A has for demonstration purposes), state the final design using the points awarded from the above table as a reference. Comment on the selection basis and relate to customer requirements.

14. Finally, score all designs against the customer requirements using the 1 to 5 scale (same as the benchmark scoring system) for completeness of the *House of Quality* and QFD process. Advance the chosen design to the detailed design phase of the project.

D.2 PROJECT STAKEHOLDERS

There’s a large range of customers and stakeholders for this project which include:

- Pamlatum village members (end-users of system)
- Pamlatum solar PV pumping committee (which will be formed if a project starts).
- System operators and maintenance personnel (also likely to be end-users of the system)
- Installation and transportation personnel
- Village members of surrounding villages, including the wider region
- Alex Zahnd and RIDS-Nepal
- Engineers Without Borders (EWB)
- System designers, manufacturers and suppliers
- Non-Government Organizations (NGOs)
- Nepalese government and local authorities
- Australian National University (ANU)
- Andre Mermoud (author of the PV software package PVSyst v4.1)
- Doners

The bulk of the customer requirements developed in this paper affect people who have direct contact with the system such as end-users, system maintainers, transporters and installers. It is out of scope for this project to consider the requirements of other stakeholders. In most cases, stakeholders will be satisfied without formally specifying their requirements. For example, by completing and submitting this Thesis document at acceptable standard of quality will satisfy the requirements of ANU.

D.3 CUSTOMER REQUIREMENTS

The following requirements have been ranked for their essentiality and importance based on my personal project understanding and engineering judgement. The customer requirements are not final and require further consultation with the village members of Pamlatum and input from other qualified people.

The customer requirements are translated into engineering specifications with measurable targets (*Appendix D.5, p.74*). The engineering specifications are based on engineering judgement. With the development of the design, more specifications can be added to the list and existing targets can be refined. The source of the specification target is a personal assumption, reference to another part of this paper or a reference to the literature.

Table: All requirements and their relative rank

Category	Requirement	Rank
Performance	Water demand	3
	Autonomy	*
	Excess water management	5
	Robust	*
	Easily accessible	*
	Efficient	8
	Reliable	*
	Long Lifetime	*
Cost	Low capital cost	7
	Low operating cost	2
	Low life-cycle cost	*
Installation	Transportable	*
	Simple to install	9
Maintenance & Repair	Maintainable	*
	Low maintenance frequency	1
Standards, Regulations, Law	Nepalese standards and local authorities	*
	Australian standards	10
Safety	Safe drinking water	*
	Injury prevention	6
Environmental	Local renewable energy	*
	Pollution free	4
Social	Village ownership and acceptance	*
	Children and women friendly	*

Table: Pair-wise comparison of desirable requirements

Desirable requirements pairwise comparison	water demand	wastewater management	efficient	low capital costs	low operating costs	simple to install	low maintenance frequency	Australian standards	safe from injury	pollution free	**Total**	**Relative Importance (%)**	**Rank**
water demand		1	1	1	0	1	0	1	1	1	7	16%	3
excess water management	0		1	1	0	1	0	1	1	0	5	11%	5
efficient	0	0		0	0	1	0	1	0	0	2	4%	8
low capital cost	0	0	1		0	1	0	1	0	0	3	7%	7
low operating cost	1	1	1	1		1	0	1	1	1	8	18%	2
simple to install	0	0	0	0	0		0	1	0	0	1	2%	9
low maintenance frequency	1	1	1	1	1	1		1	1	1	9	20%	1
Australian standards	0	0	0	0	0	0	0		0	0	0	0%	10
injury prevention	0	0	1	1	0	1	0	1		0	4	9%	6
pollution free	0	1	1	1	0	1	0	1	1		6	13%	4
											45	**100%**	

Table: Importance scores awarded to desirable requirements based on rank

Desirable Requirement	**Importance Score**
low maintenance frequency	10
low operating cost	9
water demand	8
pollution free	7
excess water management	6
injury prevention	5
low capital cost	4
efficient	3
simple to install	2
Australian standards	1

D.4 BENCHMARK EVALUATION

This section looks at one benchmark – the existing gravity-fed water service system. The importance of the benchmark evaluation is to determine what is good with the existing water service system and what elements require improving. The idea of this is to try to develop design solutions that retain the good features and what works well with the existing system, while at the same time, removing any problems and limitations in the benchmark design. The following table evaluates the design in regards to its current operation as well as its potential if it were to be ideally constructed and maintained. The scores awarded are based on my understanding of the existing water service system from the village assessment and field survey, engineering judgement and personal communications with Alex Zahnd.

Table: Benchmark evaluation

Requirement	Current Score	Potential Score
Water Demand	**5**	**5**
11,840 litres per day flows out of Pamlatum's taps per day. The minimum specified water demand for Pamlatum is 4,320 litres per day and therefore meets the specified demand.		
Autonomy	**2**	**5**
There are tanks within the villages. Pamlatum has a primary tank which separates the flows between Chauganphaya and Pamlatum. This tank is approximately 400 metres away from the village. It is uncertain what the tank capacity is but it is believed to be insufficient to supply three days autonomy. However, the advantage of this water service system is that water flows from taps consistently, 24 hours a day, and therefore the requirements on a storage tank is somewhat reduced. There is potential for providing autonomy by installing larger tanks.		
Excess Water Management	**2**	**5**
There is no formalised excess water management. The water either is a hazard (stagnant pools, erosion, paths) or a benefit (informal irrigation, stock watering pool). There are also water leakages. There are no controllable head works so taps flow continuously.		
Robust	**1**	**5**
The system is poorly constructed and pipes near the surface tend to freeze overnight during the winter months, and do not defrost until mid morning when temperatures rise above zero. Debris (such as grass and twigs) and animals (such as frogs, snakes, rodents) can become stuck in tanks and pipe connections and block (and contaminate) flow. In many areas, pipes lie on the surface exposed to vandalism (particularly from children and livestock) and landslides.		
Easily Accessible	**1**	**3**
Water is not easily accessible due to long distances to only two tap outlets and insufficient flow rates. Access to maintenance is difficult due to large distribution lengths and buried pipe.		
Efficient	**1**	**5**
It is efficient in terms of utilizing gravity to supply water to the village but not efficient in terms of utilizing the water resource with minimal wastewater. Water flows from taps are not controlled, leaks occur and much of the water is wasted and lost. There is potential to increase the water utilization efficiency by introducing larger tanks within the village to store larger volumes of water, utilizing controllable taps and properly fixing leaks. 31% of water entering Pamlatum is lost through leaks. 11% of the water that's not lost through leaks, but flowing out of Pamlatum's taps, is utilized effectively by village members (based on average daily consumption of 7 litres per person). The rest of the water becomes excess wastewater collecting in pools and flowing down mountain slopes.		
Reliable	**2**	**5**
Pipes often get blocked and it is common for taps to stop functioning. System breakdown is frequent. Currently all taps in Pamlatum are operational, but there are many taps in other surrounding villages that have stopped working. When working properly, the system continually supplies consistent water flows during the year.		
Long Lifetime	**3**	**5**
If the system was constructed well, it could potentially have a very long system lifetime.		

However, because this is not so, the system can degrade quite quickly due to exposure to damage, blockages, and wear and tear.		
Low Capital Cost	**4**	**4**
The capital cost of a system like this is unknown. It is assumed to be reasonably low.		
Low Operating Cost	**4**	**5**
It is uncertain what the exact operating cost is. Maintenance requirements are frequent which increases operating cost. Village members find ways to fix the system, usually through poor quality repairs using any materials and skills that are available.		
Low Life-Cycle Cost	**5**	**5**
The life-cycle cost of a system like this is unknown. It is assumed to be low.		
Transportable	**3**	**3**
It is uncertain what the transportation requirements are for a system like this. There is however large lengths of pipes required (~4km) due to the large distribution network.		
Simple to Install	**2**	**2**
The biggest installation challenge is digging trenches for laying down water pipe. There is a very large distance (~4km) between the spring source and the villages. It is also a very dangerous job. The rest of the system is fairly simple to install. The advantage is that local people can be used for the installation with little guidance.		
Maintainable	**2**	**3**
The system is not easy to maintain and repair as the village people do not have sufficient tools or materials to effectively repair leakages and blockages in pipes and tanks. Theoretically, it should be fairly easy to maintain as long as leaks blockages in pipes do not occur. The major limitation is it is hard to find blockages and leaks due to large distribution distances.		
Low Maintenance Frequency	**1**	**5**
The system often breaks down. Apparently village members travel once week (4 hours walk) to check pipes at the spring source and conduct maintenance as necessary. If constructed well the system could potentially require no maintenance.		
Nepalese Standards and Local Authorities	**5**	**5**
It is assumed that the system complies with Nepalese standards and local authorities.		
Australian Standards	**2**	**5**
It is likely that this water service system does not meet Australian standards as the construction of the water service is poor and the system is inadequately maintained.		
Safe Drinking Water	**4**	**5**
The tap outlet *E.coli* levels are acceptable with 3 to 4 colonies per 100ml sample. Turbidity levels are also under 5 NTU. In some cases, livestock were observed to intermingle with people and use the tap outlet as a source of drinking water. This is potentially a health risk.		
Injury Prevention	**2**	**3**
Collecting water from taps is an injury free task. However maintenance can be treacherous as long distances sometimes have to be travelled along steep mountain-sides over difficult and rocky terrain. There is also exposure to slippery ice and snow during the winter as well as the potential for rock falls and minor landslides. Exposed and excess water flows can cause hazards on access paths.		
Local Renewable Energy	**5**	**5**

The water service is a gravity-fed system which is a renewable form of energy.		
Pollution Free	**5**	**5**
This type of water service does not pollute the local environment.		
Village Ownership and Acceptance	**2**	**5**
There is to some degree a sense of ownership as the village members were involved in the installation and are actively involved in maintaining the system. The village members do not pay for the water services and the ownership of the system is not clearly defined as there is no drinking water committee. The water service creates conflict between village members. There is not very much confidence in the operation of water service system, and not widely accepted, as people are forced to travel to the river for additional water needs. There would be potential for community acceptance if the water service system was operating as intended.		
Children and Women Friendly	**1**	**5**
The water service system is not children or women friendly. One hour waiting periods are common and there are only two taps in Pamlatum. Some families have to travel long distances to tap outlets. In addition, the inaccessibility of water forces children and women to travel to the river to fetch for water creating further problems. There is potential for better water distribution throughout the village using storage tanks, more taps and higher tap flow rates.		

D.5 Engineering Specifications & Targets

Design Specification	Description	Units	Target	Target Source
energy source	The choices of local renewable energy to power the water service system include gravity (G), solar (S), wind (W) and hydro-electric (H).	G, S, W, H	any	Chapter 4 Customer Requirements, p.15
daily system energy efficiency	The type of energy source that powers the water service system shall determine the efficiency of the system. For instance, typical daily system efficiencies for a solar powered water pump of 4% or higher can be expected.	%	>4	Hammad (1999), Odeh [ca. 1995]
pollutants produced	It is important for the system no to pollute its environment from waste products. Waste products include toxic and dangerous chemicals, fossil fuel gases and other waste products associated with the operation, maintenance and repairs of the system.	Y/N	N	Chapter 4 Customer Requirements, p.15
daily water supplied	The specified daily water demand for the village has been calculated to be 4320 litres per day. Village growth has not been accounted for and therefore sets the minimum target for daily water supply.	m^3 per day	4.32	Appendix C, p.63
seasonal water demand variation	Does the design account for seasonal water demand variation due to seasonal migrations, seasonal climate, seasonal village activities, etc? It is unsure exactly what the variation in water demand quantity is throughout the year and future village assessments will need to be completed. What is known, is when these seasonal variations are likely to occur.	Y/N	Y	Section 3.2.4 Seasonal Migration, p.7, Section 3.2.7 Local Climate, p.9
village water storage capacity	The water service system must be capable of storing 3 days worth of the village water supply. Based on a minimum average consumption of 4,320 litres per day, the water storage capacity needs to be at least 13,000 litres.	m^3	13	Appendix C, p.63
maximum household distance to a water outlet	To increase the water service level to 'intermediate access', the distance to a tap outlet shall not exceed 100m.	metres	<100	Section 2.1 Water Accessibility, p.4
number of water outlets	More village water tap outlets are needed to increase the accessibility to water. 7 tap outlets equates to about 30 people per tap or about 4 to 5 households per tap.	qty.	7	Assumption
average water outlet flow rate	To increase the water service level to 'intermediate access', the total time required to collect water shall not exceed 5 minutes. Based on a maximum 30 litres (30 kg) of water carried in one trip, the water outlets shall have an average flow rate of 0.167 L/s. It will then take approximately 3 minutes to fill a 30 litre vessel. This allows 2 minutes travelling time between water outlet and household. If all 7 water outlets were flowing at the same time, it will take just over 1 hour to supply the specified daily water demand for Pamlatum.	litres per second	0.167	Section 3.3.5 Water Collection & Consumption, p.12 (max. water carried), Section 2.1 Water Accessibility, p.4 (water collection time)
water-use efficiency	This specification is the percentage of water supplied to the village that is collected and used productively by village members rather than lost through leaks and excess water flows. The existing gravity-fed spring system has a water-use efficiency of approximately 7.2%. It would be desirable to increase this past 70%.	% of total water supplied	>70	Section 3.3.5 Water Collection & Consumption, p.12 (water-use efficiency), Assumption (target)
excess water properly managed	It is hard to quantify this design specification. A score of 1 to 5 shall be given based on the same scoring method used in the benchmark evaluation as part of the QFD process.	1-5	5	Chapter 4 Customer Requirements, p.15 (excess water management), Appendix D, p.65 (scoring method)
missing water	This is the percentage of the specified water demand that the water service system can not supply for the entire year. This does not take into account missing water caused by system failure or routine maintenance interruptions. It assumes that the water service system operates everyday of the year. This is usually expressed as the Loss of Load (LoL) probability. For critical systems such as telecommunication repeaters, a LoL probability of 0.001% would be expected. For non-critical systems such as Pamlatum's water service infrastructure, a LoL of under 5% should be designed to.	%	<5	Markvart (2000)
output *Escherichia coli* concentration	The detection of *E.coli* in the village water outlets shall comply with Nepalese water quality standards of under 10 colonies per 100ml water sample.	qty. of colonies per 100ml	<10	Section 2.2 Water Quality, p.4
output turbidity level	Drinking water should have a turbidity of 5 NTU or less. Turbidity of more than 5 NTU would be noticed by users and may cause rejection of the supply. Where water is chlorinated for sterilization, turbidity should be less than 5 NTU and preferably less than 1 NTU for chlorination to be effective.	NTU	<5	Section 2.2 Water Quality, p.4

Design Specification	Description	Units	Target	Target Source
system lifetime	The system needs a long lifetime for it to be sustainable and economically feasible. For a solar powered water pumping system, the PV panels should last at least 20 years. Since PV modules are typically the most expensive component in the system, the design should be designed to operate for at least 20 years.	years	20	CRC for Water Quality and Treatment (2005)
lifetime of weakest link	The weakest link represents a component in the system that when broken or faulty, requires a complete replacement of that component for the system to remain operational. For a solar-powered system with battery buffered power control, usually the weakest link in the system will be batteries. Batteries typically have a lifetime of 5 years if maintained well. The brushes inside DC motors will typically last 1 to 5 years until they need replacing. Solar pumps will typically have a lifetime of 7 to 10 years before they need replacing.	years	>5	Markvart (2005) (battery lifetime), Wenham [*et al.* no date] (motor brush lifetime), CRC for Water Quality and Treatment (2005) (pump lifetime)
wind speed tolerance	From the NASA surface meteorology measurements, the maximum wind speed at a height of 50m did not get above 7 m/s (25 km/h). It is assumed the system should tolerate wind speeds up to 28 m/s (~100 km/h) to give factor of safety.	metres per second	28	Stackhouse (*et al.* 2007), Assumption (safety factor)
operating ambient air temperature range	From the NASA surface meteorology measurements, the yearly temperature ranged from approximately -10 to 17 C. HARS-Simikot recorded temperatures ranged from -7 to 32 C. An operating temperature of -15 to 40 C is an appropriate target.	°C	-15-40	Stackhouse (*et al.* 2007) & Appendix B, p.60 (temperature range), Assumption (safety factor)
operating river water temperature range	The temperature range of the river and spring water is 5 to 14 C. A target range of 1 to 16 C is appropriate.	°C	1-16	Section 3.2.6 Hepka River, p.8
tolerant to water turbidity	The turbidity of the Hepka river at the pump site was 12 NTU. However this is likely to increase during the monsoon season and it is anticipated to double. Tolerance to turbidity of 30 NTU is appropriate to give a level of safety. If the water is sourced from the mountain springs then the water turbidity will be much lower (less than 5 NTU).	NTU	30	Section 3.2.6 Hepka River, p.8
tolerant to water sediment particle size	It is unsure at this stage what the typical type of particle is in the Hepka river and this will need to be confirmed at a later stage. It will be assumed particles up to size 'fine sand' will be suspended in the water. This represents a particle size of 0.063 - 0.125 mm using the Wentworth Grade Scale.	mm	0.125	Assumption (sediment size), Ongley (1996) (Wentworth Grade Scale)
tolerant to UV radiation	A number of components will most likely be exposed to the sun's radiation and therefore these components need to be tolerant or protected from UV radiation.	Y/N	Y	Assumption
tolerant to ground soil	Any components installed under ground or on top of the ground need to be tolerant to the soil and not degrade. It is assumed at this stage that the ground soil does not contain aggressive chemicals and substances.	Y/N	Y	Assumption
system components protected	All system components shall be protected from theft, potential failures, damage, vandalism caused by animals, debris, children, vegetation, landslides, unauthorised people, and climate, etc.	1-5	5	Chapter 4 Customer Requirements, p.15
system components accessible	All system components shall be easily accessible for routine maintenance and repairs.	1-5	5	Chapter 4 Customer Requirements, p.15
system faults easily identified	It is important that when the system does fail, the problem can be identified quickly and easily so that swift action can be taken to correct the problem and get the water service system operating again.	1-5	5	Chapter 4 Customer Requirements, p.15
system maintenance duration	It would be desirable to keep system downtime due to routine maintenance under three days to prevent the village water storage from running dry (design is for 3 days autonomy). This assumes that maintenance occurs when the storage tank is full and there is enough solar irradiation to meet the village water needs after maintenance is completed.	days	<3	Assumption
number of maintenance personnel	At least two people should be trained and carry out routine system maintenance and repairs. Women should also be trained in operation and maintenance as they are likely to be the main users of the water service system.	qty.	2	Assumption
local materials, parts and equipment can be obtained	All materials, parts and equipment for system installation, routine maintenance and repairs should be available within the local region or at least easily accessible and transportable at a affordable cost from other towns and cities. Where possible, the system should be designed to utilize natural resources and materials accessible by the local community (i.e. gravel and sand from the local river for filtration, fired mud bricks for tank, housing, etc)	1-5	5	Section 3.3.4 System Maintenance, p.12, ADP (*et al.* 2006)

Design Specification	Description	Units	Target	Target Source
maintenance frequency	The system needs to be robust and operate for extended periods of time without maintenance. This represents routine system maintenance only and not repairs when the system fails. Currently routine maintenance occurs weekly. It would be desirable to only need monthly inspections and maintenance.	qty. per year	<12	Section 3.3.4 System Maintenance, p.12 (current maintenance frequency), Assumption (target)
weight of heaviest component	There are numerous references on how much a pack mule can carry ranging from 60 kg to 120kg. It all depends on the type of equipment - e.g. density, centre of gravity, shape, etc. Pack mules or a similar animal shall carry the heaviest equipment. These animals will be sourced from the Pamlatum village itself. Since it is likely that heavy equipment will be bulky and hard to handle, a maximum weight of 60kg for a single component shall set the target for this specification. Though it will be assumed an animal can carry a total of 100kg.	kg	60	Assumption
total equipment weight	This is the total weight of all equipment and materials needed to install the system. This will help determine the number of people and animals required to carry supplies.	kg	<3000	Assumption
number of people/animals required for transportation	The number of people required is based on one person being able to carry a 60 kg load with 20kg of the load for personal equipment such as food, water and other gear. Pamlatum has 26 household and assuming one adult male per household, and 50% shall be available for transporting equipment, 13 village people shall be available. In addition, there will be other volunteers and support personal from other parts of Nepal and other countries (i.e. EWB volunteers). Assuming and additional 7 people and hence a total of 20 people for transportation shall set the target. The transport personnel shall be able to carry 800kg (20x40) of the total 3000kg of equipment. Animals shall to carry the remainder 2200 kg. Assuming one animal can carry 100kg, 22 animals shall be required for transportation.	qty. (people/animals)	20/22	Section 3.2.2 Population, Education & Skills, p.6 (households), Assumption (human carrying capacity, available human resources)
number of people required for installation	Pamlatum has 26 households. Assuming one person per household can help with installation and additional 7 non-village personnel (i.e. EWB volunteers), a total of 33 people shall be available to help with installation.	qty.	33	Section 3.2.2 Population, Education & Skills, p.6 (households), Assumption (available human resources)
installation duration	This includes transportation, installation, testing, fault finding and hand over. It is the time from when the transportation of equipment and materials into Pamlatum is initiated until when the system is handed over to the village people. The duration of installation will depend on the number of people installing it. 12 weeks (3 months) will set the target which represents approximately 2772 man-days with 33 people available for installation.	weeks	12	Assumption
complies with Nepalese standards/local authorities	All appropriate Nepalese standards, regulations and local authorities shall be consulted and complied with.	Y/N	Y	Assumption
complies with Australian or equivalent standards	The water service system shall comply with applicable Australian or equivalent standards.	Y/N	Y	Assumption
total capital costs	The capital costs include all materials, equipment, labour, transportation, etc to install the entire system to a full operational state. All costs shall be in Australian dollars.	$AUD	<50,000	Appendix G.3, p.96 (PVSyst pre-size tool)
annual operation and maintenance cost	Operation and maintenance cost shall include the cost of and materials and products keep system components well maintained and in good working order. It shall also include the cost of employing someone to carry out the regular system maintenance. It shall include the cost of repairs when the system breaks down such as spare parts, transport, wages, etc. O&M costs are typically 3% of the total capital costs. All costs shall be in Australian dollars.	$AUD per year	<1,500	Markvart (2000)
unit water cost	The lifecycle cost of the system which includes all cost such as capital, installation, O&M, replacement parts, etc, will determine the unit cost of water. This should be as low as possible so that the villagers can afford to pay for the system and take ownership. All costs shall be in Australian dollars.	$AUD per m^3	<4	Appendix G.3, p.96 (PVSyst pre-size tool)

D.6 SPWP CONCEPT DESIGN VS ENGINEERING TARGETS

The table below presents the list of engineering specifications from *Appendix D.5, p.74*. The engineering targets are compared to the results of the SPWP concept design. Results that have been assumed or expected have been given a '?' next to the value to indicate uncertainty.

Table: SPWP concept design vs. design targets

Design Specification	Units	Target	SPWP Concept Design	Design Specification	Units	Target	SPWP Concept Design
energy source	G, S, W, H	any	S & G	tolerant to water sediment particle size	mm	0.125	0.125?
daily system energy efficiency	%	>4	4.86	tolerant to UV radiation	Y/N	Y	Y
pollutants produced	Y/N	N	N	tolerant to ground soil	Y/N	Y	Y
daily water supplied	m^3/d	4.32	4.33	system components protected	1-5	5	5
seasonal water demand variation	Y/N	Y	Y	system components accessible	1-5	5	5
village water storage capacity	m^3	13	20	system faults easily identified	1-5	5	5
average household distance to a water outlet	m	<100	<100	system maintenance duration	dys	<3	1-2
number of water outlets	qty.	7	7	number of maintenance personnel	qty.	2	2-4?
maximum water outlet flow rate	l/s	0.167	0.167?	local materials, parts and equipment can be obtained	1-5	5	?
water-use efficiency	% of total water supplied	>70	96.2	maintenance frequency	qty./yr	<12	12+
excess water properly managed	1-5	5	5	weight of heaviest component	kg	60	~30
missing water	%	<5	4.3	total equipment weight	kg	<3000	61,224
output *Escherichia coli* concentration	qty./100ml	<10	<10?	number of people/animals required for transportation	qty. (people/animals)	20/22	36/30 (2 weeks)
output turbidity level	NTU	<5	<5?	number of people required for installation	qty.	33	36
system lifetime	yrs	20	20?	installation duration	wks	12	12
lifetime of weakest link	yrs	>5	1-5	complies with Nepalese standards/local authorities	Y/N	Y	Y?
wind speed tolerance	m/s	28	28?	complies with Australian or equivalent standards	Y/N	Y	Y?
operating ambient air temperature range	°C	-15-40	-15-40?	total capital costs	$AUD	<50,000	60,000
operating river water temperature range	°C	1-16	1-16	annual operation and maintenance cost	$AUD/year	<1,500	2,000
tolerant to water turbidity	NTU	30	30?	unit water cost	$AUD/m^3	<4	6.1

D.7 House of Quality

The *House of Quality* brings everything together into one illustrative figure (see below). The *House of Quality* contains the customer requirements, benchmark evaluation, engineering specifications, design targets and the results of the SPWP concept design. It also illustrates the relationships between the customer requirements and engineering specifications. This is to determine whether a requirement has been satisfied, by evaluating the design results of all the engineering specifications related to that requirement. In addition, it illustrates the relationships between the engineering specifications themselves. This is to allow the optimisation of the system by analysing the trade-offs between engineering specifications. If the optimisation of one engineering specification aids in the optimisation of another engineering specification, then there is a positive relationship between the two specifications. Alternatively, if the optimisation of one engineering specification aids in the detriment of another specification, then there is a negative relationship between the two specifications. A negative relationship will indicate that a trad-off between the specifications is required to optimise the design. For example, one would want do minimize the number of tap outlets to decrease complexity and costs. However, this will cause the average distance to a water outlet to increase, and therefore a trade-off between the two engineering specifications is required. The following table provides a key to the relationships in the *House of Quality*.

Table: Key to *House of Quality* relationships

Customer requirements vs. engineering specifications	
+9	Strong relationship
+3	Medium relationship
+1	Weak relationship
engineering specifications vs. engineering specifications	
+9	Strong positive relationship
+3	Medium positive relationship
+1	Weak positive relationship
–9	String negative relationship
–3	Medium negative relationship
–1	Weak negative relationship

	energy source	daily system energy efficiency	pollutants produced	daily water supplied	seasonal water demand variation	village water storage capacity	maximum household distance to a water outlet	number of water outlets	average water outlet flow rate	water-use efficiency	excess water properly managed	missing water	output *Escherichia coli* concentration	output turbidity level	system lifetime	lifetime of weakest link	wind speed tolerance	operating ambient air temperature range	operating river water temperature range	tolerant to water turbidity	tolerant to water sediment particle size	tolerant to UV radiation	tolerant to ground soil	system components protected	system components accessible	system faults easily identified	system maintenance duration	number of maintenance personnel	local materials, parts and equipment can be obtained	maintenance frequency	weight of heaviest component	total equipment weight	number of people/animals required for transportation	number of people required for installation	installation duration	complies with Nepalese standards/local authorities	complies with Australian or equivalent standards	total capital costs	annual operation and maintenance cost	unit water cost
energy source																																								
daily system energy efficiency	+1																																							
pollutants produced	+9																																							
daily water supplied																																								
seasonal water demand variation				+3																																				
village water storage capacity				-3																																				
maximum household distance to a water outlet																																								
number of water outlets							-9																																	
average water outlet flow rate						-9		+3																																
water-use efficiency				-9	+9	-3																																		
excess water properly managed			+1	-3	+3	-3				+9																														
missing water				+9	+9	-9																																		
output *Escherichia coli* concentration			+1																																					
output turbidity level			+1										+9																											
system lifetime																																								
lifetime of weakest link															+9																									
wind speed tolerance															+3	+3																								
operating ambient air temperature range															+3	+3																								
operating river water temperature range															+3	+3																								
tolerant to water turbidity														+3	+3	+3																								
tolerant to water sediment particle size															+3	+3																								
tolerant to UV radiation															+3	+3																								
tolerant to ground soil															+3	+3																								
system components protected															+3	+3																								
system components accessible															+3	+3																								
system faults easily identified															+3	+3									+9															
system maintenance duration																									+9															
number of maintenance personnel																									+3		-3													
local materials, parts and equipment can be obtained																											+3													
maintenance frequency																									+1		-3	+3												
weight of heaviest component																																								
total equipment weight																															+1									
number of people/animals required for transportation																															+1	+9								
number of people required for installation																															+1	+3								
installation duration																															+1	+3		-9						
complies with Nepalese standards/local authorities			+9										+9																											
complies with Australian or equivalent standards																																				+3				
total capital costs		-3		-3		-3		-1																-3									-3	-3	-3					
annual operation and maintenance cost																								+9			+9	+9	+9	+9								+3		
unit water cost																																						+9	+3	

Pamlatum Village Water Service System	Rank	energy source	daily system energy efficiency	pollutants produced	daily water supplied	seasonal water demand variation	village water storage capacity	maximum household distance to a water outlet	number of water outlets	average water outlet flow rate	water-use efficiency	excess water properly managed	missing water	output *Escherichia coli* concentration	output turbidity level	system lifetime	lifetime of weakest link	wind speed tolerance	operating ambient air temperature range	operating river water temperature range	tolerant to water turbidity	tolerant to water sediment particle size	tolerant to UV radiation	tolerant to ground soil	system components protected	system components accessible	system faults easily identified	system maintenance duration	number of maintenance personnel	local materials, parts and equipment can be obtained	maintenance frequency	weight of heaviest component	total equipment weight	number of people/animals required for transportation	number of people required for installation	installation duration	complies with Nepalese standards/local authorities	complies with Australian or equivalent standards	total capital costs	annual operation and maintenance cost	unit water cost	**Benchmarks**	Existing village spring water service infrastructure (Current)	Existing village spring water service infrastructure (Potential)	Solar powered water pump concept design
performance																																													
water demand	8				9	9	3						3																														5	5	4
autonomy	*						9						3																														2	5	5
excess water management	6				3	3	3				9	9																															2	5	5
robust	*															3	3	9	9	9	9	9	9	9	9																		1	5	5
easily accessible	*							9	9	9																9																	1	3	5
efficient	3	3	9								9																																1	5	4
reliable	*						3						9				3														3												2	5	4
lifetime	*															9	9																										3	5	5
cost																																													
low capital costs	4																																						9		9		4	4	3
low operating costs	9																																							9	3		4	5	3
low life-cycle costs	*																																								9		5	5	2
installation																																													
transportable	*																													3		9	9	9									3	3	2
simple to install	2																															3	3		9	9							2	2	2
maintenance and repair																																													
maintainable	*								1																	9	9	3	3	9	3												2	3	2
low maintenance frequency	10																											3	3	9	9												1	5	4
standards, regulations and law																																													
Nepalese standards and local authorities	*													9	3																						9						5	5	5
Australian standards	1																																					9					2	5	5
safety																																													
safe drinking water	*													9	9																						9						4	5	5
injury prevention	5																								9	9		1			1	1	1										2	3	5
environmental																																													
local renewable energy	*	9	3	9																																							5	5	5
pollution free	7			9							1	3																															5	5	5
social																																													
village ownership and acceptance	*			3	9	9	9	9	9	9		9	9	9	9	9	9								1	9	1	9	9	9	9			9	9	9					9		2	5	3
children and women friendly	*						9	9	9	9			9	9	9																												1	5	3
Units		G, S, W, H	%	Y/N	m^3/d	Y/N	m^3	m	qty.	l/s	% of total water supplied	1-5	%	qty./100ml	NTU	yrs	yrs	m/s	°C	°C	NTU	mm	Y/N	Y/N	1-5	1-5	1-5	dys	qty.	1-5	qty./yr	kg	kg	qty. (people/animals)	qty.	wks	Y/N	Y/N	$\$AUD$	$\$AUD/year$	$\$AUD/m^3$				
Targets		any	>4	N	4.32	Y	13	<100	7	0.167	>70	5	<5	<10	<5	20	>5	28	-15-40	1-16	30	0.125	Y	Y	5	5	5	<3	2	5	<12	60	<3000	20/22	33	12	Y	Y	<50,000	<1,500	<4				
Existing village spring water service infrastructure (current)		G	n/a	N	11.84	N	~0	>100	2	<0.07	7.2	2	71.2	3-4	<5	<20	<5	28	1-40	1-16	30	0.125	Y	Y	2	1	1	~1	2-4	3	25-50	?	?	?	?	?	?	?	?	?	?				
Solar powered water pump concept design		S & G	4.86	N	4.33	Y	20	<100	7	0.167?	96.2	5	4.3	<10?	<5?	20?	1-5	28?	-15-40?	1-16	30?	0.125?	Y	Y	5	5	5	1-2	2-4?	?	12+	~30	61,224	36/30 (2 weeks)	36	12	Y?	Y?	60,000	2,000	6.1				
Future concept designs		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				

E Concept Design Generation

E.1 INTRODUCTION

In the following, I have provided a methodology for generating concept designs for water service systems. The methodology is based entirely on my own ideas and my understanding of the components required for the formation of a water service system.

Each concept design is conceptualised into three distinct stages: 1) the water collection, 2) water distribution network and 3) water outlet. These three stages collectively are termed as a *water service system*. The final design may contain one or more of these systems whereby the water outlet of one system feeds into the water collection of the next system.

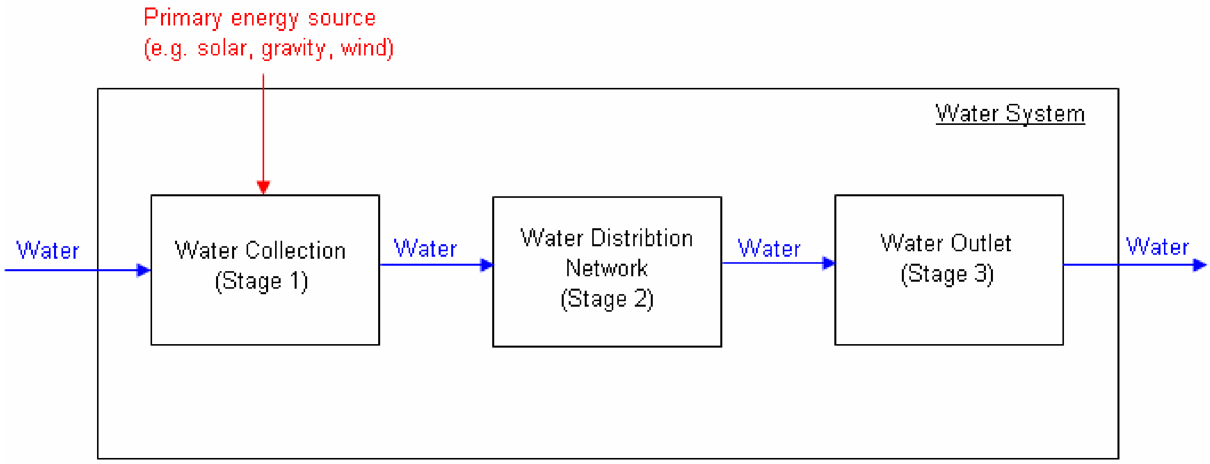


Figure: Conceptualised block diagram of the water service system broken down into three stages.

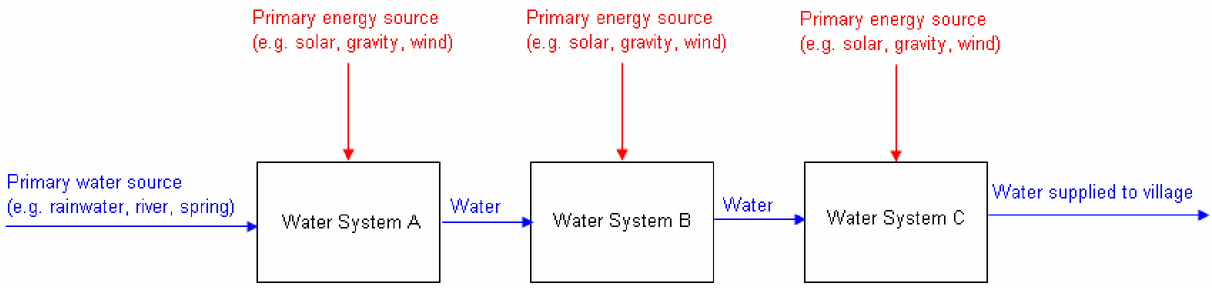


Figure: How a design solution may incorporate multiple water service systems.

E.2 WATER SYSTEM STAGES

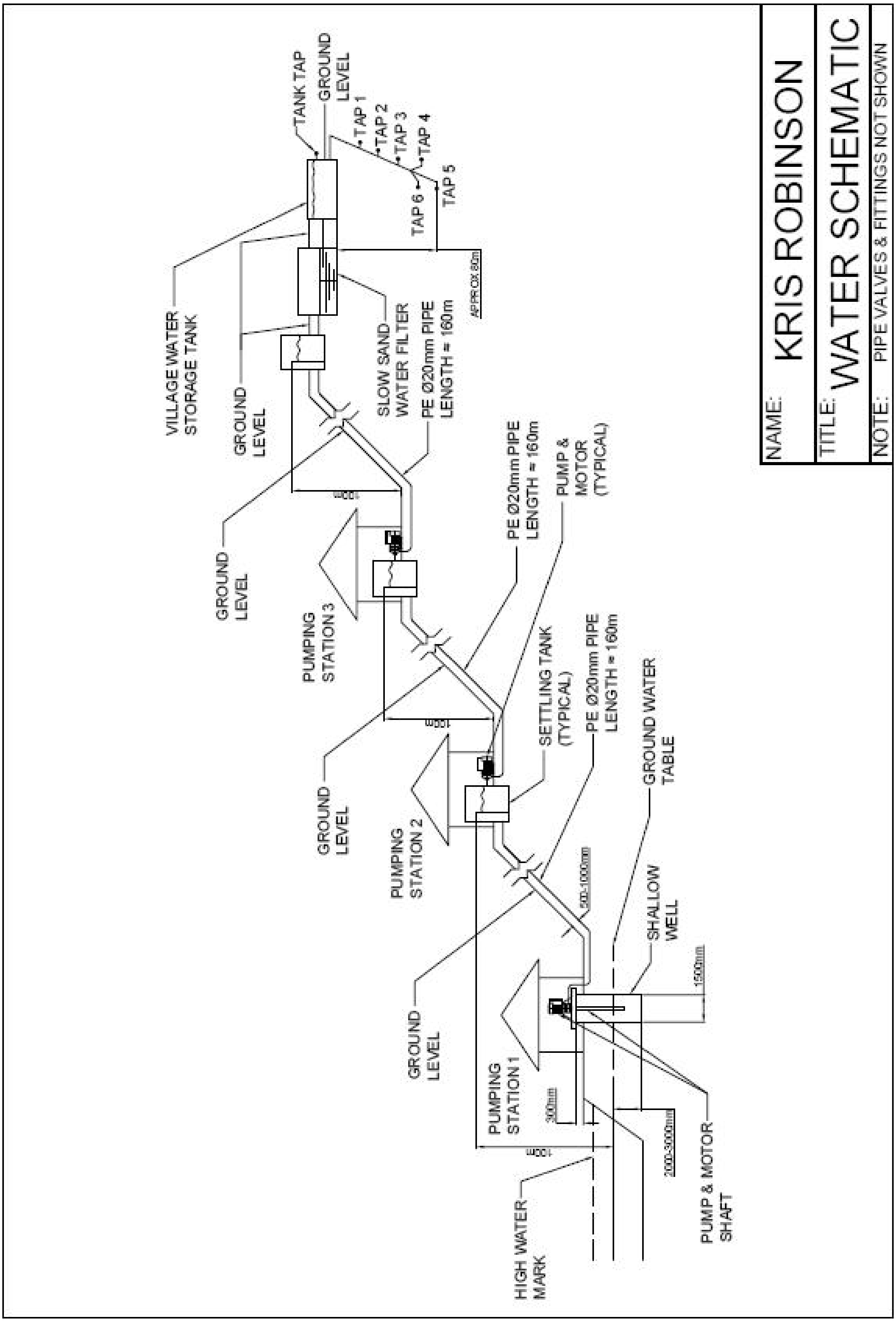
The water collection (stage 1) is where the water is retrieved and collected from a source such as a river, spring, rain water or water collection point. The water collection shall include all system components that contribute to preparing the water for entering the distribution network and will utilize a primary energy source (e.g. solar, gravity, wind) to impart the necessary hydraulic energy to the water. The water distribution network (stage 2) includes all components that are used to transfer the water from the water source to the water outlet. The final stage to the system is the water outlet (stage 3) which shall feed water from the distribution network into storage or village water access points. The components that make up each stage may include and are not limited to the following:

Table: System components of each stage in the water system

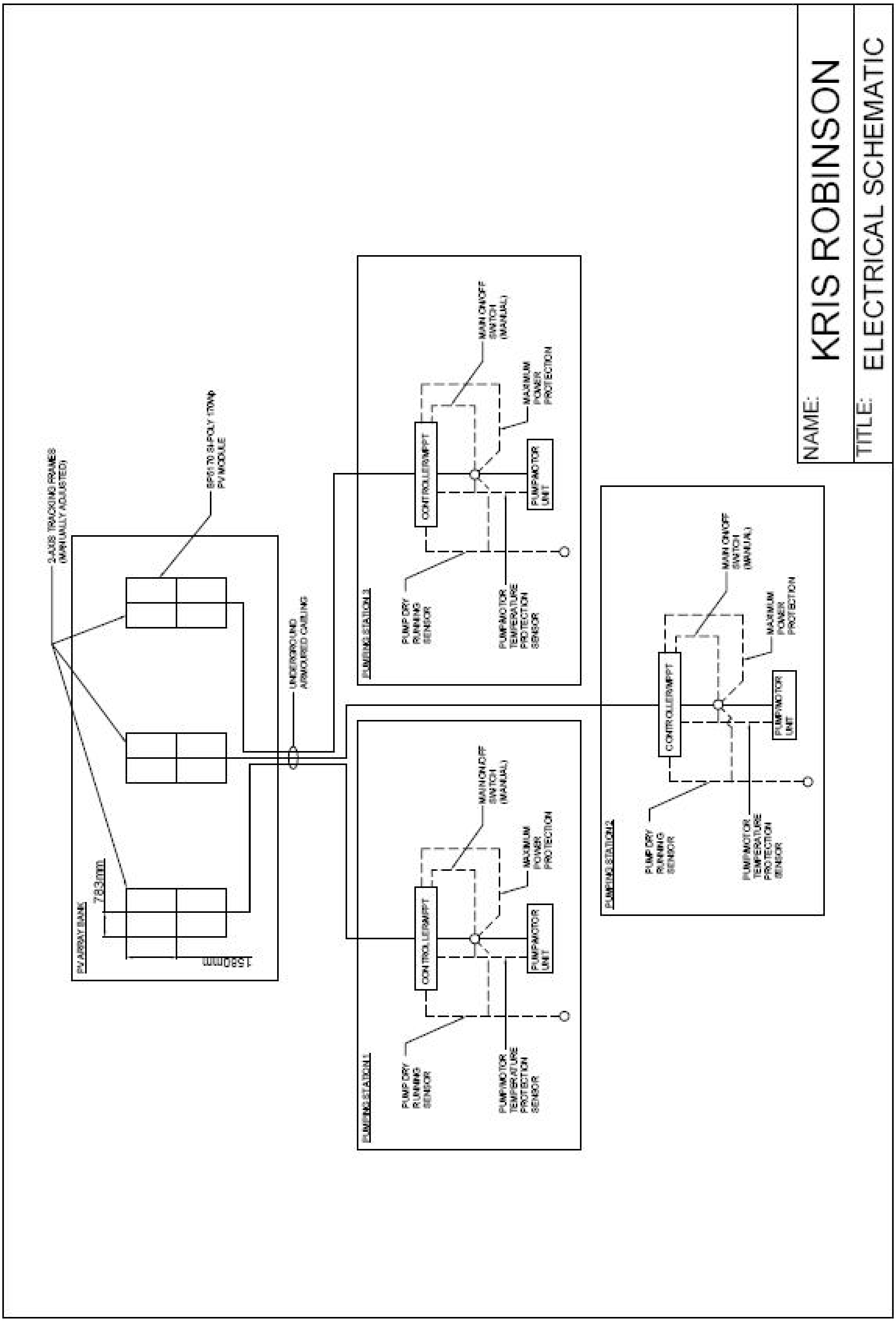
Water System Stage	Stage Components
Water Collection	• Water tanks and wells • Roofs • Water intakes • Filtration and water treatment • Suction piping and valves • Pumps • Motors • Power generators and power conditioning equipment • Controllers, sensors and wiring
Water Distribution Network	• Water pipe and valves • Open water channels • Gutters
Water Outlet	• Taps • Pipe or gutter exits • Water fountains • Hoses • Water channel outlets

Once the water service system has been conceptualised, a more detailed explanation and design of the components that make up the concept design can be executed.

E.3 WATER SCHEMATIC DIAGRAM



E.4 ELECTRICAL SCHEMATIC DIAGRAM



E.5 SPWP SYSTEM LAYOUT

Figure: Layout of the complete SPWP system, source: Google (2007)

F Equipment Specifications

F.1 MINOR LOSS COEFFICIENTS

Table: Nominal loss Coefficients *K* (Turbulent Flow), source: Potter and Wiggert (2002)

Type of fitting		*Screwed*			*Flanged*		
Diameter		2.5 cm	5 in.	10 cm	5 cm	10 cm	20 cm
Globe valve	(fully open)	8.2	6.9	5.7	8.5	6.0	5.8
	(half open)	20	17	14	21	15	14
	(one-quarter open)	57	48	40	60	42	41
Angle valve	(fully open)	4.7	2.0	1.0	2.4	2.0	2.0
Swing check valve	(fully open)	2.9	2.1	2.0	2.0	2.0	2.0
Gate valve	(fully open)	0.24	0.16	0.11	0.35	0.16	0.07
Return bend		1.5	0.95	0.64	0.35	0.30	025
Tee	(branch)	1.8	1.4	1.1	0.8	0.64	0.58
Tee	(line)	0.9	0.9	0.9	0.19	0.14	0.10
Standard elbow		1.5	0.95	0.64	0.39	0.30	0.26
Long sweep elbow		0.72	0.41	0.23	0.30	0.19	0.15
45˚ elbow		0.32	0.30	0.29			

F.2 POLYETHYLENE PIPE

Benefits of PE-X

- **Superior Physical Properties**
  - outstanding restoring forces (memory effect)
  - smooth bore (excellent flow, reducing pressure loss)
  - thick wall (reduce sound transmission, quiet)
  - ability to expand quickly and reduce slowly (absorbs water hammer effect)
- **Excellent Thermal Properties**
  - resistance to heat transfer
- **Non-Toxic (suitable for potable water)**
- **Odourless and Tasteless**
- **Non-Corrosive**
- **Outstanding Mechanical Properties**
  - optimum ratio of flexibility to pressure loading capacity
  - ability to expand quickly and reduce slowly (absorbs water hammer effect)

Source: REHAU Unlimited Polymer Solutions

F.3 GRUNDFOS SQF 1.2-2 HELICAL ROTOR PUMP PACKAGE

Project:	Pamlatum Solar Powered Water	**Client:**	-
Reference Number:	-	**Client Number:**	-
		Contact:	-

Position	*Qty.*	*Description*	*Single Price*
	1	**SQF 1.2-2**	On request

Note! Product picture may differ from actual product

Product No.: 96027328
The 3" SQF pump with helical rotor is for high heads and low flows.

Features and benefits:
-Dry-running protection
-High efficiency permanent-magnet motor (PM motor)
-Over- and undervoltage protection
-Overload protection
-Maximum Power Point Tracking (MPPT)
-Wide voltage range

Liquid:

Maximum liquid temperature:	40 °C

Technical:

Approvals on motor nameplate:	CE

Materials:

Pump:	Stainless steel 1.4301 DIN W.-Nr. 304 AISI

Installation:

Maximum ambient pressure:	15 bar
Pump outlet:	Rp 1 1/4
Minimum borehole diameter:	76 mm

Electrical data:

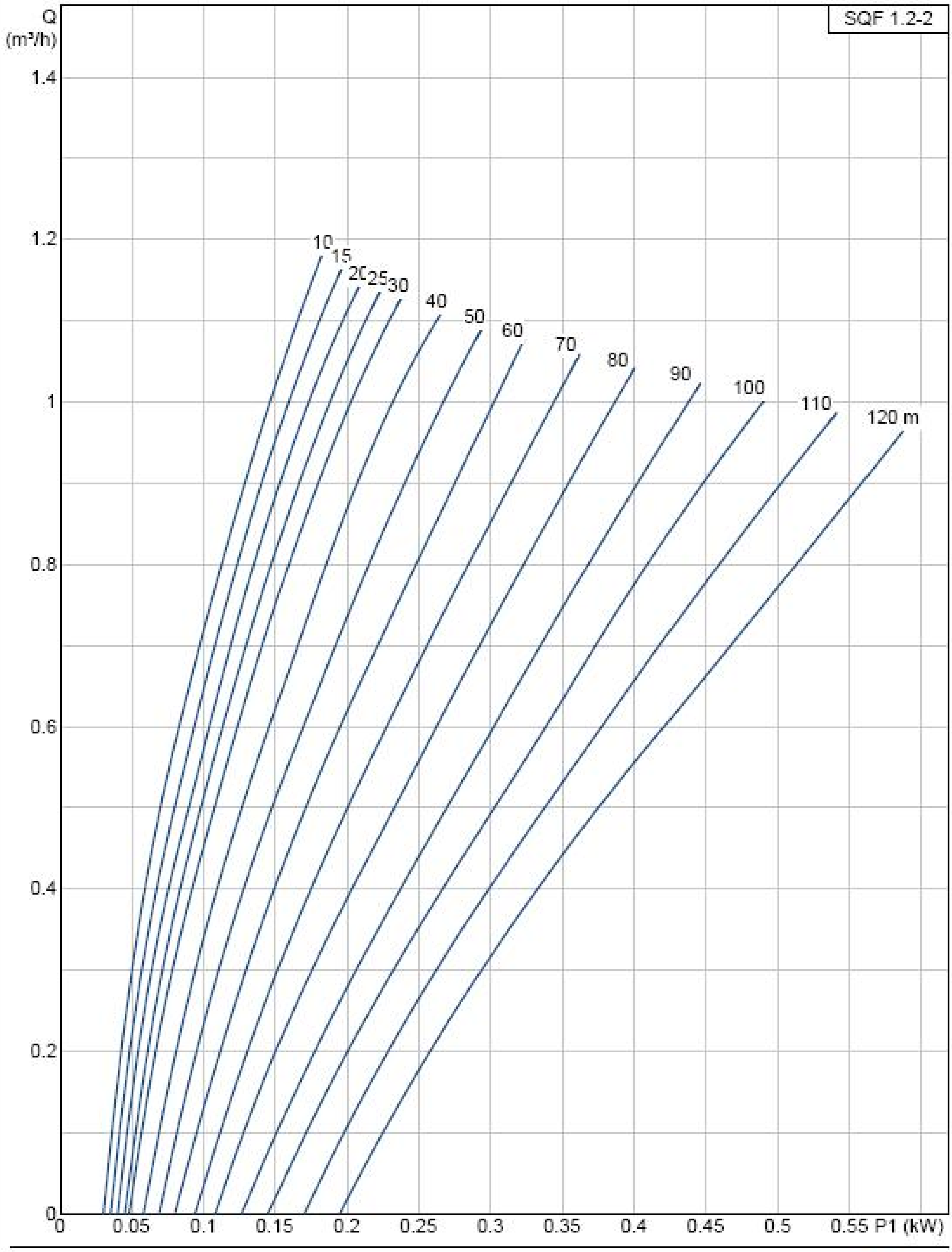
Motor type:	MSF3
Power input - P1:	0.9 kW
Rated voltage ac:	1 x 90-240 V
Rated voltage dc:	30-300 V
Start. method:	direct-on-line
Rated current:	8.4 A
Power factor:	1
Rated speed:	500-3000 rpm
Enclosure class (IEC 34-5):	IP68
Insulation class (IEC 85):	F
Length of cable:	2 m

Others:

Net weight:	7.9 kg
Gross weight:	9.7 kg
Shipping volume:	0.024 m³

Project: Pamlatum Solar Powered Water **Client:** -
Reference Number: - **Client Number:** -
Contact: -

95027328 SQF 1.2-2



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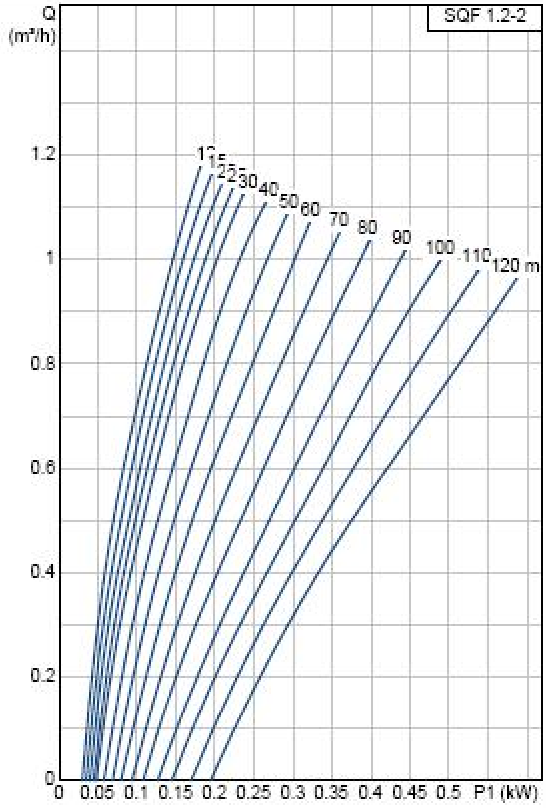
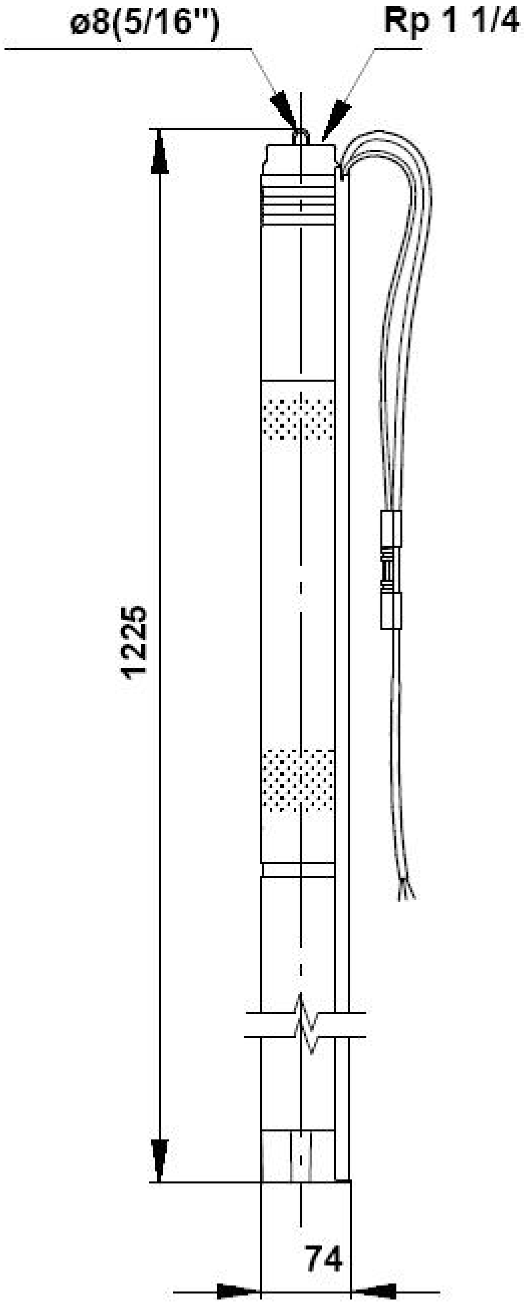
Project: Pamlatum Solar Powered Water
Reference Number: -
Client: -
Client Number: -
Contact: -

Description	Value
Product name:	SQF 1.2-2
Product No:	95027328
EAN number:	5700834791727
Technical:	
Approvals on motor nameplate:	CE
Pump No:	95027411
Stages:	2
Valve:	pump with built-in non-return valve
Materials:	
Pump:	Stainless steel
	1.4301 DIN W.-Nr.
	304 AISI
Rotor:	Stainless steel
	1.4301 DIN W.-Nr.
	304 AISI
Stator:	Stainless steel / EPDM
	1.4301 DIN W.-Nr.
	304 AISI
Installation:	
Maximum ambient pressure:	15 bar
Pump outlet:	Rp 1 1/4
Minimum borehole diameter:	76 mm
Liquid:	
Maximum liquid temperature:	40 °C
Electrical data:	
Motor type:	MSF3
Power input - P1:	0.9 kW
Rated voltage ac:	1 x 90-240 V
Rated voltage dc:	30-300 V
Start. method:	direct-on-line
Rated current:	8.4 A
Power factor:	1
Rated speed:	500-3000 rpm
Enclosure class (IEC 34-5):	IP68
Insulation class (IEC 85):	F
Motor protec:	Y
Thermal protec:	internal
Length of cable:	2 m
Motor No:	96275334
Others:	
Net weight:	7.9 kg
Gross weight:	9.7 kg
Shipping volume:	0.024 m³
Sales region:	Europe/S-AMREG/Japan



Project: Pamlatum Solar Powered Water **Client:** -
Reference Number: - **Client Number:** -
Contact: -

95027328 SQF 1.2-2



Note! All units are in [mm] unless others are stated.

F.4 BP 5170 170W_P PV MODULE

bp solar

BP 5170

170-Watt High-Efficiency
Monocrystalline Photovoltaic Modules

The BP 5170 photovoltaic module uses the world's leading commercial laser cell processing technology to produce volume-manufactured photovoltaics with exceptional efficiency. Its premium laser-grooved buried grid monocrystalline cells and large module area provide a premium power performance of 170 watts nominal maximum power and 24 volts of nominal output, providing more power than any other BP Solar module. Powering DC loads or, with an inverter, AC loads, its high efficiency is particularly suited for applications that need maximum energy generation from a limited array area, and for climates with poor insolation. Applications include utility grid-connected residential and commercial roof systems, building facades, distributed generation systems, telecommunication systems, and other arrays requiring high energy density.

Available versions include:
BP 5170S – Framed module with rugged clear-anodized frame;
BP 5170L – Unframed laminate version of the BP 5170S.

Proven Materials and Construction

BP Solar's quarter-century of field experience shows in every aspect of these modules' construction and materials:

- Frame strength exceeds requirements of certifying agencies;
- Laser patterning and processing minimizes cell front shading, maximizes efficiency;
- 72 high-efficiency monocrystalline cells laminated between sheets of ethylene vinyl acetate (EVA) and high-transmissivity low-iron 3mm tempered glass;
- Integral bypass diodes;
- Asymmetrical cables enable side-by-side or end-to-end module placement in arrays
- DC-rated plug-and-socket connectors provide reliable low-resistance connections and eliminate wiring errors.

DC Connectors

Limited Warranties

- Power output for 25 years;
- Freedom from defects in materials and workmanship for 5 years.

See our website or your local representative for full terms of these warranties.

Clear Anodized Universal Frame

Quality and Safety

- Manufactured in ISO 9001-certified factories;
- Conforms to Directives 89/336/EEC, 73/23/EEC and 93/68/EEC of the European Community;
- BP 5170S is listed by Underwriter's Laboratories for electrical and fire safety (Class C fire rating);
- BP 5170S is certified by TÜV Rheinland as Class II equipment;
- BP 5170S complies with the requirements of IEC 61215, including:
  - repetitive cycling between -40°C and 85°C at 85% relative humidity;
  - simulated impact of 25mm (one-inch) hail at terminal velocity;
  - a "hot-spot" test, which determines a module's ability to tolerate localized shadowing (which can cause reverse-biased operation and localized heating);
  - static loading, front and back, of 2400 pascals (50 psf); front loading (e.g. snow) of 5400 pascals (113 psf).
- The BP 5170L is recognized by Underwriter's Laboratories for electrical and fire safety.

BP 5170S

UL TÜV CE

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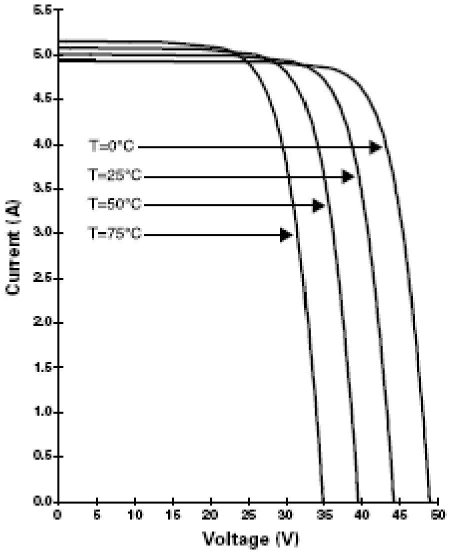
Electrical Characteristics[1]

	BP 5170	BP 5160[4]
Maximum power (P_{max})[2]	170W	160W
Voltage at P_{max} (V_{mp})	36.0V	36.0V
Current at P_{max} (I_{mp})	4.72A	4.44A
Warranted minimum P_{max}	161.5W	152W
Short-circuit current (I_{sc})	5.0A	4.7A
Open-circuit voltage (V_{oc})	44.2V	44.0V
Temperature coefficient of I_{sc}	(0.065±0.015)%/°C	
Temperature coefficient of V_{oc}	-(160±10)mV/°C	
Temperature coefficient of power	-(0.5±0.05)%/°C	
NOCT[2]	47±2°C	
Maximum series fuse rating	15A	
Maximum system voltage	600V (U.S. NEC rating) 1000V (TÜV Rheinland rating)	

Notes

1. These data represent the performance of typical BP 5160 and BP 5170 modules and laminates as measured at their output terminals. The data are based on measurements made in accordance with ASTM E1036 corrected to SRC (Standard Reporting Conditions, also known as STC or Standard Test Conditions), which are:
   - illumination of 1 kW/m² (1 sun) at spectral distribution of AM 1.5 (ASTM E892 global spectral irradiance);
   - cell temperature of 25°C.
2. The cells in an illuminated module operate hotter than the ambient temperature. NOCT (Nominal Operating Cell Temperature) is an indicator of this temperature differential, and is the cell temperature under Standard Operating Conditions: ambient temperature of 20°C, solar irradiation of 0.8 kW/m², and wind speed of 1 m/s.
3. During the stabilization process which occurs during the first few months of deployment, module power may decrease approximately 3% from typical P_{max}.
4. The power of solar cells varies in the normal course of production; the BP 5160 is assembled using cells of slightly lower power than the BP 5170.

BP 5170 I-V Curves

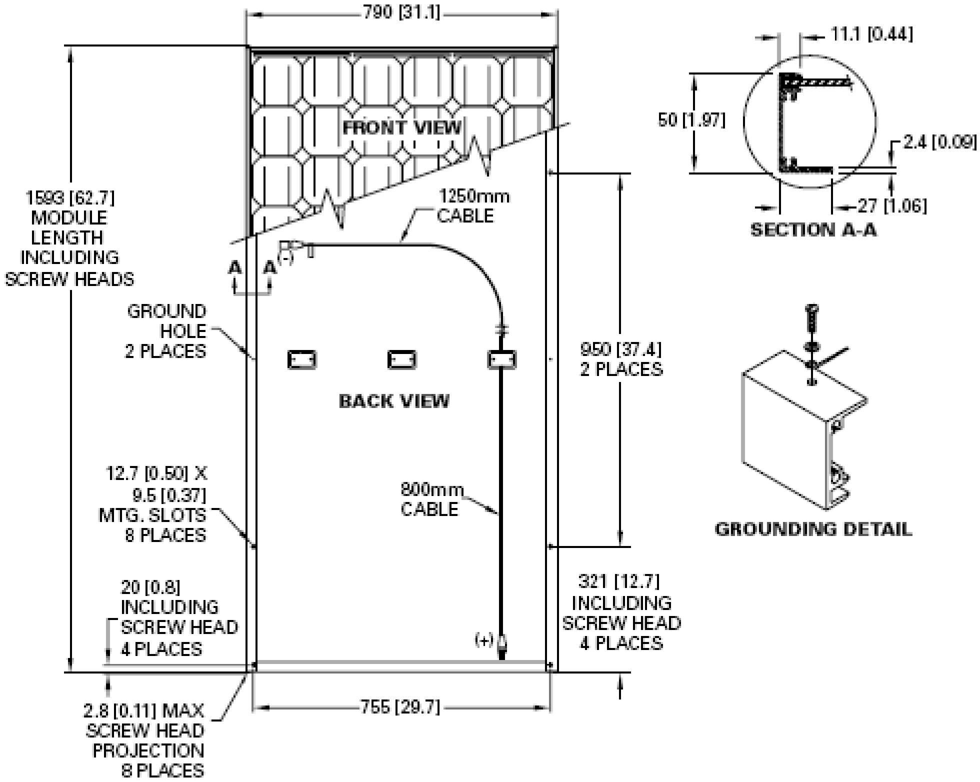


Mechanical Characteristics

Weight
BP 5170S 15.0 kg (33.1 pounds)
BP 5170L 12.4 kg (27.3 pounds)

Output
Asymmetrical RHW AWG# 12 ($3.3mm^2$)
2-conductor cable with weatherproof polarized connectors

Dimensions
BP 5170S: See drawing
BP 5170L: 1580 [62.2] x 783 [30.8] x 19 [0.75]
Unbracketed dimensions are in millimeters.
Bracketed dimensions are in inches.
Overall tolerances ±3mm (1/8")



BP 5170S

G PVSyst v4.1 Design Modelling & Simulation

G.1 Introduction To PVSyst v4.1

PVSyst v4.1 is a PC software package for the study, sizing and data analysis of complete PV systems. Andre Mermoud is the author and developer of the software package and can be contacted at Andre.Mermoud@cuepe.unige.ch. PVSyst v4.1 deals with grid-connected, stand-alone, pumping and DC-grid (public transport) PV systems, and includes extensive meteo and PV systems components databases, as well as general solar energy tools. This software is geared to the needs of architects, engineers and researchers. It is also very helpful for educational training. PVSyst v4.1 offers three levels of PV system study, roughly corresponding to the different stages in the development of a real project:

- **Preliminary design:** this is the pre-sizing step of a project
- **Project design:** it aims to perform a thorough system design using detailed hourly simulations.
- **Measured data analysis:** when a PV system is running and carefully monitored, this part permits the import of measured data to display tables and graphs of actual performances, and to perform close comparisons with the simulated variables.

Only the first two levels have been used to simulate the performance of the concept design generated in this project. In addition, hourly meteorology data on solar insolation and ambient temperature were recorded by Alez Zahnd during 2006 at the High Altitude Research Station (HARS) at Simikot, Nepal (*Appendix B.1, p.60*). This data was used to create a synthetic meteo file for the use of simulating the concept design. PVSyst is very thorough and detailed in the modelling of PV systems and offers many input parameters. To reduce modelling complexity, PVSyst also allows the use of preset or default values. As this project only presents a design concept, the modelling was simplified by taking advantage of the default values where deemed appropriate. Once a concept design is selected, complexities can be introduced into the model to aid in the detailed design of the concept. The following sections only describe, step by step, how the meteo file was generated and how the concept design was modelled and simulated with PVSyst. The modelling does not provide discussion to the steps or descriptions to areas of PVSyst that were not used. Where no description was provided on certain parameters, the default parameters were used.

G.2 Generating The Synthetic Meteo File

First of all, an ASCII meteo file needs to be created. The ASCII file created for this project included hourly insolation data and ambient temperature which were recorded at the HARS-Simikot during 2006. Wind velocity was also used in the meteo file which was taken from the NASA website (*Appendix B, p.60*). When PVSyst is initiated, the user is presented with the 'main project screen'.

- Select 'tools'.

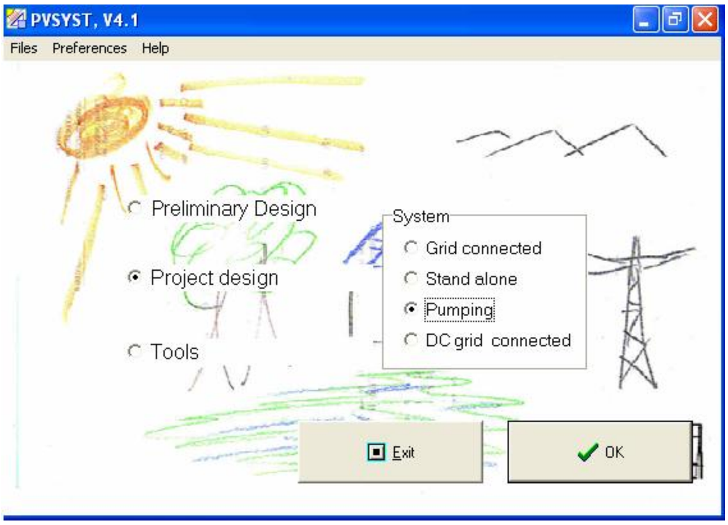


Figure: Main project screen

- Select 'import ASCII meteo file'.

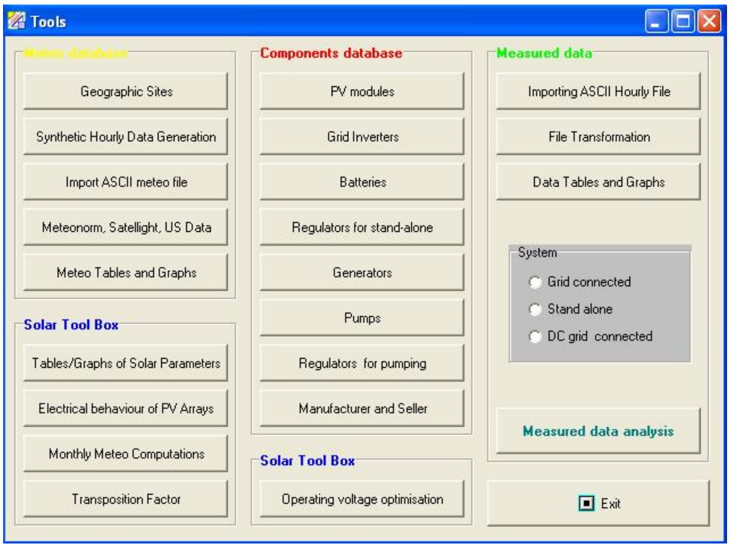


Figure: Tools

- Choose the source ASCII file.
- 'Open' the geographic site.

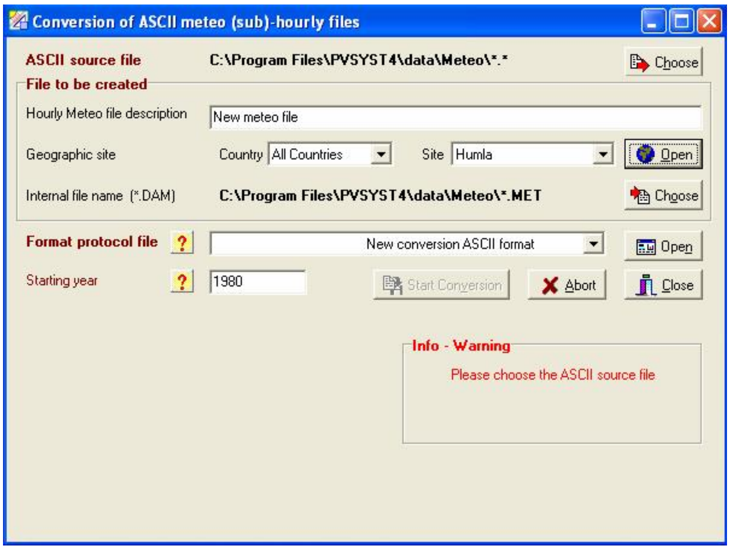


Figure: Conversion of ASCII Meteo (sub)-hourly files

- Fill in the geographic site details.
- Select 'next'.

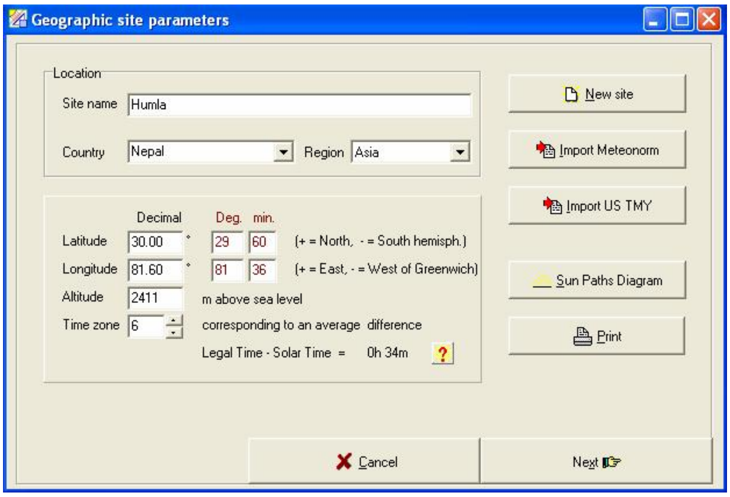


Figure: Geographic site parameters 1

- Enter monthly average global insolation, ambient temperature and wind velocity.
- Select 'ok'. This will take you back to the 'conversion of ASCII meteo (sub)-hourly files' screen.

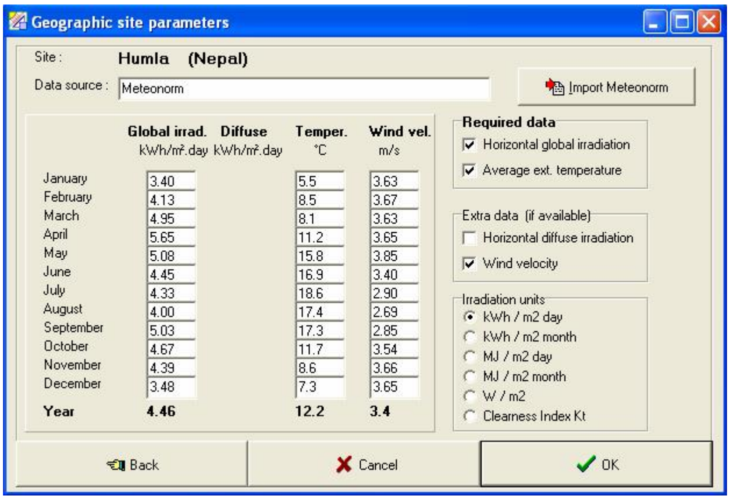


Figure: Geographic site parameters 2

- The user then needs to create a format file protocol. The format protocol tells PVSyst how the ASCII file is presented and how to read the file for creating the synthetic meteo file.
- Once all required data is entered, select 'start conversion'. The synthetic meteo file will be created.
- Exit back to the 'main project screen'.

G.3 PRE-SIZING MODELLING

The pre-sizing tool was used to get a feel for the size, power requirements, cost and performance of the concept design. Some of these results were used to set targets for the engineering specifications presented in *Appendix D.5, p.74*.

- In the 'main project screen', select 'preliminary design' and then 'pumping'.
- In the 'pumping system pre-sizing' screen, select 'location'.

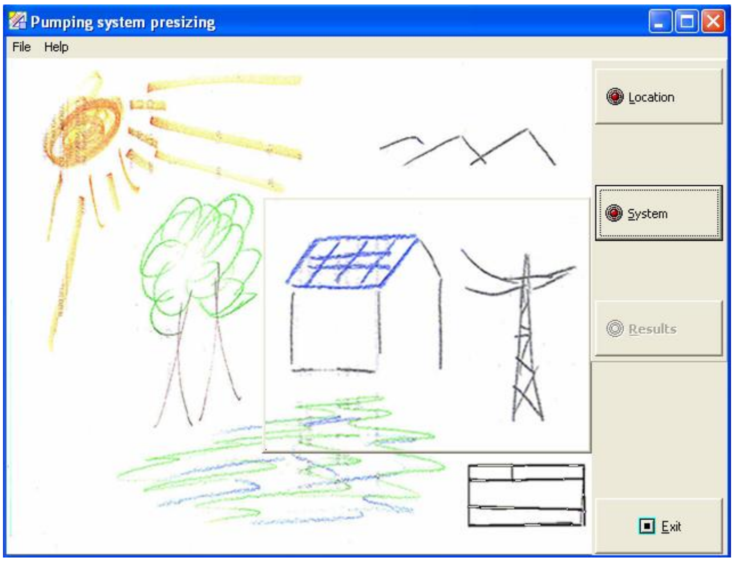


Figure: Pumping system pre-sizing

- Provide a project name and select the site (synthetic meteo file).
- Select 'horizon' and load the horizon model (see *Appendix B.3, p.62*).

- Select ‘ok’ and go back to the ‘pumping system pre-sizing’ screen.
- Select ‘system’.

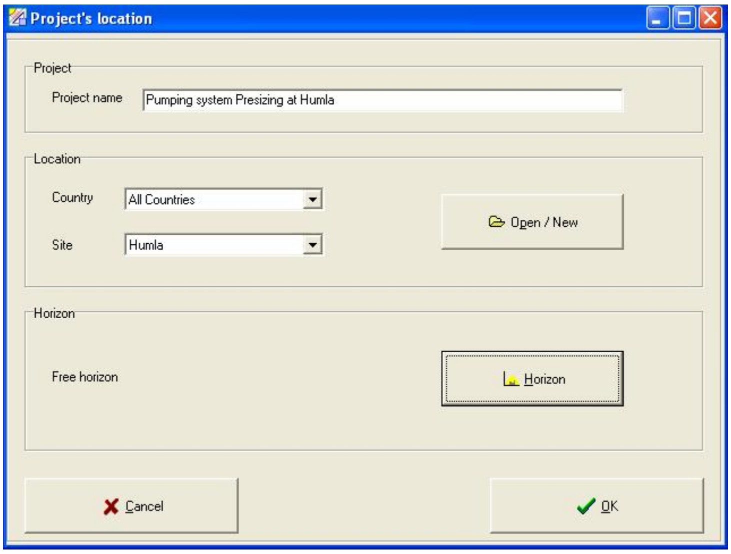


Figure: Project’s location

- Define the system specification by entering water needs, pipe length, pipe internal diameter, static head (level difference), pump technology, power converter, pump layout and collector plane orientation.
- Select ‘next’ to go back to the ‘pump system pre-sizing’ screen.
- Select ‘results’.

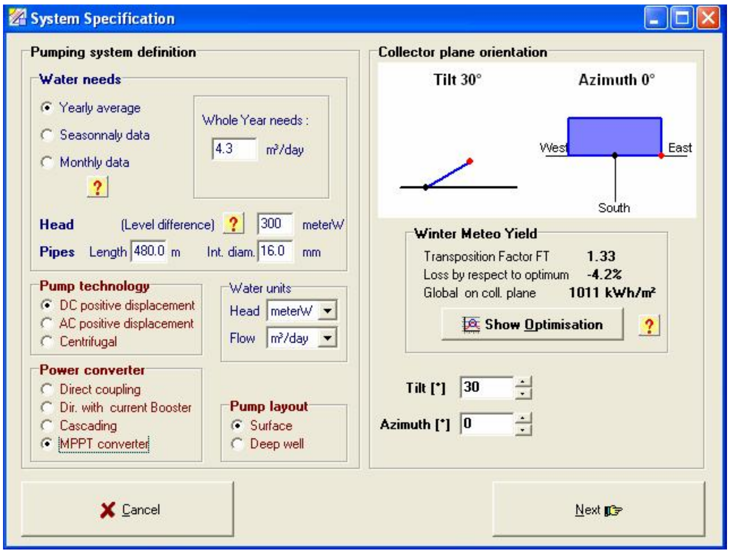


Figure: System specification

- The results screen presents an estimation on the system size including costs and other performance parameters.
- Select ‘ok’ and go back to the ‘main project screen’ to start a more detailed project design.

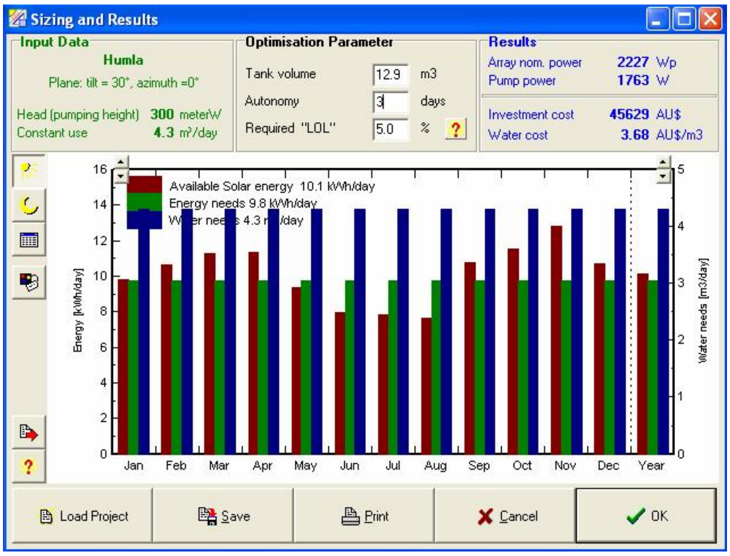


Figure: Sizing and results

G.4 Project Design Modelling & Simulation

The project design tool allows the model to be specified in more detail, including simulation and the presentation of detailed performance results.

- In the ‘main project screen’ select ‘project design’ followed by ‘pumping’ to go to the ‘main model screen’.
- Select ‘project variant’.

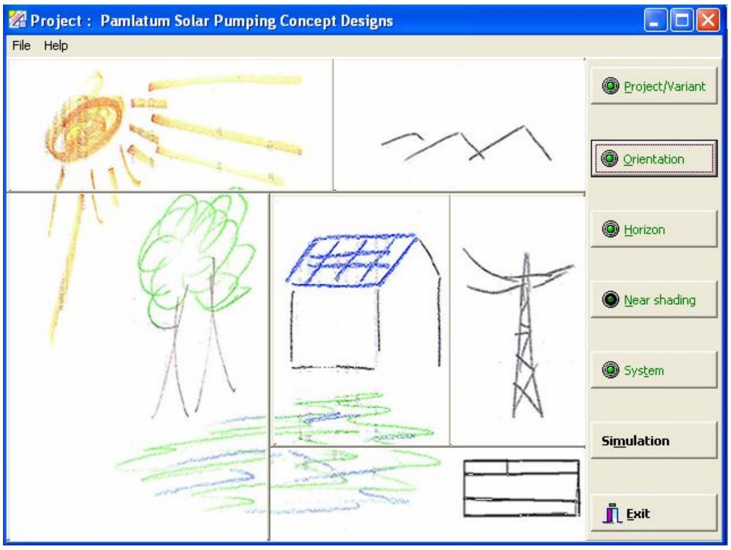


Figure: Main model screen

- Define the project and name the simulation variant. The software allows one or more design variants to be generated to aid in the comparison of results and optimisation of the design. This tool was used, but the results are not described in this paper. Only the final design concept after optimisation is presented in this paper.
- Select ‘next’.

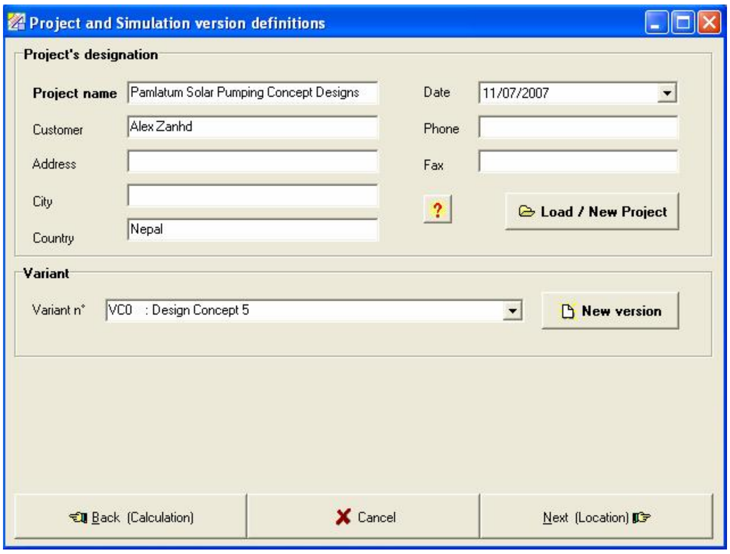


Figure: Project and simulation versions

- Define the location and select the synthetic meteo file.
- Select 'next'.

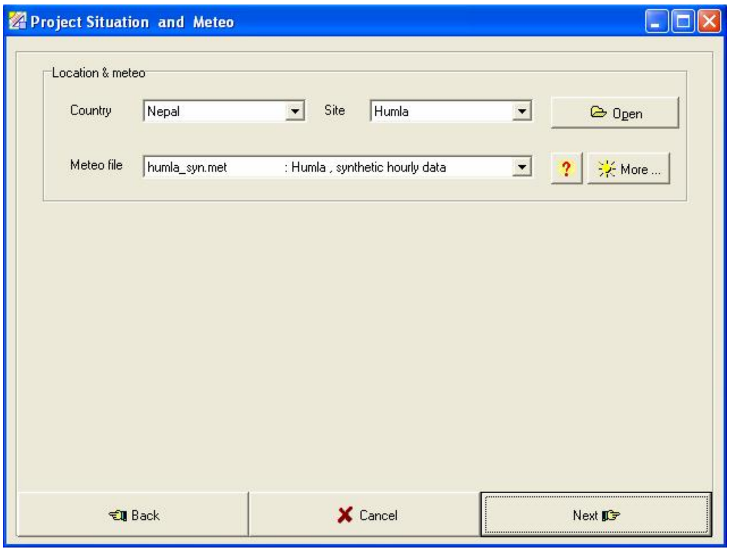


Figure: Meteo file selection

- The values on the 'Albedo values' screen are defaults and were not changed.
- Select 'ok' to go back to the 'main model screen'.
- Select 'orientation'.

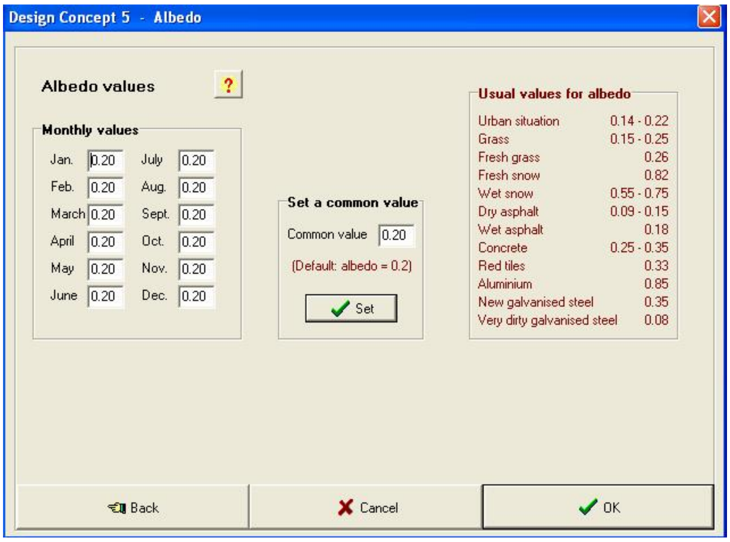


Figure: Albedo values

- Define the collector field type and orientation.
- Select ‘ok’ to go back to the ‘main model screen’.
- Select ‘horizon’.

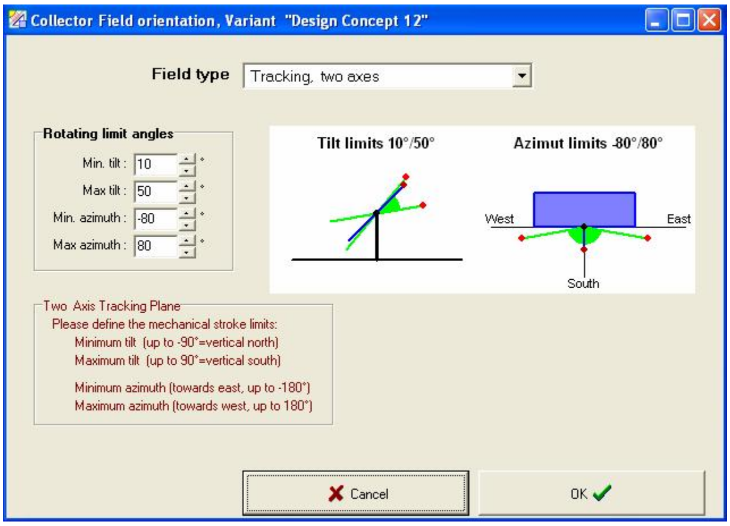


Figure: Collector field orientation

- Load the horizon model (see *Appendix B.3, p.62*).
- Select ‘ok’ to go back to the ‘main model screen’.
- ‘Near shading’ was not used in the model. Select ‘system’.

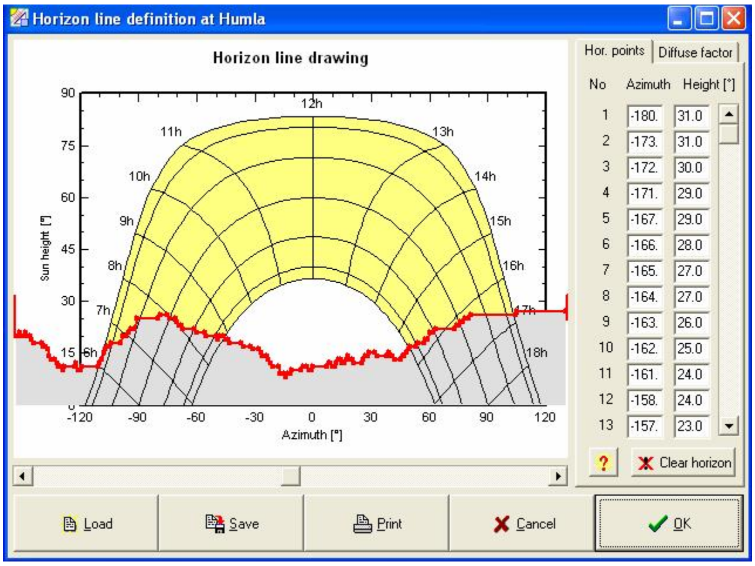


Figure: Horizon line definition

- Define the hydraulic circuit such as static head (level depth), pump depth, storage tank and distribution piping.
- Select ‘water needs’.

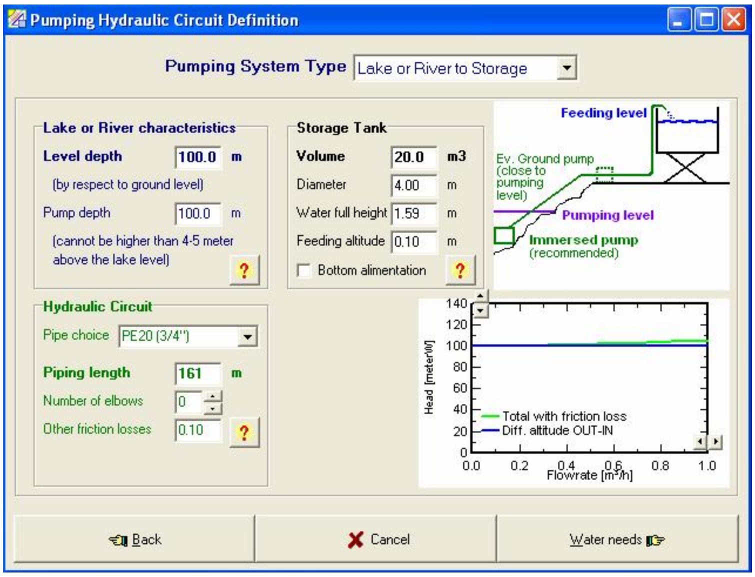


Figure: Pumping hydraulic circuit definition

- Enter the river water depth variations (‘year constant’ was used in the model).
- Select ‘monthly needs’ to define water demand.

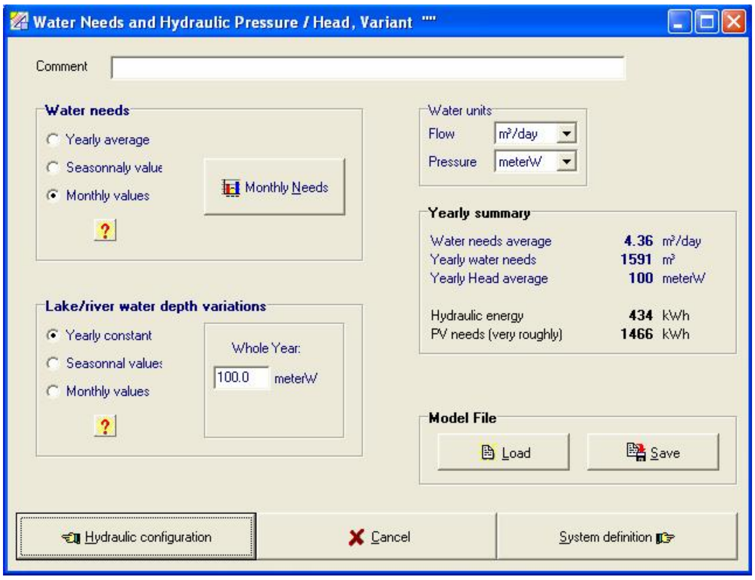


Figure: Water needs and hydraulic head

- Define the monthly water demand. The monthly values entered were based on the optimisation of the water demand based on minimizing excess water flows, minimizing the missing water and maximizing the allowable water consumption.
- Select ‘ok’ to go back to the ‘water needs and hydraulic head’ screen.
- Select ‘system definition’.

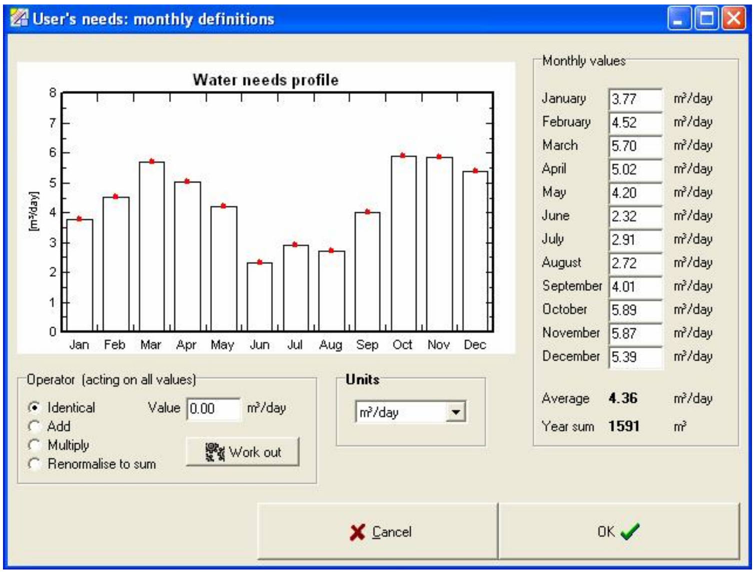


Figure: Monthly water needs

- Define the system such as requested autonomy, accepted missing water, pump technology and quantity and PV module technology and quantity.
- Select ‘regulation’.

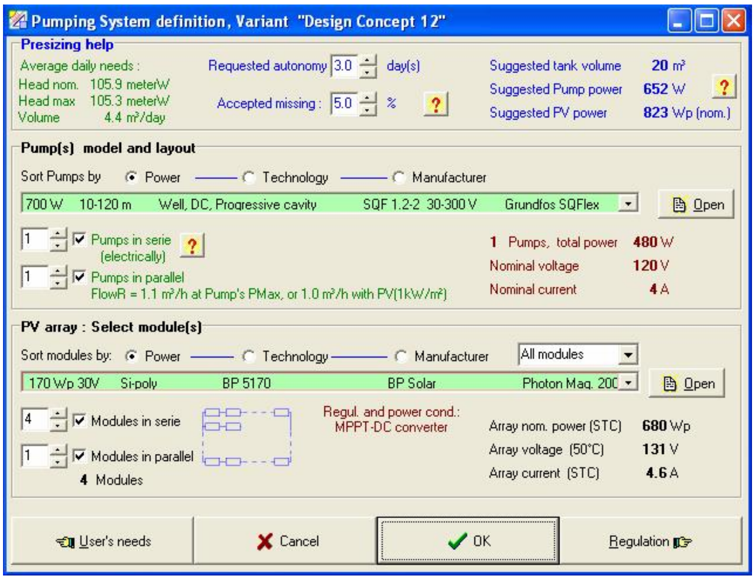


Figure: Pump system definition

- Define the regulation technology. The design concept in this project used the default Maximum Power Point Tracker (MPPT) provided by PVSyst.
- Select 'array losses'.

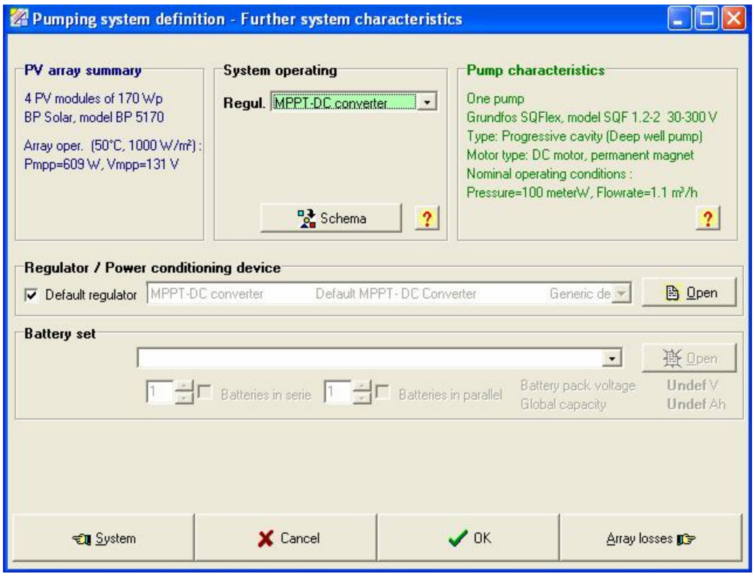


Figure: Further system characteristics

- All array losses were set to the default values provided by PVSyst.
- Select 'ok' to go back to the 'main model screen'.
- Select 'simulation'.

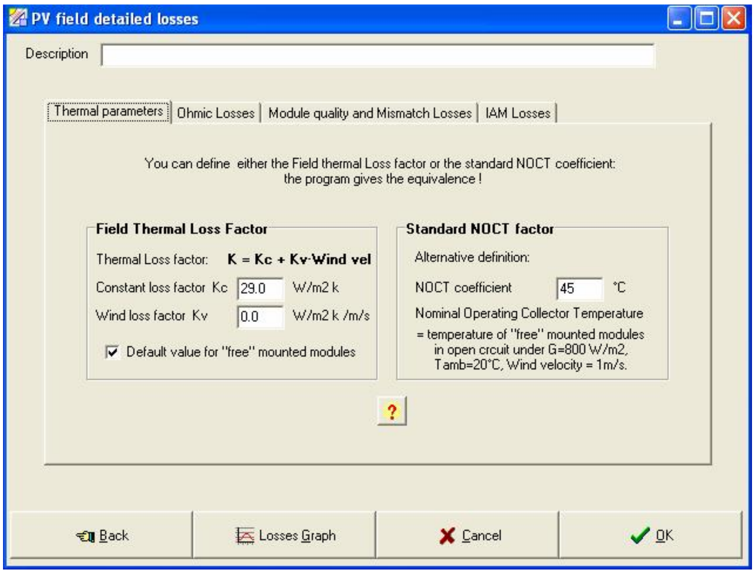


Figure: PV field detailed losses

- Select 'simulation'.

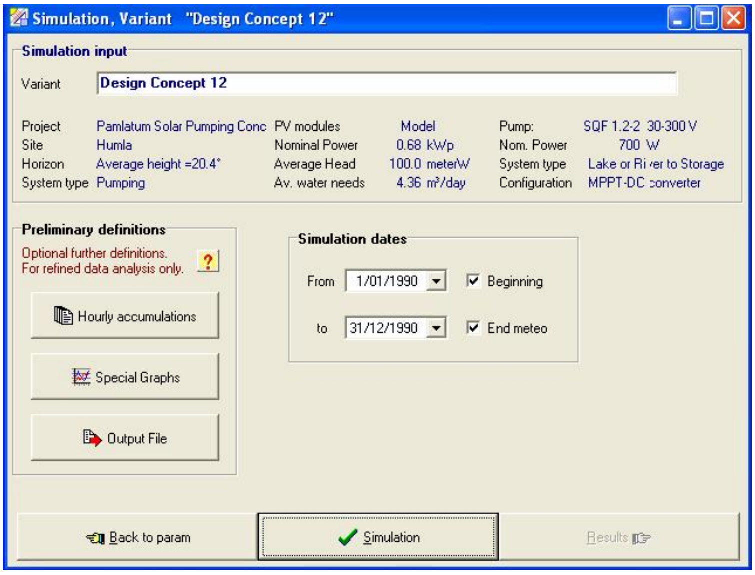


Figure: Simulation

The following 'results' screen is presented. From this screen, a wide range of tables and graphs can be access to view and analyse the performance of the design. A report (*Appendix H.1, p.106*) can also be generated which details the design including the specified equipment used and some general results.

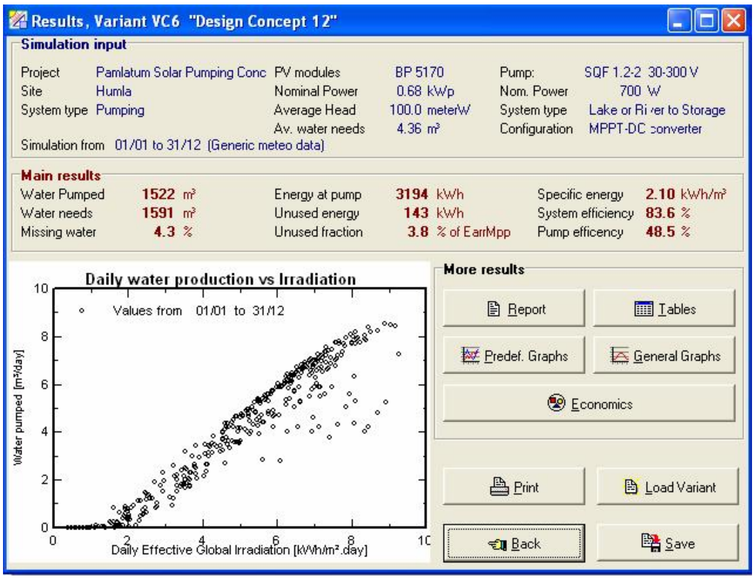


Figure: Results

H PVSyst Results

H.1 Report

The following is a report on the design concept produced by PVSyst which outlines the system including the equipment specified and some general results.

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Pumping PV System: Basic simulation parameters

Project :	**Pamlatum Solar Pumping Concept Designs**			
Geographical Site	**Humla**		**Country**	**Nepal**
Situation	Latitude	30.0°N	Longitude	81.6°E
Time defined as	Solar Time		Altitude	2411 m
	Albedo	0.20		
Meteo data :	Humla , synthetic hourly data			

Simulation Variant :	**Design Concept 12**			
	Simulation date	28/08/07 00h34		

Simulation parameters

Pumping System parameter	System type	**Lake or River to Storage**		
Lake or River to Storage	Level depth	100 m		
	Pump depth	25 m	Max. pumping depth	24 m
Storage tank	Volume	20.0 m³	Diameter	4.0 m
Feeding by top	Feeding altitude	0.1 m	Height (full level)	1.6 m
Hydraulic circuit	Piping length	161 m	Pipes PE20 (3/4")	Dint = 22 mm
	Number of elbows	0	Other friction losses	0.100
Water needs	Yearly Average	4.36 m³/day	Monthly Distribution	See next page
Pump	Model	**SQF 1.2-2 30-300 V**		
	Manufacturer	Grundfos SQFlex		
Pump Technology	Progressive cavity	Deep well pump	Motor	DC motor, permanent
Associated or Integrated converter	Type	MPPT	Voltage range	30 - 300 V

Operating conditions	Head Min	Head Nom	Head Max	
	10.0	80.0	120.0	mWater
Corresponding maximum Flow Rate	1.34	1.14	1.07	m³/h
Required power	280	480	700	W

Tracking plane, two axis	Minimum Tilt	10°	Maximum Tilt	50°
Rotation Limitations	Minimum Azimuth	-80°	Maximum Azimuth	80°
Horizon	Average Height	20.4°		

PV Array Characteristics

PV module Si-poly	Model	**BP 5170**		
	Manufacturer	BP Solar		
Number of PV modules	In series	4 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	4	Unit Nom. Power	170 Wp
Array global power	Nominal (STC)	**680 Wp**	At operating cond.	609 Wp (50°C)
Array operating characteristics (50°C)	U mpp	131 V	I mpp	5 A
Total area	Module area	**4.9 m²**		
Control device	Model	Generic device (optimised for the system)		
	System Configuration	**MPPT-DC converter**		

Pumping PV System: Detailed Simulation parameters

Project : **Pamlatum Solar Pumping Concept Designs**

Simulation Variant : **Design Concept 12**

Main system parameters — System type: **Lake or River to Storage**

System Requirements	Basic Head	100.1 meterW	Water needs	4.4 m³/day (aver.)
Pump	Model / Manufacturer	SQF 1.2-2 30-300 V / Grundfos SQFlex		
PV Array	Model / Manufacturer	BP 5170 / BP Solar		
	Nb. of modules	4 in series	Array Power	680 Wp
System Configuration	Control Strategy	**MPPT-DC converter**		

Water needs: monthly values

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
3.77	4.52	5.70	5.02	4.20	2.32	2.91	2.72	4.01	5.89	5.87	5.39	4.36	m³/day

System Operating Control (Generic device, params adjusted acc. to the system)

Power conditioning unit MPPT - DC converter

Operating conditions	Minimum MPP Voltage	30 V	nominal power	672 W
	Maximum MPP Voltage	300 V	Power Threshold	34 W
	Maximum Array Voltage	300 V	Max. efficiency	96.0 %
	Maximum Input Current	23.0 A	EURO efficiency	94.5 %

PV Array loss factors

Heat Loss Factor	ko (const)	29.0 W/m²K	kv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (800 W/m², Tamb=20°C, wind 1 m/s)			NOCT	45 °C
Wiring Ohmic Loss	Global array res.	926.8 mOhm	Loss Fraction	3.0 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.5 % at STC
Module Quality Loss			Loss Fraction	3.0 %
Module Mismatch Losses			Loss Fraction	4.0 % (fixed voltage)
Incidence effect, ASHRAE parametrization	IAM =	1-bo (1/cos i - 1)	bo Parameter	0.05

Pumping PV System: Horizon definition

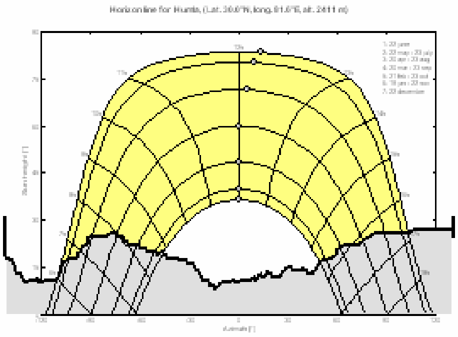
Project : **Pamlatum Solar Pumping Concept Designs**

Simulation Variant : **Design Concept 12**

Main system parameters — System type: **Lake or River to Storage**
System Requirements — Basic Head: 100.1 meterW — Water needs: 4.4 m³/day (aver.)
Pump — Model / Manufacturer: SQF 1.2-2 30-300 V / Grundfos SQFlex
PV Array — Model / Manufacturer: BP 5170 / BP Solar
Nb. of modules: 4 in series — Array Power: 680 Wp
System Configuration — Control Strategy: **MPPT-DC converter**

Horizon — Average Height: 20.4° — Diffuse Factor: 0.86
Albedo Factor: 100 % — Albedo Fraction: 0.31

Height [°]	31.0	31.0	30.0	29.0	29.0	28.0	27.0	27.0	26.0	25.0	24.0	24.0	23.0
Azimuth [°]	-180.0	-173.0	-172.0	-171.0	-167.0	-166.0	-165.0	-164.0	-163.0	-162.0	-161.0	-158.0	-157.0
Height [°]	22.0	21.0	20.0	20.0	21.0	20.0	20.0	21.0	20.0	20.0	19.0	18.0	18.0
Azimuth [°]	-156.0	-155.0	-154.0	-152.0	-151.0	-150.0	-149.0	-148.0	-147.0	-146.0	-145.0	-144.0	-140.0
Height [°]	17.0	17.0	16.0	14.0	13.0	13.0	12.0	11.0	11.0	10.0	11.0	11.0	12.0
Azimuth [°]	-139.0	-138.0	-137.0	-136.0	-135.0	-133.0	-132.0	-131.0	-130.0	-129.0	-128.0	-123.0	-122.0
Height [°]	10.0	10.0	11.0	11.0	12.0	13.0	15.0	16.0	17.0	17.0	18.0	18.0	20.0
Azimuth [°]	-121.0	-120.0	-119.0	-111.0	-110.0	-109.0	-108.0	-107.0	-106.0	-105.0	-104.0	-99.0	-98.0
Height [°]	20.0	21.0	22.0	22.0	25.0	25.0	26.0	26.0	25.0	25.0	24.0	23.0	23.0
Azimuth [°]	-96.0	-95.0	-94.0	-92.0	-91.0	-80.0	-79.0	-75.0	-74.0	-71.0	-70.0	-69.0	-68.0
Height [°]	22.0	22.0	21.0	21.0	20.0	20.0	19.0	20.0	20.0	19.0	19.0	18.0	18.0
Azimuth [°]	-67.0	-61.0	-60.0	-56.0	-55.0	-50.0	-49.0	-48.0	-46.0	-45.0	-44.0	-43.0	-37.0
Height [°]	17.0	17.0	16.0	16.0	15.0	14.0	14.0	13.0	12.0	11.0	11.0	9.0	9.0
Azimuth [°]	-36.0	-32.0	-31.0	-28.0	-27.0	-26.0	-24.0	-23.0	-22.0	-21.0	-18.0	-17.0	-15.0
Height [°]	8.0	9.0	9.0	10.0	10.0	11.0	11.0	10.0	10.0	11.0	11.0	12.0	12.0
Azimuth [°]	-14.0	-13.0	-12.0	-11.0	-6.0	-5.0	-3.0	-2.0	-1.0	0.0	7.0	8.0	9.0
Height [°]	11.0	11.0	12.0	13.0	13.0	12.0	12.0	13.0	14.0	13.0	13.0	12.0	12.0
Azimuth [°]	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	25.0
Height [°]	13.0	14.0	14.0	15.0	15.0	14.0	14.0	15.0	14.0	14.0	13.0	13.0	14.0
Azimuth [°]	26.0	27.0	28.0	29.0	32.0	33.0	38.0	39.0	40.0	41.0	42.0	45.0	46.0
Height [°]	14.0	15.0	16.0	17.0	17.0	18.0	18.0	19.0	19.0	21.0	21.0	22.0	22.0
Azimuth [°]	47.0	48.0	49.0	50.0	53.0	54.0	57.0	58.0	59.0	60.0	62.0	63.0	73.0
Height [°]	23.0	23.0	24.0	24.0	25.0	25.0	26.0	26.0	27.0	27.0	26.0	26.0	25.0
Azimuth [°]	74.0	75.0	76.0	77.0	78.0	80.0	81.0	104.0	105.0	131.0	132.0	142.0	143.0
Height [°]	25.0	26.0	26.0	27.0	27.0	28.0	28.0	29.0	30.0	30.0	31.0	31.0	
Azimuth [°]	148.0	149.0	155.0	156.0	157.0	158.0	162.0	163.0	164.0	168.0	169.0	179.0	



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Pumping PV System: Main results

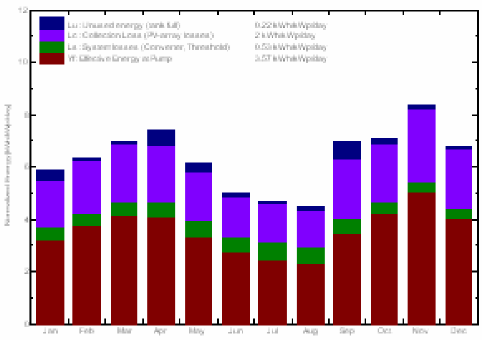
Project : **Pamlatum Solar Pumping Concept Designs**

Simulation Variant : **Design Concept 12**

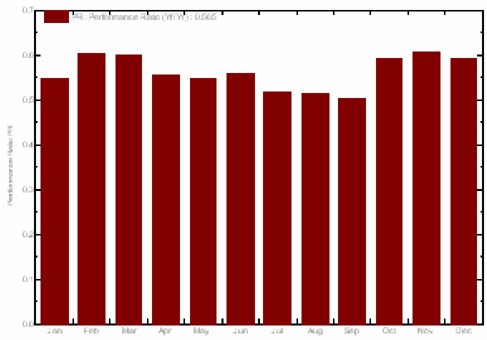
Main system parameters	System type	**Lake or River to Storage**		
System Requirements	Basic Head	100.1 meterW	Water needs	4.4 m³/day (aver.)
Pump	Model / Manufacturer	SQF 1.2-2 30-300 V / Grundfos SQFlex		
PV Array	Model / Manufacturer	BP 5170 / BP Solar		
	Nb. of modules	4 in series	Array Power	680 Wp
System Configuration	Control Strategy	**MPPT-DC converter**		

Main simulation results				
System Production	**Water Pumped**	**1522 m³**	Specific	222 m³/kWp/bar
	Water needs	1591 m³	Missing Water	4.3%
	Energy At Pump	3194 kWh	Specific	2.10 kWh/m³
	Unused PV energy (Tank full)	143 kWh	Unused Fraction	3.8 %
	System efficiency	83.6 %	Pump efficiency	48.5 %

Normalized productions (per installed kWp): Nominal power 680 Wp



Performance Ratio PR



Design Concept 12

Balances and main results

	GlobEff	EArrMPP	E PmpOp	ETkFull	H Pump	WPumped	W Used	W Miss
	kWh/m²	kWh	kWh	kWh	meterW	m³	m³	m³
January	142.1	83.9	68.1	5.707	103.0	117.5	108.7	8.14
February	140.1	81.1	72.1	0.667	102.9	126.3	126.6	0.00
March	172.1	100.4	87.9	1.199	103.2	156.4	174.9	1.76
April	180.6	103.9	84.0	8.148	103.1	147.0	139.8	10.77
May	157.6	88.7	70.6	4.748	102.4	117.7	123.9	6.35
June	125.7	70.1	56.5	1.499	101.6	86.2	68.0	1.59
July	121.9	67.4	51.4	1.124	101.3	73.4	90.2	0.00
August	116.6	64.7	48.9	2.016	101.8	74.6	77.0	7.35
September	165.6	92.3	71.2	9.019	103.1	125.5	106.9	13.45
October	175.0	101.0	88.6	2.494	103.3	160.0	178.7	3.91
November	194.1	112.9	103.3	1.641	104.0	189.1	172.8	3.29
December	161.9	94.9	84.6	1.571	103.2	148.2	164.5	2.56
Year	1853.4	1061.5	887.2	39.832	102.8	1522.0	1532.0	59.16

Legends: GlobEff	Effective Global, corr. for IAM and shadings	H Pump	Average total Head at pump
EArrMPP	Array virtual energy at MPP	WPumped	Water pumped
E PmpOp	Pump operating energy	W Used	Water drawn by the user
ETkFull	Unused energy (tank full)	W Miss	Missing water

H.2 TABLED RESULTS

The following table is a key to the tabled results. One thing to point out is the ‘unused energy’ (tank-full) result. PVSyst v4.1 does not allow the pump to operate when the tank is full, and therefore classifies the ‘unused energy’ as the energy that would have been used if the pump was in operation. However in the concept design, I have assumed that the pump operates continually, even if the tank is full. One way to get around this is to multiply the amount of hours the tank is off due to the tank-full state with the average flow rate for the month. This gives an approximation on the monthly amount of excess water that would flow from the tank due to the tank-full state. The monthly excess water can then be divided by the number of days in that month to calculate the average daily excess water flows.

Table: Key to tables

Meteo and incident energy	GlobHor	Horizontal global irradiation
	DiffHor	Horizontal diffuse irradiation
	T Amb	Ambient Temperature
	GlobInc	Global incident in coll. Plane
	DifSInc	Sky diffuse incident in coll. plane
	Alb Inc	Albedo incident in coll. Plane
	DifS/GI	Incident sky diffuse / global ratio
Effective Incident Energy	GlobHor	Horizontal global irradiation
	GlobInc	Global incident in coll. Plane
	GlobIAM	Global corrected for incidence (IAM)
	GlobEff	Effective Global, corr. For IAM and shadings
Optical Factors	GlobHor	Horizontal global irradiation
	GlobInc	Global incident in coll. Plane
	FTransp	Transposition factor GlobInc / GlobHor
	FIAMBm	IAM factor on beam
	FIAMGl	IAM factor on global
	FIAMShd	Combined IAM and shading factors on global
Losses in PV system	ModQual	Module quality loss
	MisLoss	Module array mismatch loss
	OhmLoss	Ohmic wiring loss
	EArrMPP	Array virtual energy at MPP
	EArUfix	Array virtual energy at fixed voltage
	EArray	Effective energy at the output of the array
Losses in pumping system	EArrMPP	Array virtual energy at MPP
	EPmpThr	En. Under pump producing threshold
	EPmpOvr	Pump overload energy
	E_PmpAv	Available energy at pump
	ETkFull	Unused energy (tank full)
	E PmpOp	Pump operating energy
Other	Pump ON	Pump running duration
	TkF OFF	Tank full duration
	H Loss	Friction head loss
	FlRate	Average flow rate when running
	WWFl	Wastewater flow

Table: Incident solar irradiation

	Meteo and incident energy							Effective Incident Energy			
	GlobHor	DiffHor	T Amb	GlobInc	DifSInc	Alb Inc	DifS/Gl	GlobHor	GlobInc	GlobIAM	GlobEff
	kWh/m2	kWh/m2	degC	kWh/m2	kWh/m2	kWh/m2		kWh/m2	kWh/m2	kWh/m2	kWh/m2
Month											
J	105.4	44.43	5.5	187.9	51.25	5.116	0.273	105.4	187.9	185.5	140.2
F	115.6	48.71	8.5	179.3	52.89	4.671	0.295	115.6	179.3	176.8	138.1
M	153.4	65.09	8.1	218.7	69.41	4.927	0.317	153.4	218.7	215.5	170.1
A	169.5	66.89	11.2	224.4	70.29	4.286	0.313	169.5	224.4	221.1	178.7
M	157.5	80.94	15.8	190.5	80.2	3.489	0.421	157.5	190.5	186.8	155.6
J	133.5	86.01	16.9	149.1	82.24	2.767	0.552	133.5	149.1	145.4	123.7
J	134.2	94.51	18.6	145.2	88.86	2.861	0.612	134.2	145.2	141.3	119.4
A	124	78.55	17.4	139.6	74.24	2.885	0.532	124	139.6	136.3	114.3
S	150.9	60.04	17.3	211.3	63.92	4.395	0.302	150.9	211.3	208.3	163.8
O	144.8	55.23	11.7	223.7	61.89	5.393	0.277	144.8	223.7	220.8	173.3
N	131.7	34.62	8.6	259.8	48.95	6.164	0.188	131.7	259.8	257.4	194.1
D	107.9	37.99	7.3	219.4	50.4	5.564	0.23	107.9	219.4	217	161.1
YEAR	**1628.4**	**753.03**	**12.26**	**2349**	**794.55**	**52.518**	**0.338**	**1628.4**	**2349**	**2312.1**	**1832.4**

Table: Optical factors

Month	Optical Factors					
	GlobHor	GlobInc	FTransp	FIAMBm	FIAMGl	FIAMShd
	kWh/m2	kWh/m2				
J	105.4	187.9	1.783	1.003	0.991	0.746
F	115.6	179.3	1.55	1.004	0.991	0.77
M	153.4	218.7	1.425	1.004	0.991	0.778
A	169.5	224.4	1.324	1.004	0.991	0.796
M	157.5	190.5	1.21	1.007	0.989	0.816
J	133.5	149.1	1.117	1.011	0.986	0.83
J	134.2	145.2	1.082	1.014	0.984	0.822
A	124	139.6	1.126	1.011	0.986	0.818
S	150.9	211.3	1.401	1.004	0.991	0.775
O	144.8	223.7	1.545	1.004	0.992	0.775
N	131.7	259.8	1.973	1.002	0.994	0.747
D	107.9	219.4	2.034	1.002	0.992	0.734
YEAR	**1628.4**	**2349**	**1.443**	**1.005**	**0.99**	**0.78**

Table: System losses

Month	Losses in the PV system						Losses in the pumping system				
	ModQual	MisLoss	OhmLoss	EArrMPP	EArUfix	EArray	EArrMPP	EPmpThr	E_PmpAv	ETkFull	E PmpOp
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
J	2.967	1.916	1.932	83.9	83.9	104.6	83.9	5.284	73.8	5.707	68.1
F	2.874	1.856	1.773	81.1	81.1	94.6	81.1	4.063	72.7	0.667	72.1
M	3.554	2.295	2.166	100.4	100.4	107.3	100.4	5.553	89.1	1.199	87.9
A	3.683	2.378	2.372	103.9	103.9	117	103.9	6.142	92.1	8.148	84
M	3.16	2.04	1.759	88.7	88.7	94.2	88.7	7.876	75.4	4.748	70.6
J	2.507	1.619	1.151	70.1	70.1	73.3	70.1	7.112	58	1.499	56.5
J	2.414	1.558	0.999	67.4	67.4	70.5	67.4	9.858	52.5	1.124	51.4
A	2.318	1.497	1.106	64.7	64.7	69.7	64.7	9.121	50.9	2.016	48.9
S	3.286	2.122	2.191	92.3	92.3	102	92.3	6.322	80.2	9.019	71.2
O	3.576	2.309	2.277	101	101	111	101	4.596	91.1	2.494	88.6
N	3.988	2.576	2.933	112.9	112.9	132.9	112.9	2.414	104.9	1.641	103.3
D	3.354	2.166	2.179	94.9	94.9	111.1	94.9	3.489	86.2	1.571	84.6
YEAR	**37.682**	**24.331**	**22.838**	**1061.5**	**1061.5**	**1188.1**	**1061.5**	**71.831**	**927**	**39.832**	**887.2**

Table: Other parameters

Month	Other					
	Pump ON	TkF OFF	H Loss	FlRate	WWFl	AdjDmd
	Hour	Hour	meterW	m□/h	m3/day	m3/day
J	181	14	2.87	0.648	0.293	3.800
F	191	1	2.847	0.663	0.024	4.544
M	223	3	3.088	0.701	0.068	5.711
A	218	17	2.992	0.675	0.383	5.044
M	209	12	2.253	0.563	0.218	4.213
J	197	4	1.492	0.438	0.058	2.323
J	194	4	1.199	0.377	0.049	2.959
A	166	6	1.664	0.45	0.087	2.570
S	183	20	3.046	0.687	0.458	4.020
O	219	6	3.209	0.73	0.141	5.905
N	232	4	3.922	0.814	0.109	5.869
D	216	3	3.137	0.687	0.066	5.374
YEAR	**2429**	**94**	**2.687**	**0.627**	**0.163**	**4.361**

H.3 SYSTEM LOSSES

The following briefly described the losses associated with the concept design.

H.3.1 Solar Irradiation Losses

1628 kWh/m^2.yr of solar insolation falls on a horizontal surface at Pamlatum village. Using a two-axis tracking frame to point the array perpendicularly at the sun throughout the day and seasons increases the effectiveness of collecting the solar irradiation by 41.9% throughout the year. Pamlatum is surrounded by the high mountain peaks of the Himalayas and approximately 19.0% of the available yearly solar insolation is lost to horizon shading. 1.0% of the radiation reaching the PV array is lost due to the incidence effect (IAM – incidence angle modifier) which accounts for losses due to irradiation reflections on the PV module glass surface.

H.3.2 PV Array Losses

The PV cells in the module after irradiation losses receive 1853 $kWh/m^2.yr$ of solar insolation, and with a collector area of $5m^2$ and a module efficiency of 13.7% at standard test conditions (STC), 1258 kWh/yr is converted in DC electrical energy at STC. Because PV modules rarely operate at STC and the efficiency of a PV module decreases with an increase in cell temperature and a decrease in the irradiance level, the output of the PV array is de-rated. 4.4% is lost due to irradiance levels and 4.2% is lost due to cell temperature effects. PV modules are never perfect due to slight variations during the manufacturing process. 3.3% is lost to PV array quality factors. 2.2% is lost to array mismatch losses which is related to the fact that the real modules in the array do not rigorously present the same *I/V* characteristics and therefore there is a loss associated with connecting a string of arrays. Ohmic wiring losses account for 2.1% and is caused by the contact resistance between electric cables connecting modules and also the resistance loss through the cable itself. It is likely that cabling losses will be higher than 2.1% due to the long cable lengths between PV arrays and power conditioning equipment. The effects of long cable lengths were not simulated.

H.3.3 MPPT & Controller Losses

The MPPT and controller unit requires a power input from the array above a certain power threshold and 0.9% is lost due to this. Once the input power is above the threshold, the MPPT and controller is in operation and 5.1% is lost through inefficiencies within the electrical equipment.

H.3.4 Motor & Pump Losses

The pump requires a power input above a certain threshold for it to start operating. This is because positive displacement pumps require high starting torques due to the binding of seals within the pump element. 7.2% is lost due to this factor. Finally 927 kWh/yr is supplied to the motor and pump. The group efficiency (combined motor and pump efficiency) is 48.5% which leaves 450 kWh/yr available for hydraulic energy which is then imparted onto the water entering the pump. The system efficiency is 4.86% which is calculated by dividing the hydraulic energy by the solar insolation collected by the PV array (450 kWh /1853kWh/m^2 x $5m^2$).

H.3.5 Hydraulic Circuit Losses

The nominated static head of the pumping system is 100m. There are friction losses due to the water flow through the pipe and fittings. Friction loss accounts for 2.6%. A total of $1582m^3$ is pumped throughout the year. When the settling tanks at the end of each pump stage reach capacity, excess water will flow from the outlet at the top of the tank. $59m^3$ is lost to excess water (wastewater flows). The nominated water demand for Pamlatum is $1591m^3/yr$. Therefore the water supplied and used effectively by the village members is $68m^3/yr$ less than the nominated water demand (1582-59-1591). This system will supply 95.7% of the nominated water demand for Pamlatum or 4.3% of the water throughout the year is missing.

I Materials Information & Calculations

I.1 Bricks, Cement, Sand & Granite Calculations

The following tables present the material calculations for the shallow well, intermittent settling tanks, village storage tank and tap stands.

Brick parameters

Item	Units	Value	Source
bare brick dimensions	l x w x h (mm)	230 x 110 x 76	Midland Brick www.midlandbrick.com.au
mortar thickness surrounding brick	mm	5	Assumption
brick dimensions with mortar	l x w x h (mm)	240 x 110 x 86	Calculation
bare brick face area (without mortar)	m^2/brick	0.01748	Calculation
brick face area with mortar	m^2/brick	0.02064	Calculation
area of mortar only	m^2/brick	0.00316	Calculation
volume of mortar only	m^3/brick	3.476×10^{-4}	Calculation

Brick and mortar quantity calculation

System Component	Height (m)	Radius (m)	Wall Area (m^2)	Qty. Bricks Required	Dimension Source	Assumptions
shallow well	5	0.75	23.6	1144	Section 6.1.1.2	Well height
intermittent settling tank 1 & 2	1 (x2)	0.6	7.5	364	Section 6.1.2.1	
village water supply settling tank	1.5	1	9.4	456	Section 6.1.2.2	
slow sand water filter	3	2	37.7	1827	Section 6.3.1	
village storage tank	1.6	2	20.1	974	Section 6.3.2	
			Total Bricks Required	**4765**		
			Cement mortar required for walls	**1.657 m^3**		

Makeup of concrete

Concrete Component	Parts	% of Concrete Makeup	Source
cement	1 part	16.7%	Section 6.1.1.4
sand	2 parts	33.3%	
small stones	3 parts	50.0%	

Concrete calculations

Concrete Slab Item	Radius (m)	Thickness (mm)	Concrete Volume (m^3)	Assumptions
shallow well cover	0.8	75	0.151	
intermittent settling tank 1 & 2	0.6	100 (x2)	0.226	slab thickness
village water supply settling tank	1.0	100	0.314	slab thickness
slow sand water filter	2.0	100	1.257	slab thickness
village storage tank	2.0	100	1.257	slab thickness
tap stand	0.5	100	0.079	slab thickness
		Total Volume of Concrete	**3.284**	slab thickness
		cement volume	0.530	
		river sand volume	1.056	
		small stones volume	1.586	

Note: It was discovered on the day that this paper was due for submission, that the concrete requirements for only one intermittent settling was calculated rather than two. In addition, only concrete requirements for one tap stand was calculated rather than seven.

Slow sand filter materials

slow sand water filter material	Volume (m^3)	Source
river sand	24	Section 6.3.1
small stones (granite chips)	4	

Total material requirements

Item	Units	Add 10% Safety Factor	Total
burned bricks	4765	477	5250
cement (including mortar for brick walls)	2.187 m^3	0.219	2.5
river sand	25.056 m^3	2.506	28
small stone (granite chips)	5.586 m^3	0.559	6.2

Number of concrete bags calculation

Cement Parameter	Value	Source
volume of concrete per 20kg bag	0.012 m^3	cement concrete & aggregates Australia www.concrete.net.au
required concrete volume	2.5 m^3	calculation
approximate number bags required	210	calculation

I.2 MATERIAL & EQUIPMENT ASSUMPTIONS & SOURCES

The following table present the information on the equipment and materials required for the design. The tables show the required number of material/equipment units, cost, weight, and the source of information or assumption for determining the values.

Number of material and equipment units required

Component	Units	Units Source
Grundfos Pump & Motor	3	Chapter 6
BP PV Module	12	Chapter 6
MPPT/Controller	3	Chapter 6
2-axis tracking frame	3	Chapter 6
20mm PE pipe	6	Table 6 + 177m for tap outlet system
Pipe fittings	50	Assumption
Valves	10	Assumption
Taps	7	Chapter 6
Armoured Cable	3	Assumption
Burned Bricks	5250	Calculation (above)
Washed River Sand	28	Calculation (above)
Gravel	6.2	Calculation (above)
Cement	210	Calculation (above)
Pump House	3	Chapter 6
PV Array Perimeter Fencing	1	Chapter 6
Installation Equipment and Tools	1	Assumption

Unit price

Component	Unit Price	Cost source
Grundfos Pump & Motor	$3,150	Grundfos (phonecall)
BP PV Module	$1,400	PV companies (phonecall) based on a typical 175W module
MPPT/Controller	$600	Renewable store www.renewablestore.com.au
2-axis tracking frame	$800	Assumption
20mm PE pipe	$100/100m	Dural Irrigation www.duralirrigation.com.au
Pipe fittings	$2	Assumption
Valves	$20	Dural Irrigation www.duralirrigation.com.au
Taps	$20	Assumption
Armoured Cable	$500/100	www.rs-components.com.au
Burned Bricks	$0.80	Assumption
Washed River Sand	$50/m3	Baulham Hills Landscape Supplies www.landscape-supplies.com.au
Gravel	$75/m3	Baulham Hills Landscape Supplies www.landscape-supplies.com.au
Cement	$6/bag	Rock Around The Block www.rockaroundblock.com.au
Pump House	$1,000	Assumption
PV Array Perimeter Fencing	$500	Assumption
Installation Equipment and Tools	$1,000	Assumption

Unit weight

Component	Unit Weight (kg)	Weight Source
Grundfos Pump & Motor	9.7	Appendix F.3 p. 80
BP PV Module	12.4	Appendix F.4 p. 84
MPPT/Controller	6	Renewable store www.renewablestore.com.au
2-axis tracking frame	30	Assumption
20mm PE pipe	15	Dural Irrigation www.duralirrigation.com.au
Pipe fittings	0.1	Assumption
Valves	1	Assumption
Taps	1	Assumption
Armoured Cable	20	Assumption
Burned Bricks	2.8	Midland Brick www.midlandbrick.com.au
Washed River Sand	1000	Assumption
Gravel	1000	Assumption
Cement	20	cement concrete & aggregates Australia www.concrete.net.au
Pump House	500	Assumption
PV Array Perimeter Fencing	500	Assumption
Installation Equipment and Tools	100	Assumption

J Solar Pump Quotes

The first quote is by Solar Pumping Solutions. The system is specified using two separate pump stations.

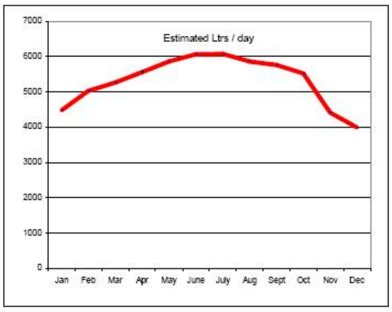
solarpumping SOLUTIONS

"Hillcrest" 7433 Castlereagh Hwy ILFORD via Mudgee
NSW 2850 Ph 0427 240294 Fax 02 63588612

Quotation No 1612
www.solarpumping.com.au

Client	Kris Robinson
Address	Devon Circuit Calwell
Town	Canberra
Lat - Long	30 n 42e
Phone	404209450
Fax	
Email	
Job	Stage one -river
Water Source	River
Bore Depth	na
SWL	na
Static Head	150m
Total Dynamic Hd	**150m**
Casing Size (mm)	na
Bore Condition	New
Water Quality	Good
Water Temperature	5c
Delivery Pipe	32mm
Delivery Distance	450m
Target	Tank
Target Size (Ltrs)	?
Max Daily Water Req.	4320 litres
Tank Full Switch	No
3 Core Sub Cable	6.0mm2
Cable Length (m)	150m
Bore Cap	No
Fittings to pipe	no
Stainless Safety	no

Est.Daily Flow Rates	Litres	Peak Sun Hours
Jan	4470	5.96
Feb	5033	6.71
Mar	5265	7.02
Apr	5558	7.41
May	5858	7.81
June	6060	8.08
July	6075	8.10
Aug	5858	7.81
Sept	5760	7.68
Oct	5528	7.37
Nov	4410	5.88
Dec	3990	5.32
Average	5322	7.10



Lorentz System Controller		PS1200
Wet End -Pump		HR03
System Watts @ 48 volts		420
SunPower 219 watt PV		2
Solar Array Frame Type		5 Star Tracker
Number of Frames		1
System Price	$	8,455.00
40mm PN10 drop-pipe		
Submersible Cabling	$	1,395.00
Safety Cable , Fittings , BC		
Tank Full Switch & cable	$	165.00
Low Level Probe & Cable	$	145.00
Dam Float		
Installation @ $45/hr		
Travel @ 60c / km		
Freight	$	110.00
Total Ex GST	**$**	**10,270.00**
GST	$	1,027.00
Total - inc GST	**$**	**11,297.00**

2 Year warranty plus 20 year panel warranty

Valid for 30 days - prices may change without notice and are specific to the clients supplied information & situation. Flow rates may vary depending on local conditions ie trees, hills, fog.

Please sign and date to accept this quotation and faxed to 0263588612

Name .... Sign.................... Date..................

www.solarpumping.com.au 10% Deposit required to confirm order - balance due prior to delivery. 7/22/2007

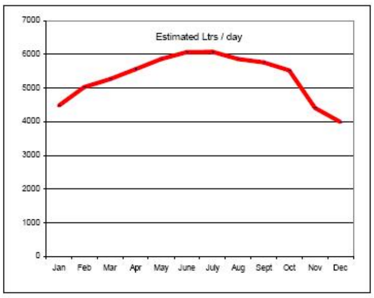
solarpumping SOLUTIONS

"Hillcrest" 7433 Castlereagh Hwy ILFORD via Mudgee
NSW 2850 Ph 0427 240294 Fax 02 63588612

Quotation No 1613
www.solarpumping.com.au

Client	Kris Robinson
Address	Devon Circuit Calwell
Town	Canberra
Lat - Long	30 n 42e
Phone	404209450
Fax	
Email	
Job	Stage Two -Tank
Water Source	River
Bore Depth	na
SWL	na
Static Head	150m
Total Dynamic Hd	**150m**
Casing Size (mm)	na
Bore Condition	New
Water Quality	Good
Water Temperature	5c
Delivery Pipe	32mm
Delivery Distance	450m
Target	Tank
Target Size (Ltrs)	?
Max Daily Water Req.	4320 litres
Tank Full Switch	No
3 Core Sub Cable	4.0mm2
Cable Length (m)	25m
Bore Cap	No
Fittings to pipe	no
Stainless Safety	no

Est.Daily Flow Rates	Litres	Peak Sun Hours
Jan	4470	5.96
Feb	5033	6.71
Mar	5265	7.02
Apr	5558	7.41
May	5858	7.81
June	6060	8.08
July	6075	8.10
Aug	5858	7.81
Sept	5760	7.68
Oct	5528	7.37
Nov	4410	5.88
Dec	3990	5.32
Average	5322	7.10



Lorentz System Controller		PS1200
Wet End -Pump		HR03
System Watts @ 48 volts		420
SunPower 219 watt PV		2
Solar Array Frame Type		5 Star Tracker
Number of Frames		1
System Price	$	8,455.00
40mm PN10 drop-pipe		
Submersible Cabling	$	172.00
Safety Cable , Fittings , BC		
Tank Full Switch & cable	$	165.00
Low Level Probe & Cable	$	145.00
Dam Float		
Installation @ $45/hr		
Travel @ 60c / km		
Freight	$	110.00
Total Ex GST	**$**	**9,047.00**
GST	$	904.70
Total - inc GST	**$**	**9,951.70**

2 Year warranty plus 20 year panel warranty

Valid for 30 days - prices may change without notice and are specific to the clients supplied information & situation. Flow rates may vary depending on local conditions ie trees, hills, fog.

Please sign and date to accept this quotation and faxed to 0263588612

Name .... Sign.................... Date..................

www.solarpumping.com.au 10% Deposit required to confirm order - balance due prior to delivery. 7/22/2007

The next quote is by B/W Solar who have provided a quote for one out of two pump stations. The final price is therefore double of what is presented.

B/W SOLAR
Established 1990

PO Box 59 | *Phone/Fax: (08) 9359 4048*
Forrestfield WA 6058 | *Mobile: 0417 931 316*
www.bwsolar.com.au | *sales@bwsolar.com.au*
Ingleton Family Trust, ABN: 90020468707. Sole Australian Importer for Lorentz sola-pumps.

Quote No:7082 | Date: 9/7/07

Water temp: 4-16C°
Static head = 0m
Friction loss = 0m

Kris Robinson
Ph:0404209450

Daily volume = 5000L.

TDH = 150m

Quote for a 720WT Maxi Pumping System

Qty.	Item	Price per Unit $			Retail ex.GST $
12	Uni-Solar panels @ 64W = **768W**	680			8160
2	5 Star Tracker F2 & LATR	1650			3300
2	2.25m Post, NB 80	150			300
10 m	Conduit & wires between the trackers	10			100
1	Contr.PS1200, RPM adj. CB & low-level sw.	1490			1490
50 m	Cable to low-level switch in bore	1.50			75
1	Plug (m&f) to pressure switch	30			30
1	Pre-Assembly & testing	675			675
1	Lorentz wet-end **HR- 03H-C°** (helical rotor)	990			990
1	Lorentz brush-less motor 96V / 1.2kW	1020			1020
1	Joining of cables for motor & low-level	40			40
50 m	Motor cable 4sqmm H07 RN-F	9.00			450
10 m	Poly - Rope 7mm	1			10
1	Float for river	250			250
1	Two level float valve 1 1/2 BSP	200			200
1	Pressure switch with gauge & cable	250			250
	Total cost before GST				17,340.00
	Plus 10% GST			total	19,074.00

Price held for 30 Days.
Conditions: 50% with order, balance before dispatch.
Packing, freight and installation are not included.

Quote accepted: ....
Warranties: 2 years on all parts
Solar Panels: 20 Years.

Equipment supplied by others

No warranty is granted for equipment supplied by others or for failures of pumping - systems caused by equipment supplied by others. (pressure switch, motor cable etc)

The final quote is by Solco as presented in the email sent to me below. Once again, the quote is for one out of two pump stations. The final price is double of what is presented.

Hi Kris,

Thanks for you email regarding the solar pump installation in Nepal.

From our conversation please find below a component supply to get you started.
This would meet your requirements, but without knowing the full scope of works it may not be the best suited system.

700watt Tenesol TSP1000 helical rotor solar water pump.
Delivers 14,000ltrs/per/day @ 70m Total Dynamic Head
Pump, motor, controller $4250
700watt array on fixed frame $6000
This doesn't include but is not not limited to, cables, mounting post, joining kits, low level water protection and freight.
You would need 4 of these systems.

Please send through the scope of works so we can best assist you with your quote.
if you require any further assistance please don't hesitate to call.

Kind Regards

Rohan McGlew

PolyTuff PTY LTD

A Solco Ltd Company

PO Box 37

Welshpool DC, WA 6986

Ph: 618 9334 8100

Fax: 618 9334 8199

Email: rmcglew@solco.com.au

<?xml:namespace prefix = u1 ns = "urn:schemas-microsoft-com:office:smarttags" />Website: www.solco.com.au

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