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Off-grid energy system for Wawashang, East Nicaragua: analysis of the energy potential and design of a micro hydropower installation

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Submission date: June 2013
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Abstract

The Wawashang Complex on the East Coast of Nicaragua is a typical example of remote rural area that can benefit from off-grid renewable energy solutions. In this Complex, the non-profit organization FADCANIC supports the development of the communities of the Caribbean Coast through an innovative agro-forestry program, a school, a carpentry workshop as well as a natural reserve. No power grid reaches the Complex, but many buildings are electrified by dislocated systems of photovoltaic modules and batteries with gasoline generators as backup.
FADCANIC is trying to exploit better the natural resources in order to provide power for more initiatives and make energy supply less expensive, more reliable and sustainable.
In February 2013 a trip to Wawashang was made to collect the necessary data.
Purpose of this thesis is to propose a micro hydropower installation in State Creek, the river flowing through the Complex. The hydropower potential was measured by inexpensive tools, i.e. a wooden folding ruler and a borrowed current meter. The Creek offers a site with a low head of 3 to $5m$ over a distance of $200m$ and a good water flow of 100-$200l/s$ at the beginning of the dry season. The power obtained could benefit either a farmer's house by the river, a coconut grinder or support the photovoltaic energy of the Complex, whenever solar irradiation is too low. A discussion will follow about the turbines to be used in such low head systems, in a power range between 0.2 and $3kW$. A $1kW$ turbine will be chosen for two alternative waterway preliminary designs, one of which using pipes and the other a wooden channel. Such solution appears satisfactory as it can deliver power to the coconut grinder during the day and electrify the farmer's house at night.
Moreover, this plan makes it possible to measure and analyze the Wawashang buildings power consumption. The measurement, taken by the use of clamping current meters, has shown a peak power demand of about $17kW$, due to the higher power requirement for the carpentry workshop. An analysis of the energy resources, also part of this work, reveals that, besides solar energy and low head micro hydropower generation in State Creek, biomasses could be an interesting option for power generation in the future. Particularly, coconut husks and shells, sugar cane, excrements and waste wood may be considered as an important resource for the production of energy within the Wawashang Complex.

Acknowledgements

So many are the people that helped me throughout this project and I would like to thank all of them, hoping not to miss anyone.

Firstly, I would like to thank Giovanna and Gianluigi, my parents, for giving me the opportunity to go on in my studies, supporting me in my difficult moments and sharing with me a lot of laughs as well. I want to thank them also for helping me actively in this project with their so wide knowledge and experience.

Then, I would like to thank the people, mainly coming from the academical environment, who helped this project with their knowledge.
My supervisor at NTNU, Dr. Eng. Marta Molinas, deserves all my gratitude for her time, wide knowledge, involvement and enthusiasm during the project. I will be always grateful to her also for giving me a big opportunity to challenge and enrich myself: submitting a paper to IEEE (*Institute of Electrical and Electronics Engineers*) and present my work at the conference IYCE 2013 (*International Youth Conference about Energy*) in June 2013.
I want to thank also Dr. Eng. Emanuela Colombo, my co-supervisor at Politecnico di Milano, my university in Italy, for giving me such good directions and material at the beginning of the project.
My deepest gratitude goes to Eng. Katie Brown from the *Renewable energy academy* in Germany, who I have never met and hope will meet one day, but directed the majority of the technical decisions in the design of the micro hydropower installation.
Dr. Eng. Knut Alfredsden and the PhD candidate Peter Joachim Gogstad from NTNU deserve my sincere thanks for their constant availability in helping me in analyzing the water flow data.

I would like to thank and send a big hug to all the people I met in Nicaragua, for helping me during the work and for the fun we had together.
Among all, Dr. Eng. Blunier Pascal, Mr Henry Meyers, Mrs Susanne Thienhaus and Mr Yoel from FADCANIC, for their hospitality and fundamental cooperation during the measurements. In addition, Gilles Charlier from BlueEnergy deserves special thanks for assisting in many technical and language issues.

I would like to thank Engineers Without Borders Norway (IUG) for organizing this Meaningful Master and having sponsored the trip to Wawashang, one of the most inspiring of my life.

All my gratitude goes also to my friends Inger Johanne Rasmussen and Linn Solheim, who came with me to Wawashang. Inger, member of IUG, for being always calm and spontaneously ready to help and for her innate organization skills. Linn, the student who worked with me on the project, for being such a funny friend, supporting me and keeping me focused on the goal of the project when I was getting distracted.

Special thanks go to my friends from Norway, Italy and all over the world that I have met during my studies and helped me with laughs or simply with their presence to overcome obstacles.

At last I want to thank Norway for these two wonderful years I have spent here, that have been fundamental in my growing process and allowed me to know many wonderful people.

Contents

List of Figures

List of Tables

Abbreviations

AC/DC	**A**lternate **C**urrent/**D**irect **C**urrent
AP	**A**nnual **P**recipitations
ET	**E**vapo **T**ranspiration
FADCANIC	**F**undación para la **A**utonomía y el **D**esarollo de la **C**osta **A**tlántica
FAO	**F**ood and **A**griculture **O**rganization
FDC	**F**low **D**uration **C**urve
GPS	**G**lobal **P**ositioning **S**ystem
GR	**G**roundwater **R**echarge
HDI	**H**uman **D**evelopment **I**ndex
ICT	**I**nformation and **C**ommunication **T**echnology
IEA	**I**nternational **E**nergy **A**gency
INETER	**I**nstituto **N**icaragüense de **E**studios **TER**ritoriales
IUG	**I**ngeniører **U**ten **G**rensen
MAGFOR	**M**inisterio **AG**ropecuario y **FOR**estal
MARENA	**M**inistero del **A**mbiente y Los **RE**cursos **NA**turales
NTNU	**N**orges **T**eknisk **N**aturvitenskapelige **U**niversitet
PV	**P**hoto**V**oltaic
PVC	**P**oly**V**inyl**C**hloride
RAAN	**R**egión **A**utónoma del **A**tlántico **N**orte
RAAS	**R**egión **A**utónoma del **A**tlántico **S**ur
SAIH	**S**tudentenes og **A**kademikernes **I**nternasjonale **H**jelpefond
SDR	**S**tandard **D**imension **R**atio
SF	**S**afety **F**actor
SR	**S**urface **R**unoff

UK	**U**nited **K**ingdom
US	**U**nited **S**tates
USB	**U**niversal **S**erial **B**us

Symbols

a	wave velocity	m/s
A	area	m^2
A^*	area	km^2
B	channel bed width	m
C	channel height	m
d	internal diameter	mm
D	nominal pipe diameter	mm
E	Young's modulus	N/m^2)
f	friction factor	-
F	freeboard allowance of channels	-
g	gravity constant	m/s^2
h	gauge height	m
H	hydraulic head	m
k	pipe roughness	mm
I	current	A
L	length	m
N	side slope of channels	-
n	Roughness of channels	-
p	perimeter	m
P	power	W (Js^{-1}), Hp
R	hydraulic radius	m
Q	water flow or discharge	m^3/s
s	pipe wall thickness	m

S	channel slope	-
t	time	s
T	channel top width	m
U	ultimate tensile strength	N/m^2
v	velocity	m/s
V	voltage	V
η	efficiency	-
ρ	density	kg/m^3
\$	dollar	-

Chapter 1

Introduction

The lack of an electrical network in remote areas and the prohibitively high cost of grid extension and rough topography often lead to the exploration of other options to satisfy the need of power. Stand- alone (or off-grid) energy systems have turned into one of the most promising ways to satisfy the electrification requirements of these areas. These energy systems usually exploit the natural resources at the location, such as water, wind, biomasses or solar irradiation. Due to the intermittent output of renewable energies, off-grid systems usually include an energy storage component and diesel/gasoline generators as backup.
Finding sustainable energy solutions for remote rural areas could be a step forward in the development of the local population by increasing economic opportunities and improving living conditions.
The Caribbean Coast of Nicaragua is a good example of an area whose development can be influenced by electricity production though off-grid renewable energy systems. Over 84% of the people in this area have no access to electricity; the remaining 16% rely on an inconsistent national grid or isolated diesel generators.

On the Caribbean Coast, in the Autonomous Regions, the FADCANIC foundation (*"Fundación para la Autonomía y el Desarrollo de la Costa Atlántica"*) supports the multi-ethnic communities in their efforts to attain sustainable, socially just and culturally diverse forms of development.

FADCANIC has established an innovative agro-forestry center in Wawashang on the Caribbean Coast of Nicaragua. The Wawashang Complex builds local capacity and knowledge and provides technical support to increase food security and economic activity by sustainable methods. It also runs a school, where valuable education programs of agro-forestry and carpentry are taught. High quality furniture for the communities of the area is regularly produced by the carpentry workshop of the Complex.
The Wawashang Complex is not reached by any power grid and the only energy supply, consisting of dislocated photovoltaic (PV) systems and gasoline generators as backup, is neither reliable nor sustainable, but expensive and limits education to daylight hours. Moreover, FADCANIC is planning to provide power to more buildings and initiatives, such as coconut and sugarcane processing, and allow the use of more appliances to the people of the Complex, which are steadily growing. The higher power demand, the need of higher efficiency and lower costs has led FADCANIC to study new sustainable and reliable energy solutions for the Complex. These solutions need to be adjusted to the cultural, social, economic, environmental and technical aspects of the Autonomous Regions of Nicaragua to make the project sustainable.
In this connection, FADCANIC has established a contact with Engineers Without Borders Norway, IUG (*"Ingeniører Uten Grensen"*), in order to reach the goal of sustainable energy supply for Wawashang. The group of IUG at NTNU (*Norwegian University of Science and Technology*) is contributing to it through "Meaningful Masters", with thesis projects like the one presented in this report. IUG has also sponsored the field trip to Wawashang in February 2013, that allowed the collection of the necessary data for the project.

The author of this thesis has worked on this Meaningful Master in cooperation with another student, Linn Solheim. Linn worked on her Master Thesis (*Scaling an optimized PV-cluster as part of a micro grid in Wawashang, Nicaragua*) at finding an optimal PV micro grid for the Wawashang Complex.

The total work of this project has been divided into three parts; the first being a project work in the fall of 2012, when the study was focused on understanding the context and finding a solution based on estimates. During the project stage, the objective was to evaluate the possibility of installing a hybrid PV and micro hydropower system to supply the amount of energy needed by the Complex. This system would have benefitted from the tropical climate at the location, characterized by a dry season and a rainy season.

However, the second step of the project, the field trip to Wawashang in February 2013, revealed that the hydropower potential was lower than expected, since the area around the Complex is quite flat. Therefore, hydropower cannot play an important role in fulfilling the power demands of the Complex. In addition, the field trip allowed to harvest the natural resources at the location, measure power consumption and potential for a possible micro hydropower generation in State Creek, the small river flowing through the Complex. Solutions for this micro hydropower installation have become the core of this thesis.

The third part of the work consists of this thesis, in which the data collected during the field trip have been processed and a research on possible solutions has been carried out.

Chapter 2

Background

The background Chapter starts with an overview about Nicaragua, followed by a description of the Caribbean Coast, where the Wawashang Complex is located. FADCANIC, the organization that built the Wawashang Complex, and BlueEnergy, installing energy systems on the Atlantic Coast, are also presented.
At last, a background about micro hydropower is given, being the focus of this thesis.

2.1 Nicaragua

Nicaragua is the largest republic of Central America, touched by the Pacific Ocean and the Caribbean Sea. The climate is typically tropical, with a dry season and a rainy one and an almost constant high temperature over the year.
Many natural disasters contrasted the growth and the development of Nicaragua: earthquakes, volcanic eruptions, cyclonic storms and floods.

The historical profile is fundamental to understand the present country situation: the Spanish invasion in the 17th century, the British pirates in the 18th, the American control between the 19th and the 20th and the civil war during the 70s and the 80s caused many socio-economic damages to the country.

At the present moment, the president of the republic is Daniel Ortega, reconfirmed in 2011; even though his election has been accused of many irregularities, he is working for the development of the country on many levels, fighting against poverty.

Nicaragua has a population of around $6millions$, whose 90% is located on the Pacific Coast. The HDI (Human Development Index) is 0.589, lower than the world average (0.682).
Among the most negative social aspects of the country there are underemployment, poverty, high infant mortality and low access to drinking water.
Moreover, the development of the roads is quite low, especially in the Caribbean areas. A substantial change in such a poor transport network would be represented by the possibility of construction of a channel crossing the country, currently under government evaluation.
On the other hand, the life expectance is quite high (over 70 years), the education level is good and the ICT (Information and Communication Technology) market is growing.
The main activities are agriculture and breeding, and exports are progressively increasing.
Industries are almost absent with exception of several manufacturing ones [1].

2.2 The Autonomous Regions of the Atlantic Coast

The present situation of the Caribbean Coast of Nicaragua (historically known as the Atlantic Coast) is caused by the events of the last two centuries.
Between 1650 and 1860, the Caribbean Coast of Nicaragua was subjected to different forms of foreign control, the main being the British Protectorate which lasted up to the mid 19th century. This fact conditioned the process of integration of the Atlantic Coast to the rest of the country which began only late, in the last decade of the 20th century.

The juridical status of autonomy, enjoyed by the inhabitants of the Atlantic Coast, is the culmination of a long quest for peace, national unity and reconciliation among coastal families and communities.

Thanks to the autonomy, an intense period marked by armed conflict, political confrontation, and historical differences came to an end.

The Autonomous Regions of Nicaragua, the North Atlantic Autonomous Region (RAAN) and the South Atlantic Autonomous Region (RAAS), were created in 1987 and elected their first regional governments in 1990. The location of RAAN and RAAS is shown in fig. 2.1.

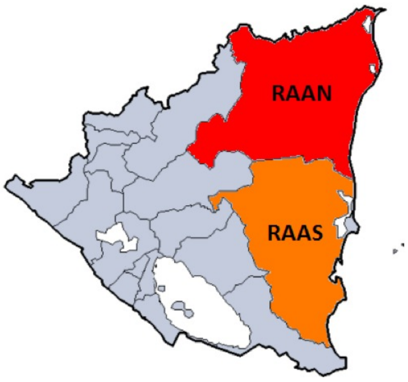


FIGURE 2.1: Location of RAAN and RAAS [1]

The Statute of Autonomy notwithstanding, the territory of the Atlantic Coast remains markedly isolated in regards to the rest of the country, due to a historical lag evidenced today in limited social and productive investments, scant transports and communications infrastructure, poor articulation of the regional productive structure, citizen insecurity, low coverage of basic services, and a still fragile institutional framework.

The original population of the Autonomous Regions is constituted by indigenous peoples and ethnic communities with multilingual characteristics (Miskitus, Kriols, Mayangnas, Ramas, and Garifunas), located in territories with a strong sense of ownership of their communal lands on the coastal and forest areas of high ecologic and environmental vulnerability.

The VII National Population Census (1995) indicates that both Autonomous Regions constitute the second most populated territorial area of Nicaragua, with

10.7% of the total population of the country, second only to Managua (25%) and followed by Matagalpa (8.81%). However, the population of the Autonomous Regions can be considered quite low since their territory occupies approximately half of the country.
The Atlantic Coast registers the highest rate of migrant population growth in Nicaragua and this is attributed to a net increase of Mestizo families that systematically settle in the agricultural frontier zones.
One third (33.3%) of the total population of the Atlantic Coast is established in urban communities and the other two thirds (66.7%) in rural zones.

The rate of illiteracy among the individuals of 10 years or older is 43%. Illiteracy is more widespread in the rural areas, where its percentage rises to 55%, with an even higher rate among the female population. The rate of illiteracy for the whole country is 24.5%. Meanwhile, 73.6 to 75% of the population of the Nicaraguan Caribbean Coast lives in situations of poverty and extreme poverty. The employed workforce earns very low wages that merely cover half of the cost of the basic consumer basket. As much as 80% of an average salary on the Coast is destined to the purchase of food items.

In September 1987, the National Assembly of Nicaragua enacted Law 28, the Autonomy Statute for the Atlantic Coast of Nicaragua. The Statute claimed historical demands of the indigenous peoples and ethnic communities of the Coast for inclusion and a more effective participation in political, social and economic decision-making (including decisions on the management and exploitation of the natural and environmental resources of the region); furthermore, it calls for the respect and promotion of their own historical and cultural traditions [2].

2.3 The foundation FADCANIC

FADCANIC is a non-partisan, non-governmental and non-profit civil society organization based in the Autonomous Regions of Nicaragua that works for improving the quality of life of the peoples of the Caribbean Coast and for development with equity and social justice.

It was established in 1990 and is working mainly on education, environment and natural resources, with the objective of strengthening the autonomy process of the Autonomous Regions of the Atlantic Coast.

The main offices of FADCANIC are in Bluefields in the RAAS and the president of the association is Mr. Ray Hookers.

Two important projects of FADCANIC on the Atlantic Coast of Nicaragua are the "Youth at Risk" and the "Wawashang Sustainable Agricultural Research and Education Center". The former consists of the emancipation of all the young people that are likely to have a troublesome life due to a dangerous familiar background. The emancipation process is carried out by providing the kids with skills and self esteem as basis for an active and positive life. The latter is the Wawashang Complex studied in this thesis and it will be presented in Chapter 3.

FADCANIC is supported by many different partners, among them the Norwegian Government, SAIH (*Norwegian Students' and Academics' International Assistance Fund*), USAID and the Swiss association Cédric Martin.

2.4 The organization BlueEnergy

BlueEnergy is a non-governmental organization that brings together divers teams, technologies and resources to create opportunities in some of the most challenging contexts of Nicaragua.

Their offices are located in Bluefields. The BlueEnergy group has been working actively in Nicaragua, especially on the Caribbean Coast, providing clean water and energy.

They are cooperating with FADCANIC in many communities. Particularly, they installed a micro grid of PV and diesel generators in the buildings of the Kahka Creek natural reserve (the natural reserve is presented in Chapter 3).

For the sake of this project, some members of the BlueEnergy organization have been essential, since they helped in understanding the present electricity system, in the installation of the current meters and in communicating in Spanish with the locals.

2.5 Energy generation through micro hydropower

Electricity production from hydropower represented, and still represents, the first renewable source used to generate electricity.
The objective of a hydropower scheme is to convert the potential energy of a mass of water, flowing in a stream with a certain fall (the "gross head") to the turbine, into electric energy at the lower end of the scheme, where the powerhouse is located.
Many people think that hydropower is only involving big dams and large-scale generating facilities. Small, mini and micro scale hydropower systems, however, are receiving a great deal of public interest as a promising, renewable source of electrical power for houses, parks and remote communities.
A micro hydropower system is generally classified as having a generating capacity lower than $100kW$.
Micro hydropower systems are appropriate in most cases for individual users or groups of users willing to be independent of the electricity supply grid. These are known as "stand alone systems" or "off-grid systems" and are chosen in absence of electrical service or if the connection to the existing electrical grid is too expensive, as in the case of the Wawashang area. They are commonly operating "run of river" meaning that there is neither a large dam nor a reservoir and therefore power is produced only if water is available [3].

Fig. 2.2 shows a typical layout of a "run of river" micro hydropower scheme.

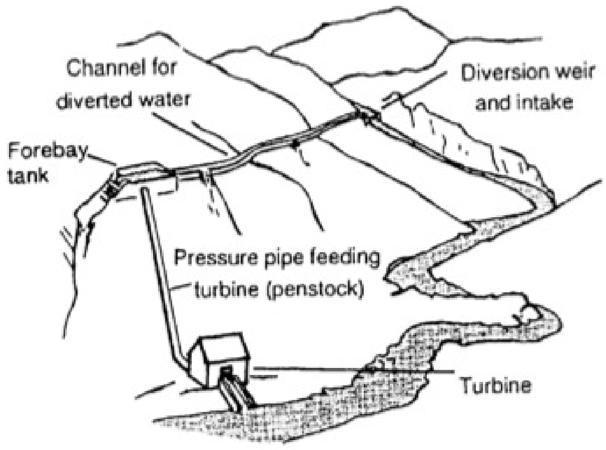


FIGURE 2.2: "Run of river" micro hydropower scheme [4]

A weir diverts part of the river flow to a waterway (channel and/or pipe), leading then to a turbine. A diversion weir causes minimal environmental impact and is simpler and less expensive than a dam. However, it does not allow water storage. Sediments settle out before the pipe entrance in the forebay tank.

The hydropower potential is a combination between head and water flow, according to equation 2.1, that gives the maximum power output P_{max}.

$$P_{max} = \rho \cdot g \cdot Q \cdot H \cdot \eta \tag{2.1}$$

Where ρ is the density of water $(1,000 kg/m^3)$, g is the gravity constant $(9.81 m/s^2)$, Q is the water flow or discharge (m^3/s) and η is the combined hydraulic, electric and mechanic efficiency of the turbine. The head H in eq. 2.1 is the net head meaning that all the losses between the forebay and the inlet section to the turbine must be subtracted from the head in m available in nature (gross head).

2.5.1 Watersheds

The concept of watershed has been relevant for this work because it gave a tool for making an estimate regarding the flow rate (essential for estimating the potential) of the rivers around the Wawashang Complex.

A basin, better known as “drainage basin”, “river basin” or “watershed”, is an extent or an area of land where surface water from rain and melting snow or ice converges to a single point. This point is the exit of the basin, where the waters join another waterbody, such as a river, lake, reservoir, estuary, wetland, sea or ocean.

The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channelling it to a single point.

Each drainage basin is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain and can be constituted by different sub-basins [5].

Nicaragua can be divided in 21 basins or “Cuencas”, as they are known by Nicaraguan people, as shown in fig. 2.3. All the water falling to the ground

FIGURE 2.3: Drainage basins of Nicaragua [6]

from annual precipitations (AP) mainly splits into three different contributions:

evapotranspiration (ET), groundwater recharge (GR) and surface runoff (SR). This yields the hydrological balance in equation 2.2:

$$AP\left[\frac{mm}{year}\right] = SR + GR + ET \tag{2.2}$$

SR includes all the water that flows over the land surface when the soil is already at its full capacity. It can be considered the fraction responsible of the discharge of the rivers and therefore the attention is focused on it.

The relation between total precipitations and SR is often complex and changes throughout the year.

The SR of a watershed could be available as average or its variation during the year provided, allowing respectively the estimation of the average discharge or of its variation during the year. Then, the SR values can be used for the estimate of the total water flow at the sea outlet of all the rivers belonging to a watershed. The calculation is as follows:

$$Q_{watershed}(m^3/s) = \frac{SR\left[\frac{mm}{year}\right] \cdot A_{watershed}}{365 \cdot 24 \cdot 3.6} \tag{2.3}$$

Where $A_{watershed}$ is the drainage area in km^2 of the watershed.

$Q_{watershed}$ can then be used to calculate the flow of each river at the desired location, that is usually where the intake of the pipes leaving the weir is located. This is done by the use of the drainage area ratio, as shown in eq. 2.4. This calculation is made on the assumption that precipitations and SR are uniform in the whole watershed.

$$Q(m^3/s) = Q_{watershed} \cdot \frac{A^*}{A_{watershed}} \tag{2.4}$$

Where A^* is the drainage area in km^2 at the intake.

The equation as 2.4 can also be used to find the water flow of the river 2 if the one of river 1 is known. This is done assuming that the two rivers have similar hydrology, geology and watershed characteristics. Then, eq. 2.4 becomes:

$$Q_2(m^3/s) = Q_1 \cdot \frac{A_2}{A_1} \tag{2.5}$$

Where A_1 and A_2 are the drainage areas at the chosen intake on the river 1 and 2 respectively.

2.5.2 Residual flow

Uncontrolled deviation of water from a stream, even if for a short track, usually has heavy consequences on the environment. The by-pass course from the intake until the power house could lead to sections of the watercourse being left almost dry with serious impacts on aquatic life.
To avoid this happening, permission or license to divert water from a river or stream will almost always specify that a certain residual flow should remain. This amount of water must be the minimum flow kept on the natural bed of the stream, in every period of the year.
Most countries with environmental policy have a rule about the residual flow. If a rule is not available, some residual flow should be left in the river anyway.

In absence of a national policy, the residual flow could be determinated as follows, according to other works and discussions with experts:

- 10% of the mean annual water flow, according to [1].
- The flow available 95% of the year was suggested by a mechanical engineer working for the *Renewable energy academy*[1] (Mrs Katie Brown).
- A percentage between 10 and 15% of the minimum annual flow is common practice in Nicaragua, according to a member of PCH (Mr Elias Juarez Moya)[2].

[1] http://www.renac.de
[2] *Pequeñas Centrales Hydroeléctricas*, small company working on small hydropower in Nicaragua

Chapter 3

The Wawashang Complex

3.1 Location

The Agroforestal Complex of Wawashang is located in the Wawashang Natural Reserve, municipality of Pearl Lagoon in the RAAS, as shown in fig. 3.1.

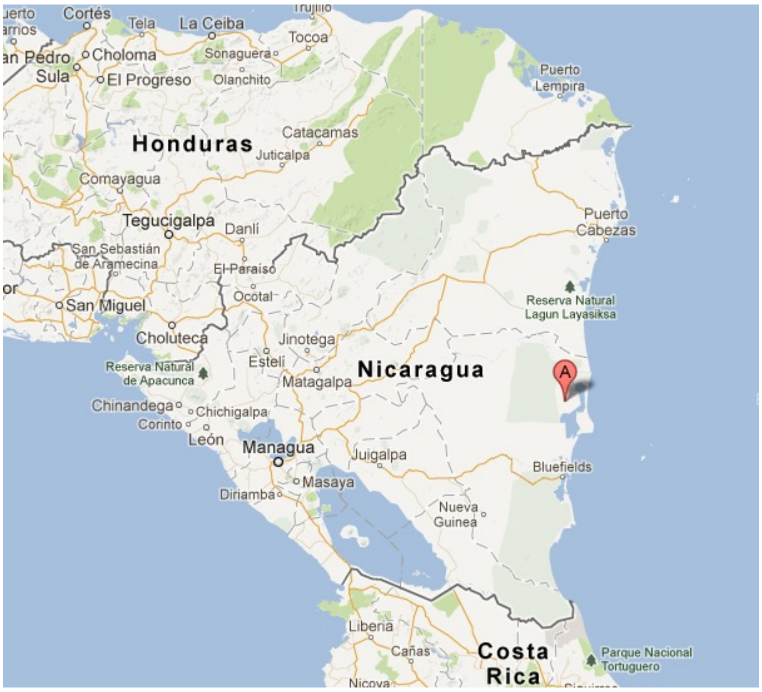


FIGURE 3.1: Location of Wawashang
N: 12.648378° W:−83.750153°

The Complex is on Rio Wawashang, the main river of the area. It is surrounded by a deep forest and boats are the only mean of transport to the neighboring villages. State Creek, a small tributary of Rio Wawashang, flows through the FADCANIC property.

Pueblo Nuevo is the closest village to the Complex, ten minutes far by boat.

Pearl Lagoon is the biggest inhabited center close to Wawashang, while the closest town is Bluefields.

Pearl Lagoon is reached by the road from Managua (Managua-Rama and then Rama-Pearl Lagoon), while Bluefields can be reached in two ways from Managua: directly by plane or by road to Rama and then to Bluefields by boat. Whatever the way Bluefields or Pearl Lagoon are reached, a boat needs to be taken to Wawashang. There are public boats leaving four times per week.

3.2 Climate

The Wawashang Complex is characterized by the typical tropical climate: high humidity and precipitations throughout the whole year.

The temperatures are more or less constant and oscillating between $25°C$ and $26°C$ [7]. Due to these high temperatures there is no need of producing heat in the buildings of the Complex.

Precipitation and temperature data are available both from the Worldbank website (average between 1990 and 2009) [8] and the FAO database (no info about the period when these data where collected) [9]. The FAO database gives even daily precipitation and temperature values. It is accessible through a free software that can be downloaded from [9]. Since there is no weather station in Wawashang, the data given by these two sources were most likely obtained by interpolation. The data show the same pattern, even though the values are different, as shown in fig. 3.2 and 3.3.

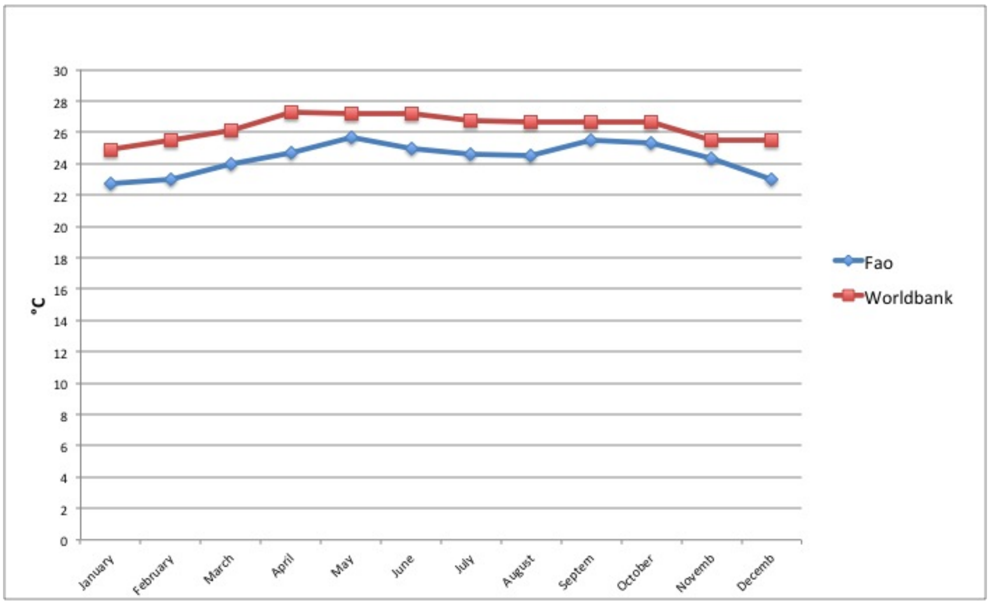


FIGURE 3.2: Temperatures in Wawashang [8],[9]

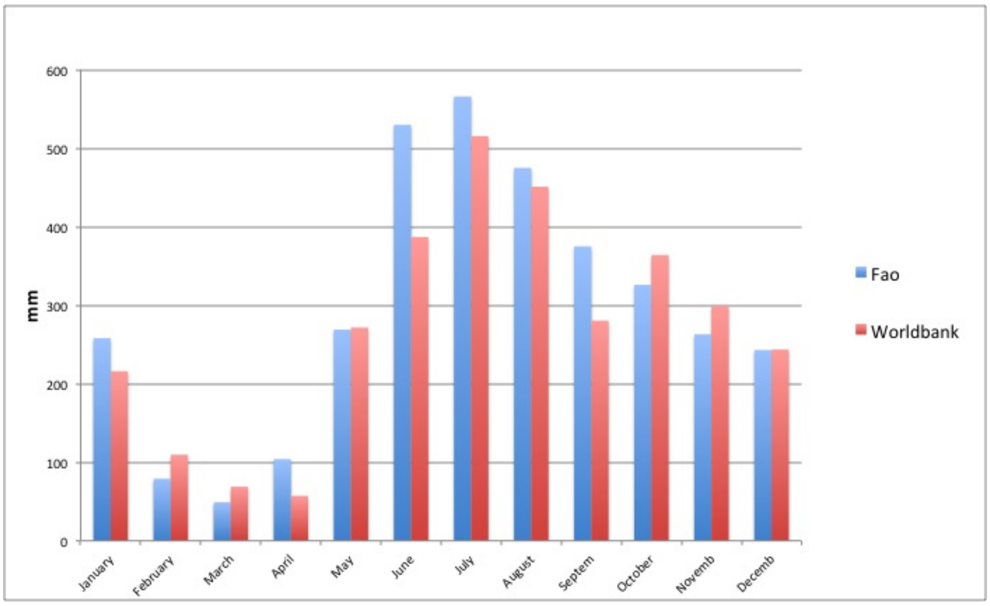


FIGURE 3.3: Precipitations in Wawashang [8],[9]

Hurricanes are another characteristic phenomenon of the climate around Wawashang. They occur more or less once every 5 years, between October and November. The most famous ones are the hurricane Joan and the hurricane Niño. These caused deforestation, together with the expansion of areas used for cattle.

The risk of hurricanes must be considered for the design of any energy system, due to their destructive power.

3.3 Layout of the Complex and population

The map of the Wawashang Agroforestal Complex is shown in fig. 3.4.

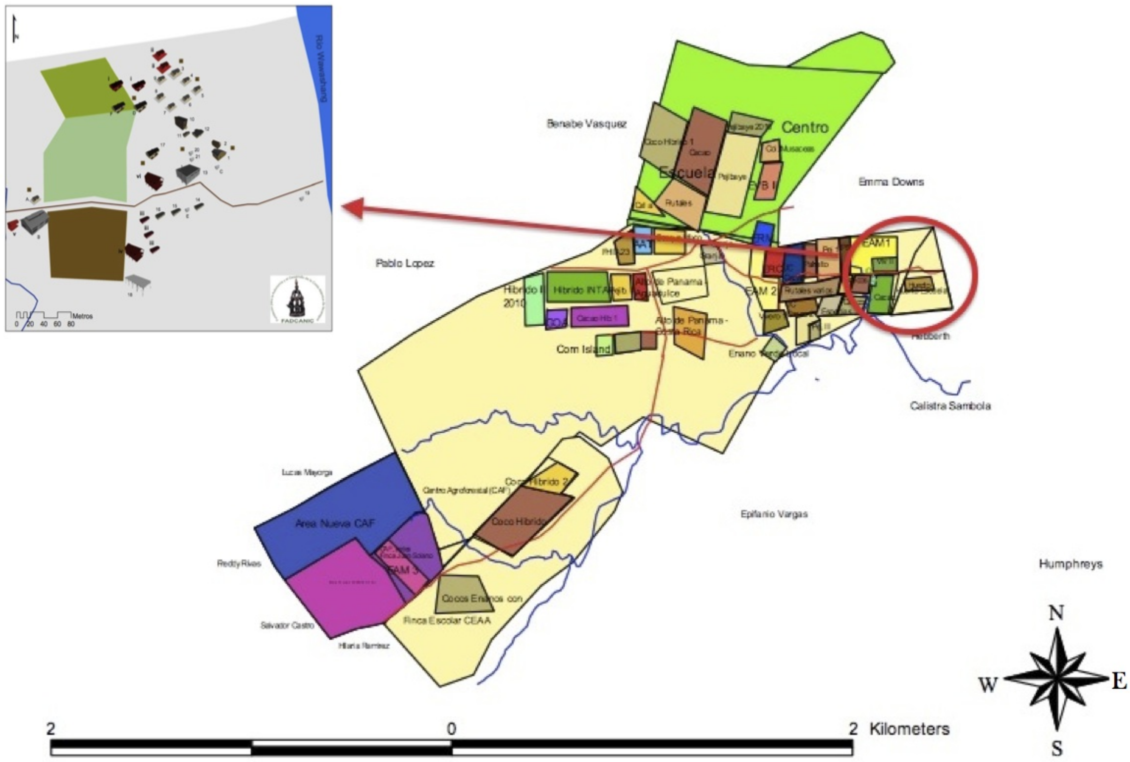


FIGURE 3.4: The Wawashang Agroforestal Complex [10]

The colored area represents the crops and the land under the property of FADCANIC, while the neighboring properties are white and with the name of the different owners (Epifanio Vargas, Calistra Sambola, Pablo Lopez, etc).
State Creek, tributary of Rio Wawashang, flows through the FADCANIC property.
The area were the buildings of the Complex are located is surrounded by a red circle and the layout is shown in a zoomed picture on the left.

Table 3.1 gives an overview of the people living and working in the Complex. In addition, it provides an overview of the possible future population.

Description	Number in 2012	Number in 2032
Students	96	234
Professors	10	21
Carpenters	5	5
Technical team of the Innovation Program	5	8
Guests	max 20	max 60
Total	136	328

Table 3.1: People in the Wawahang Complex [11]

3.4 The activities

FADCANIC is working on two different projects in the Wawashang Complex. The former is the Agricultural Center Innovation Program, whose responsible is Mrs Susanne Thienhaus, while the latter is the school, directed by Mr Winston Cash. In addition, the natural reserve of Kahka Creek can be considered part of the program.

Overall, the focuses of FADCANIC in the Wawashang Complex are: high quality seed production, genetic collection, conservation and scientific research, creation of a space for self-realization for women, involvement of local producers, accommodation for groups, education and manufacturing of wood products.

The field trip of February 2013 revealed that FADCANIC members are skilled and motivated people, making Wawashang the best place for spreading knowledge and encouraging development in many fields, energy technologies included.

3.4.1 The Agricultural Center

The Agricultural Center is composed of around $260Ha$ $(10,000m^2)$ of native trees and agricultural crops.

The main objectives of the Center are the conservation and multiplication of the genetic diversity of appropriate plants and crops for the area; among all: coconut, sugarcane, heart of the palm, breadfruit, ginger, turmeric, lemon and vegetables.

The knowledge is then transmitted by FADCANIC to the various farmers of the region, in order to achieve an agricultural sustainable development of the Caribbean Coast.
Moreover, the Center has a nursery with pigs, chickens and African goats.

A facility is also part of the Center, where coconut, cacao, ginger, heart of palm and turmeric are processed in order to obtain coconut oil, sweets made with coconut, chocolate and palmito.
The stoves of the processing facility are powered with gas coming from Rama, because the air inside the processing facility needs to be kept as clean as possible. Even though the quality of the products is high, the production is quite low, because most of the work is manual.
Grinding coconuts (for production of coconut oil and sweets with coco) is the activity that could benefit the most from an automatic system, powered by a machine. At the moment, coconuts are ground manually, as shown in fig. 3.5.

FIGURE 3.5: Manual coconut grinder in Wawashang

Nearby the processing facility, two dryers are located. One works simply by exposing the products to the sun and can be covered by a roof in case of rain. The other one is a solar dryer, which is also equipped with a fan driven by the batteries of the PV system of the lab or of the main offices. Both of them have the drawback of being used only during the dry season.

The solar drier has the advantage of providing better protection of food against animals, dust and moist. The two driers are shown in fig. 3.6.

FIGURE 3.6: Dryers in Wawashang
Left: solar dryer
Right: simple dryer with roof

A building that will host some drying ovens has just been constructed. The ovens are fueled by coconut husks and shells.

3.4.2 The school

The secondary school of the Complex has the objective of combining both theoretical and practical knowledge.

The students can choose between a school of agroforestry or carpentry.

Students come from all over the region, very often from small and remote communities, and belong to the different ethnic groups of the Atlantic Coast.

The subdivision in different ethnic groups of the Wawashang students is shown in fig. 3.7.

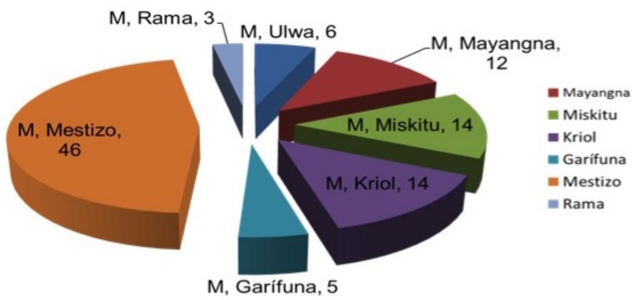


FIGURE 3.7: Ethnic groups of the Wawashang students (2012)

The main ethnic groups are Misquitu, Mestizo and Kriol. Misquitu people speak their own language and come from the mixture between Spanish people and the local Indians. Mestizos speak Spanish and they can be considered a mixture between Spanish people and Indians from the pacific side. Kriols, inhabitants of the Caribbean Coast, are English speakers.

The school program is fairly intensive, with activities from Monday to Saturday. Sunday is the free day of the week, when the students take care of their personal duties. From Monday to Friday the students wake up at 6 am, starting with one hour of practical work. Classes start at 8 am, after the breakfast (between 7 and 7:30 am) and continue up to lunch at 12 am. In the afternoon the activities continue mainly with practical work until dinner at 5 pm.

Students spend almost the whole year in Wawashang. They leave it only from December to January (Christmas time), at the end of March (Easter time) and between June and July (summer holiday).

The school has its own agricultural production, whose responsible is Mrs Indiana Gonzales. Its main products are sugar cane and coconuts.

Due to the absence of an automatic machine, sugar canes are not processed for obtaining the juice (guarapo). Sometimes the processing work is done manually by workers and students. Therefore, at the moment, only a small quantity of bagasse[1] is produced.

Fig. 3.8 shows a manual process of sugar cane processing in Wawashang.

FIGURE 3.8: Manual sugar cane processing in Wawashang

The carpentry of the Wawashang Complex can be considered part of the school. Besides the instruction role, it is also producing high quality furniture.

The wood used comes from trees destroyed by the hurricane allowing a sustainable consumption. The wood is dried outside the carpentry before the use. A system for accelerating this process might be useful, due to the high humidity at the location.

According to some members of FADCANIC, the carpentry of the Wawashang Complex, located in the middle of the forest, has a higher production than any other similar workshop of the area, thanks to its skilled and hardworking employers.

Don Roberto and Don Alvaro are the coordinators of the carpentry. Don Roberto said that the production is lower than the actual request, due to the lack of power and space.

[1]Fibrous matter that remains after sugarcane stalks are crushed and that can be used as biofuel

3.4.3 The Kahka Creek natural reserve

The natural reserve of Kahka Creek is the third project of FADCANIC in the Wawashang area. It is located on the other side of Rio Wawashang, next to the neighboring village Pueblo Nuevo.

It is named after the river Kahka Creek and is around $600Ha$ $(6,000,000m^2)$ wide. It is meant to protect the rainforest and the creatures that live in it. Moreover, FADCANIC members are working on the reforestation of the area, after the hurricanes and the expansion of cattle.

In the natural reserve, tourists and scientists walk through paths, having numerous observation points outfitted with informational placards describing flora and fauna.

Besides the forest, the reserve has also a guest house, a small classroom (seldom used), a carpentry workshop and the house of the ranger of the forest (Don Tito). Moreover, a kitchen is being built.

Chapter 4

Energy consumption and present energy supply

4.1 Preliminary considerations

The knowledge of the energy consumption of the Wawashang Complex is the first step before starting the design of a more efficient energy system.
Knowing the demand means consequently what form of energy is needed (mechanical power, heat and/or electricity), where and how much is needed. This info will influence the size of the energy and storage system, the design of the transmission line and whether mechanical power is directly used or converted to electricity.
In addition, a forecast of the future power demand should be made, since the system should last several years.

Electricity is the primary energy form needed in the buildings of the Wawashang Complex and therefore it was directly measured.
Due to the high temperatures, no room or tap water heating is needed.
Heating is needed for drying purposes: first, the wood of the carpentry needs to be dried before usage (it is currently slowly dried under sunlight); second, some food products (banana, curcuma, etc.) have to be dried as part of the processing.

At the moment, solar driers and ovens burning coconuts are used.
Mechanical power could be used directly for processing coconuts and sugar cane.

4.2 Measurements of electricity consumption

This Chapter will be focused on the assessment of the present and future electricity demand of the Complex.
The present electricity demand was directly measured by installing current meters in each building for 8-12 days (the measurement started in different days for each building).
The diagrams showing the electricity demand are called “load profiles”, presenting time on the x-axis and the power (kW) on the y-axis.
Finding a total representative load profile for the whole Complex for the week and the weekend was the objective.
The method for the elaboration of the data is explained in this Chapter and the results of the electricity demand measurements of each building of the Complex analyzed separately, according to the function of each building.
A total electricity consumption of the Complex was also calculated as demand of a future micro grid. This total demand was then scaled up in order to forecast the future requirements, after a discussion with the responsible of “monitoring&evaluation” in FADCANIC (Mr Henry Meyers).

A direct measurement of the electricity demand as such is not always feasible and therefore two possible estimate methods are commonly used.
The first one consists in adopting and adjusting the known load profile of a building or village with expected similar needs. The second one consists in making an assessment of all the appliances used, their rated power and time of usage. The latter approach was used to estimate the demand of the Wawashang Complex by BlueEnergy members; this estimate will be compared with the real data harvested in this Chapter.

Together with the electricity demand, the present energy supply is also described for each building in this Chapter.

4.3 The OWL current meter

OWL+USB sold by the OWL company was used to measure the electricity consumption of the buildings of the Wawashang Complex. The OWL company (UK) was discovered in the paper "A review of Smart Metering" by Robert Johnson. This meter was chosen because of its simplicity and low cost.

The current meter kit is available both in single phase and three phase version. It is composed by a sensor (three sensors in case of three phase kit), a transmitter, a monitor and a USB cable.
The sensor has to be clamped to the phase and connected to the transmitter, sending data to the monitor. The monitor, able to store data for 30 days, can then send data to a computer through the USB cable.
Data are stored on a minute basis, but the hourly value can also be displayed. The system frequency and voltage (V) need to be set in the monitor. In Nicaragua, these are $60Hz$ and $120V$ respectively. In case of three phase systems, the line-to-neutral voltage is required by the monitor[1].

The sensor measures the current (I) flowing in the cable, that has to be AC current. Then the monitor "times" the current, meaning that the product $I \cdot time$ is calculated.
The "timing" occurs whenever the transmitter sends data to the monitor, that can be in a range between 12 and $60s$. If no value after $60s$ is transmitted, zero is stored in the memory for that minute.

[1] $V_{line\ to\ line} = \sqrt{3} \cdot V_{line\ to\ neutral}$

The energy consumption of each minute displayed in the downloaded data is then calculated, for single phase systems, through:

$$P_i\left(\frac{Wh}{min}\right) = V \cdot I \cdot time \tag{4.1}$$

or, in case of three phase systems:

$$P_i\left(\frac{Wh}{min}\right) = 3 \cdot V \cdot I \cdot time \tag{4.2}$$

No power factor ($cos\phi$) is considered by the monitor in the calculation. All the data were therefore corrected by multiplying times 0.95, assuming that lighting and chargers are the main appliances used. The correction is not needed in three phase systems.

The hourly value displayed in the downloaded data is found by the monitor by summing all the minute records.

Fig. 4.1 shows an installed current meter in Wawashang.

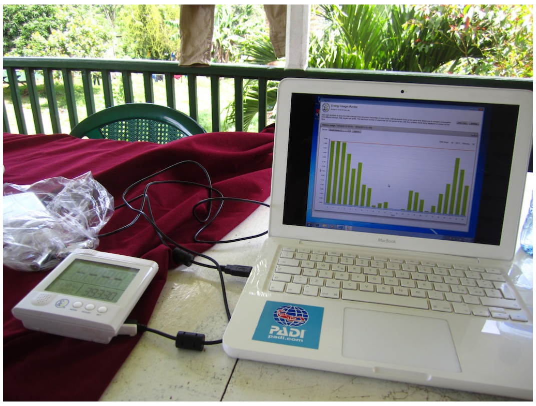


Figure 4.1: OWL+USB current meter
Left: installed clumped meter with clamping sensor and transmitter
Right: monitor plugged to a laptop and downloading data

The installation of the current meters has presented some difficulties. First, the electric system of each building is not well rationalized in Wawashang, hindering the research of the measurement point. Second, phase and neutral are insulated

together.
Therefore, cutting the insulation was needed in order to clamp the sensor only on the phase.

4.4 Elaboration of the data

4.4.1 Averaging and maximization: two different approaches for data reading

The monitor is storing data on a minute basis. Using these data properly to find an hourly load profile has been the main issue of this part of the project.
Two are the possible approaches. The first one consists in using the average of the sixty minutes as hourly power consumption. In this way the system will supply all the required energy, but it will not be able to cover the peaks of power. The second one uses the minute with maximum consumption as representative for an hour. This second approach allows the system to cover the power peaks, but the system will produce more energy than needed.
The second one is the approach chosen for data elaboration in this project allowing to make a design based on conservative assumptions.

4.4.2 Averaging: the approach of the OWL monitor

As already mentioned, the hourly value of power is calculated by the monitor by summing all the minute values. This results in the amount of Wh consumed in one hour, that is also the average power required in one hour.
Therefore, the monitor follows the first approach.
The following equation clarifies why the sum of the Wh of each minute is equal to

the average power required in one hour.

$$P_{average} = \frac{1}{60} \cdot \sum_{i=1}^{60} P_i \left[\frac{Wh}{min} \right] \cdot 60 \frac{min}{h} = \sum_{i=1}^{60} P_i \left[\frac{Wh}{min} \right] \tag{4.3}$$

Where P_i is the energy consumed in each minute, calculated with eq. 4.2.

4.4.3 Maximizazion: the approach chosen

Finding the hourly power consumption by averaging the powers of each minute might lead to an under scaling of the system. Such system will, indeed, satisfy the energy demand, but it will not be able to satisfy the required instantaneous power.

Therefore, the minute with the maximum power consumption was used to represent the hourly power need for each building. In this way, a load profile of each building for each day was found.

The next step of the data elaboration was finding a typical week and weekend day profile. This was again performed by maximization: for each hour, the day with the highest power demand during the week was taken. A week of 6 days was considered, since Saturday is a working day in the Complex. This makes the day profile of Sunday 24th of February the representative weekend profile for each building.
Finally, typical week and weekend day profiles were obtained. These will be shown in the following sections for each building.

Due to the maximization approach, the energy system based on these profiles will be able, as already mentioned, to provide always the required power.

4.5 The electricity demand and present supply

In this section the load profile of a weekday and a weekend day for each building will be presented and analyzed. Each building has a number or letter in brackets that allows to locate it on the map in fig. 4.2.

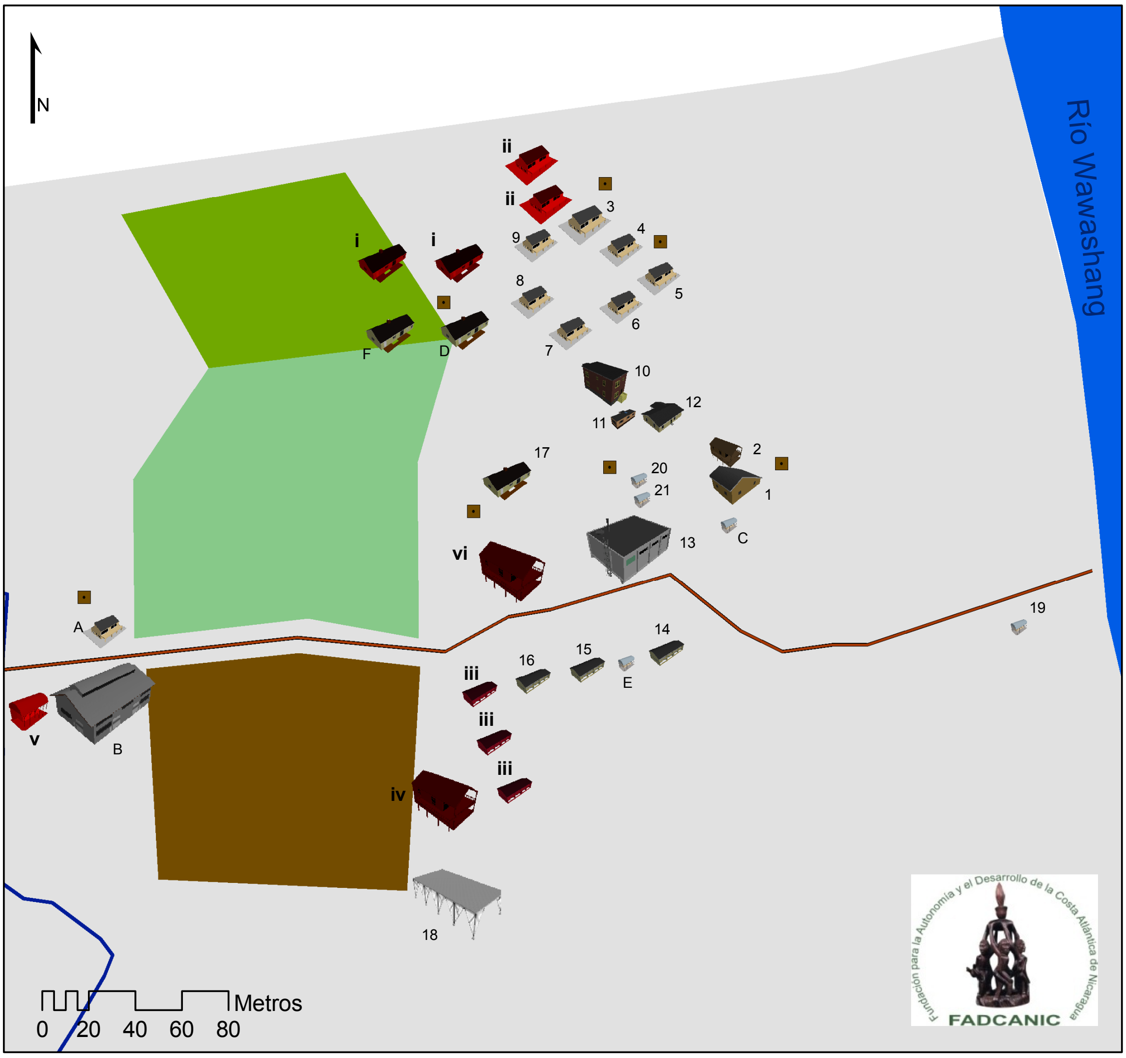


FIGURE 4.2: Buildings of the Wawashang Complex [10]

The present energy supply of each building is also described in this section. A detailed table with all the installed components is shown in Appendix A. Each building in the Complex, if electrified, has its own PV system with batteries. Gasoline generators are used as backup when the batteries are not charged enough.

The system is therefore highly dislocated, reducing the global efficiency. The efficiency of the PV systems is also reduced because sometimes installed under the shadow of trees, with non-optimal orientation and without MPPT[2] technology. In addition, the use of gasoline, that needs to be carried to Wawashang by boat, increases the operative cost considerably. The consumption of gasoline is shown in Appendix B.

4.5.1 The auditorium (10)

The meetings of the FADCANIC members take place in this building. In addition, it houses rooms for some guests.

Electricity is needed to power lights, fans, a fridge and occasionally a projector, laptops' and mobile phones' chargers.

The auditorium is currently powered by PV panels and batteries. The gasoline generator in the food processing building (13 in fig. 4.2) is used as a backup when the batteries are not charged enough. A manual switch allows to draw power either from the batteries or from the backup generator.

The weekday power demand is higher due to FADCANIC members' meetings. The peak power demand occurs at 18, when the majority of people is in the building.

[2]Maximum Power Point Tracking

Fig. 4.3 shows the weekday and weekend load profiles of the auditorium.

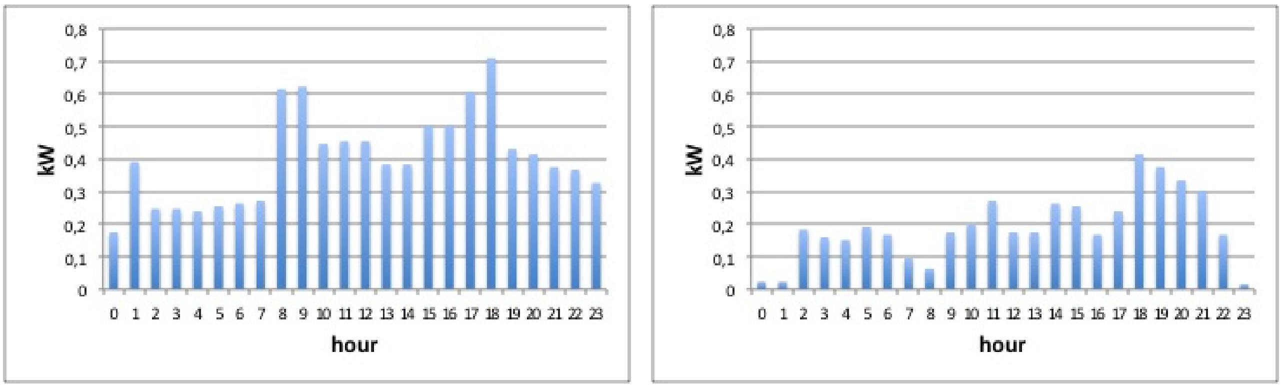


FIGURE 4.3: Auditorium's load profiles
Left: Weekday
Right: Weekend

4.5.2 The carpentry workshop (B)

Practical lessons for the carpentry students are held in this building. In addition high quality furniture is produced and delivered to the communities of the Atlantic coast, where FADCANIC operates.

Electricity is needed to power the machines of the carpentry workshop, some tools and some lights. The carpenters usually use the same machines simultaneously that can therefore be divided in working groups. Some machines are three phase, some require high power and $440V$.

The carpentry workshop is powered by two diesel generators; the small one ($10kW$) is used in normal operation, while the big one ($26kW$) is used to power the big machines, since it can provide $440V$. The consumption of diesel is around 14 gallons per day [14].

Fig. 4.4 shows the weekday load profile of the carpentry workshop, operating only from Monday to Saturday.

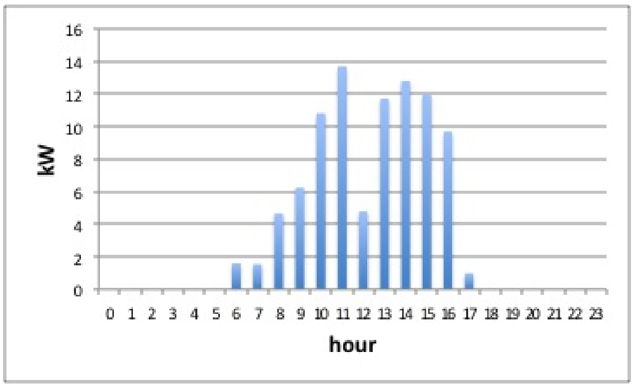


FIGURE 4.4: Carpentry workshop's weekday load profile

This load profile was obtained by using a current meter with three phase kit on the big generator ($V_{line\,to\,line} = 440V$), since it was the only operating one during the field trip. The voltage was set in the monitor to $V_{line\,to\,neutral} = 440/\sqrt{3} \approx 254V$. It should be pointed out that, in the measurement period, the big generator was also providing energy to a welding machine in another building of the Complex.

The carpentry workshop has the highest power demand in the Complex. Its load profile describes a typical working day of the carpenters, that usually goes from 10 to 16, with a lunch break between 12 and 13.

4.5.3 Computer room and teachers offices (14)

Teachers have their working desks in this building. In addition, it houses a computer room used by the students. At the moment, the school of the Complex is waiting for new computers and therefore the computer room is not operative. Electricity is needed to power lights, some fans and the computers of the professors.

This building is powered by PV panels and batteries.

Fig. 4.5 shows the weekday and weekend profile of this building.

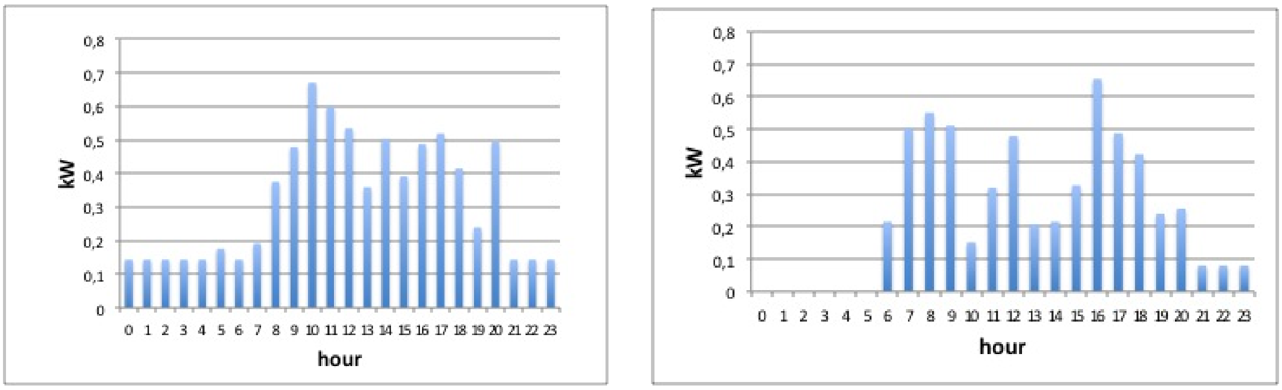


FIGURE 4.5: Computer room's and teachers offices' load profile
Left: Weekday
Right: Weekend

During the week, a base load of around $0.1W$ is present both during day and night and is caused by the computers that are never switched off completely. They might have switched off all the appliances during the night between Saturday and Sunday as can be seen in the Weekend profile.

4.5.4 The backup gasoline generator in the food processing building (13)

The food processing building does not have any electricity supply. However, two gasoline generators are located in this building, that are used as backup for the entire Complex. The power from one of these generators can be directed either to the kitchen and the dining room or to the auditorium. The choice of power direction can be made through a manual switch located in the small warehouse 21. The gasoline generators used to be a backup also for the guest house (building 17), but the connection is broken at the moment.

One of the two generator is the most frequently used and therefore the OWL current meter was applied only to it.

Fig. 4.6 shows the gasoline generator's usage.

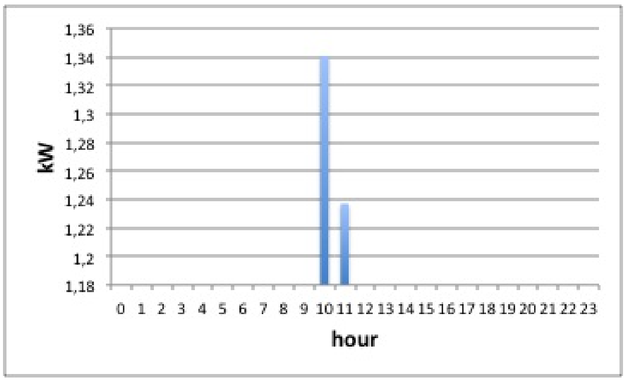


FIGURE 4.6: Backup gasoline generator's usage

During the measurement period, the generator was used only a couple of times and for purposes other than backup. The power consumed, indeed, is too high for being backup power for the auditorium or the kitchen and the dining room.

4.5.5 The guest house (17)

Guests and some teachers sleep in the guest house.
Electricity, provided by PV panels on the roof and batteries, is needed to power some lights and fans, plus occasionally computer and mobile phones chargers.
Fig. 4.7 shows the weekday and weekend profile of the guest house.

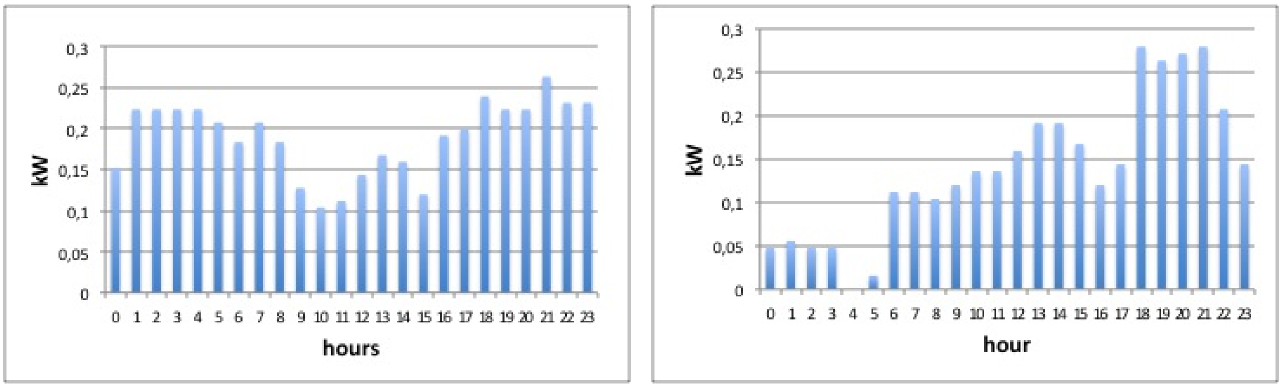


FIGURE 4.7: Guest house's load profile
Left: Weekday
Right: Weekend

The energy consumption is higher during the week, when more people are living in this building (the majority of the professors head home in the weekend), keeping many appliances plugged during the entire day and also at night.

4.5.6 The house of carpenters (A)

The carpenters sleep in this building.

It used not to be electrified, until February 2013, when some PV panels and batteries where installed. Fig. 4.8 shows a picture taken during the installation.

FIGURE 4.8: Installation of PV panels on the roof of the carpenters' house

Fig. 4.9 shows the weekday and weekend profile of the carpenters' house.

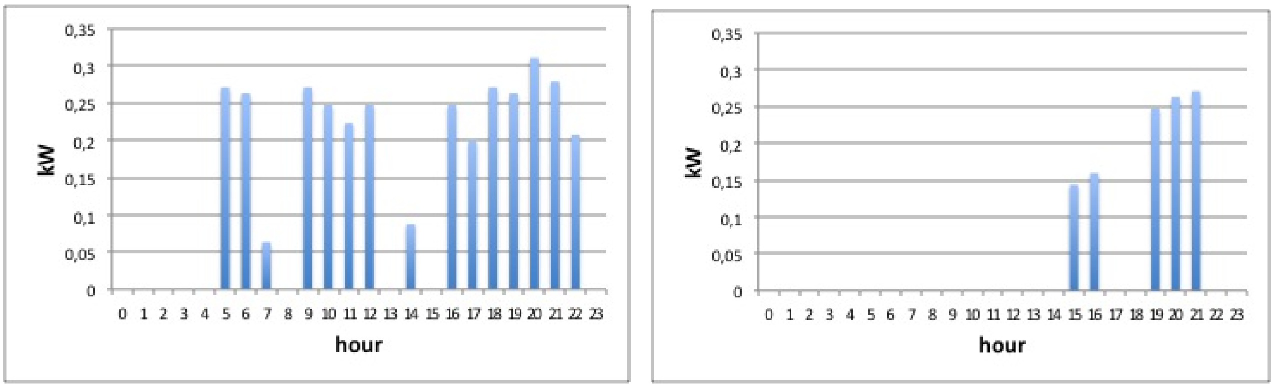


FIGURE 4.9: House of carpenters load profiles
Left: Weekday
Right: Weekend

Using electricity before starting the working day and before sleeping at night is common habit of the carpenters.

4.5.7 The professors' and students' dorms (from 3 to 9)

The student dorms are six, while one is the building where some professors live. Some professors live in the guest house (17), some others in the USAID building and several return back home every night, since they live in the neighboring villages.

Electricity, provided by PV panels and batteries located in the professors' building, is needed mainly for lights and chargers. Professors switch on electricity for the students only between 6 pm and 9 pm.

Fig. 4.10 shows the weekday and weekend profile of these buildings.

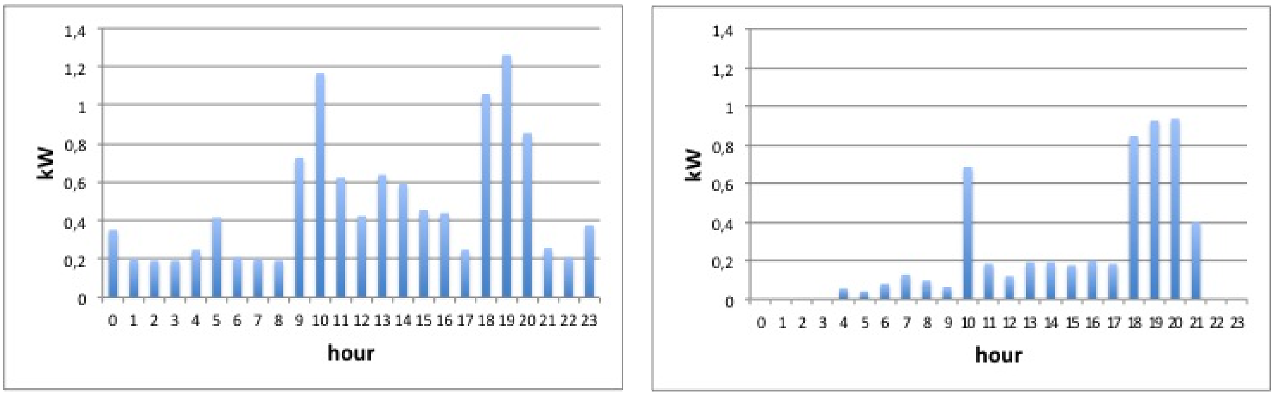


FIGURE 4.10: Professors' and students' dorms' load profiles
Left: Weekday
Right: Weekend

The electricity consumption is higher during the week than in the weekend, because some professors, living in the neighboring villages, leave the Complex. The highest power demand of the students' and professors' dorm occurs between 6 pm and 9 pm, when also the students are using the electricity.

4.5.8 Kahka Creek

Kahka Creek is not on the map in fig. 4.2 because it is located on the other side of the river Wawashang. In the Kahka Creek natural reserve several buildings are located: a guest house, a small classroom (seldom used), a carpentry workshop, the ranger's house and a kitchen (under construction).

Electricity is mainly needed for fans, lights and chargers in the guest house, the ranger's house and the kitchen. The carpentry has also machines requiring high power.

A micro grid was installed by the organization BlueEnergy. PV panels and the gasoline generator in the carpentry workshop charge the batteries. The gasoline generator is used only when the high power machines in the carpentry are running.

According to the people working in Kahka Creek, the system is working properly and has no weak points. Therefore, Kahka Creek can be excluded from the improvement of the energy system in Wawashang.
Fig. 4.11 shows the weekday and weekend load profiles of the system in Kahka Creek.

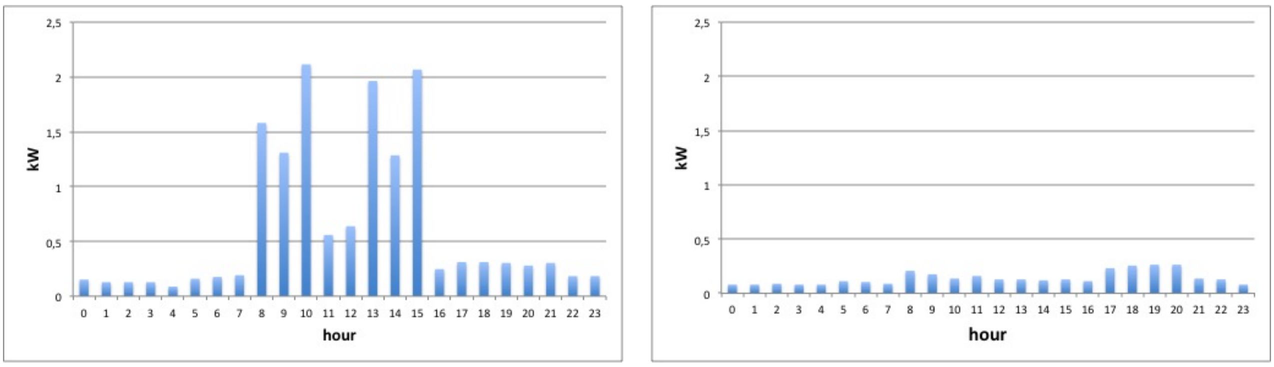


FIGURE 4.11: Kahka Creek's load profiles
Left: Weekday
Right: Weekend

The base load of the buildings of Kahka Creek is quite low. The peaks of power occur due to the use of the machines in the carpentry.

4.5.9 The kitchen and the dining room (1-2)

The dining room is the building where students, professors and members of FADCANIC have their meals. A kitchen is built next to it, where the cooks coming from the neighboring village prepare three meals per day.
In February 2013, the kitchen was still equipped with old inefficient stoves burning wood. These were harmful for the health of the cooks and consume a lot of wood. However, a more efficient stove is being built.

Electricity, provided by PV panels and batteries located in the dining room, is used for lights and chargers.
Fig. 4.12 shows a weekday and weekend profile of the kitchen and dining room.

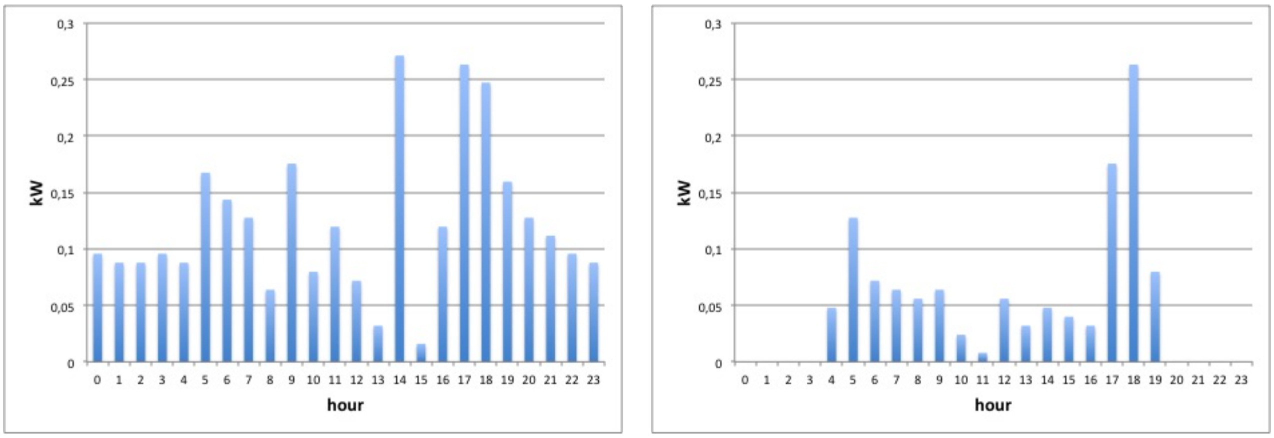


FIGURE 4.12: Kitchen's and dining room's load profiles
Left: Weekday
Right: Weekend

The main electricity consumption occurs before and during the meals. During the meals, the students usually plug in their mobile phones to the sockets of the dining room. Some consumption at night is caused by some lights or appliances left accidentally turned on.

4.5.10 The main office (12)

The FADCANIC members have their desks in this building.

Electricity, provided by a PV and batteries system, is used for lights and computers.

Fig. 4.13 shows the weekday and weekend load profiles of the office.

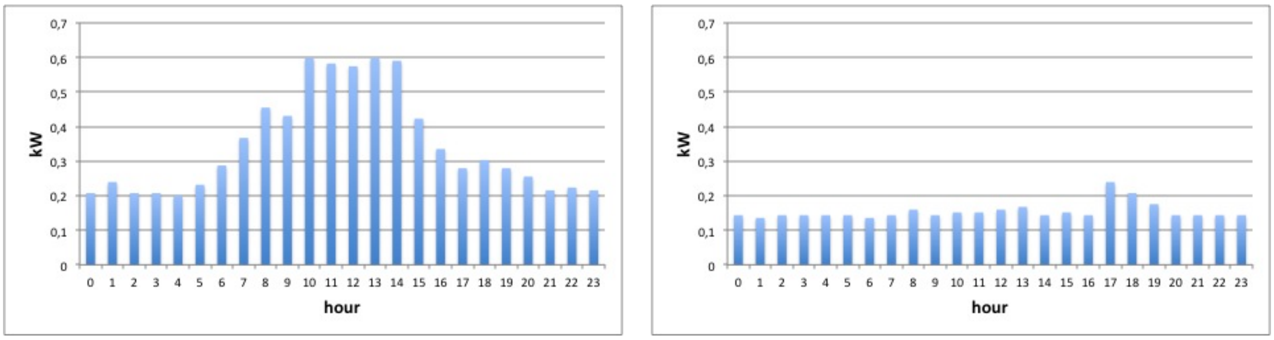


FIGURE 4.13: Main office's load profiles
Left: Weekday
Right: Weekend

A base load is present everyday, due to the plugged computers. During the week the energy consumption is higher, because some FADCANIC members work in the office. Around lunch time the consumption is higher because the workers, taking a break from the crops, spend some time in front of the computer.

4.5.11 The USAID building (F)

Some of the teachers sleep in this building, donated by USAID.

It is powered by a PV and batteries system and electricity is needed for lights and occasionally chargers.

Fig. 4.14 shows the weekday and weekend profiles of the USAID building.

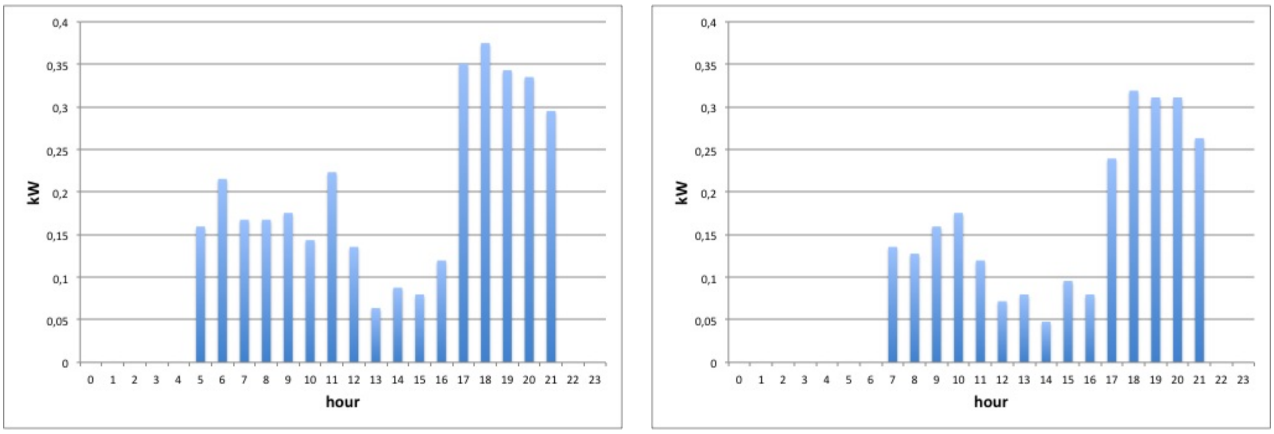


FIGURE 4.14: USAID building's load profiles
Left: Weekday
Right: Weekend

The weekday and the weekend profiles are similar with a power peak in the evening, when people come back from the daily work.

4.5.12 The water processing building (C)

In this building the water pumped from the well is purified and bottled for drinking purposes.

The pumping system uses a gasoline generator. The purification system works with ultraviolet radiation and is powered by PV modules.

Fig. 4.15 shows the power consumption of the water processing facility.

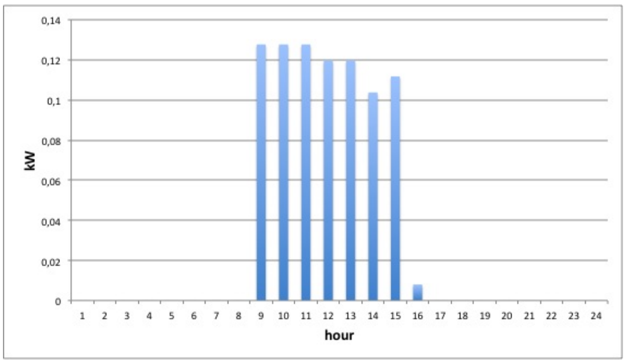


FIGURE 4.15: Water processing building's load profile

Water is not processed every day. During the measuring period the processing system was used twice, with almost constant need of power.

4.5.13 The present and future total demand

Fig. 4.16 shows the total present power demand, calculated by summing the power demands of each building.

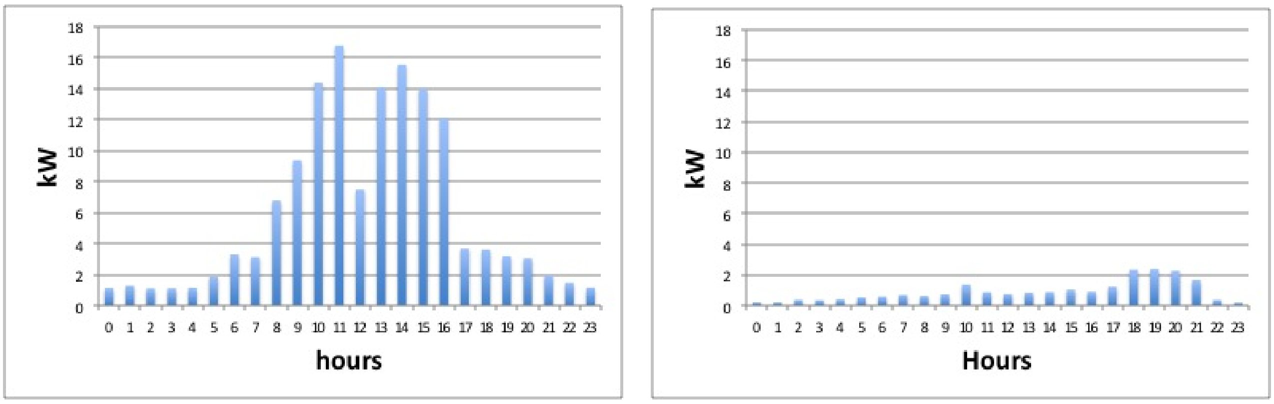


FIGURE 4.16: Total present demand of the Complex
Left: Weekday
Right: Weekend

Kahka Creek is excluded from the sum, because far away from the buildings of the Complex and because its energy system is working properly. In addition, the

backup generator in the food processing building is excluded from the sum, because used for purposes other than backup during the measurement period.
Due to the carpentry workshop, the power demand is higher during the week than the weekend, reaching a maximum of about $17kW$ in the middle of the day. The peak power demand during the weekend, when the machines in the carpentry are not used, is about $2.5kW$ and occurs in the evening, when people return to the buildings.

Finding a multiplication factor to scale up the present demand and forecast the future one was the last step of the energy consumption analysis. According to table 3.1, in 2032 people in the Complex are expected to increase about three times in respect to 2012. Therefore, a factor three was considered at the beginning. However, the responsible of "monitoring&evaluation" in FADCANIC (Mr Henry Meyers) suggested that the present power demand should be multiplied by five to forecast the future needs.
The carpentry workshop is an exception: it is not likely to have five times the power needs in the future; therefore its future demand can be estimated by only doubling the present demand.
Fig. 4.17 shows the forecasted future power demand of the Complex, with a power peak of about $47kW$ during the week and $13kW$ during the weekend.

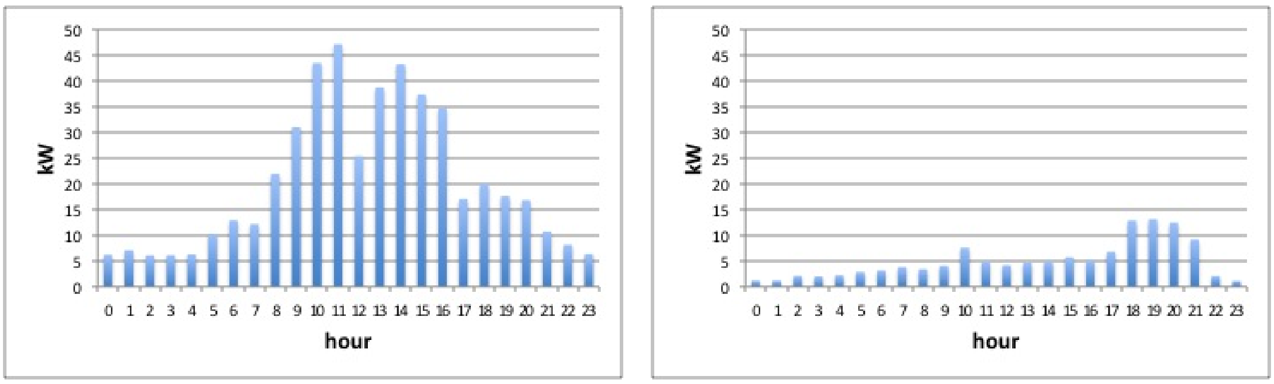


FIGURE 4.17: Total future demand of the Complex
Left: Weekday
Right: Weekend

Chapter 5

Energy potential

5.1 Connection to the national grid

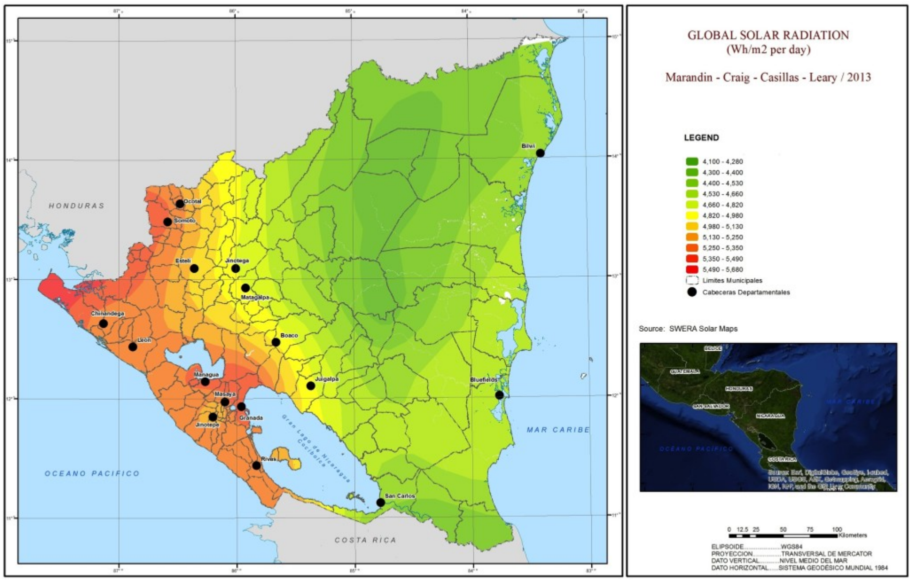
The first step in the analysis of the alternatives for energy supply in off grid systems should be the evaluation of a connection to the grid.
At the beginning of the project, a map provided by ENATREL (*"Empresa Nacional de Transmisón Eléctrica*) was used to find the closest connection point to the grid.
Thanks to the field trip in February 2013, an updated electricity map was obtained from BlueEnergy (fig. 5.1).
According to the map of ENATREL, Bluefields (around $70km$ far) is the closest connection point to the grid. However, the new map revealed that it is even closer, either in Brown Bank or in Kakabila (around $28km$ far), both on Laguna de Perlas. These two places are indicated with an arrow on the right of fig. 5.1, while the Wawashang Complex is marked with a red circle.
This information shows that the Nicaraguan national grid is improving and might improve further in the future, maybe reaching Wawashang. However, FADCANIC has not considered this option so far and is looking for off-grid solutions.

FIGURE 5.1: Nicaragua's national Grid [12]

5.2 Solar resource

The Atlantic Coast, where the Wawashang Complex is located, has a good solar irradiation, while the Pacific Coast has the highest one in the country.

Fig. 5.2 shows the global solar irradiation of Nicaragua and the one at the Wawashang Complex.



	Global Irrad. kWh/m².mth	Diffuse kWh/m².mth	Temper. °C	Wind Vel. m/s
January	133.0		24.8	
February	143.8		25.1	
March	169.6		25.8	
April	174.3		26.7	
May	156.9		26.6	
June	121.2		26.4	
July	115.0		26.2	
August	124.6		26.3	
September	131.4		26.2	
October	128.7		26.0	
November	118.5		25.7	
December	121.8		25.2	
Year	**1638.8**		**25.9**	

FIGURE 5.2: Global Solar Irradiation
Above: global solar irradiation in Nicaragua [12]
Below: global solar irradiation in Wawashang [13]

The good solar irradiation, the need of low maintenance, the simplicity in installation and the easiness of technology transportation made solar energy the most attractive solution in the rural areas of the Caribbean Coast of Nicaragua.
In addition, imports of solar technology are subsidized by the Nicaraguan government as described the following sections.

5.3 Wind energy

The wind resource is really good only on the Pacific Coast, while the majority of the Nicaraguans living with no electricity is on the Atlantic Coast.
Fig. 5.3 shows the wind potential in the country.

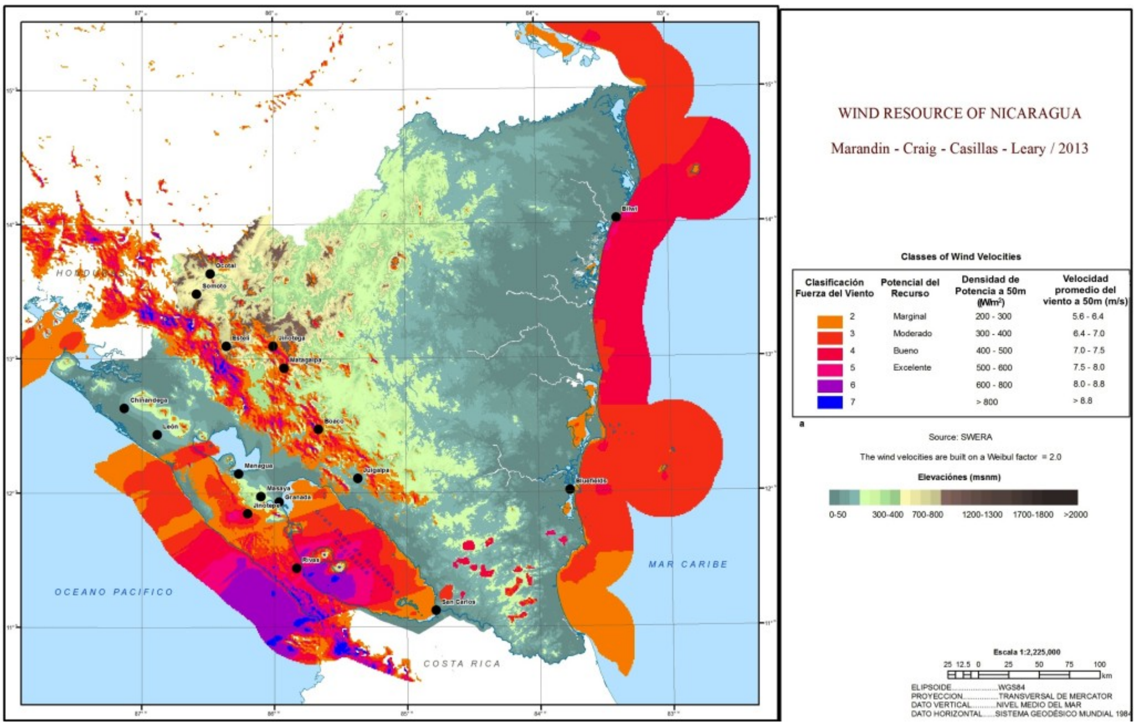


FIGURE 5.3: Wind resource [12]

BlueEnergy has been installing wind turbines on the Atlantic Coast of Nicaragua for 7 years now.
The area revealed to be one of the most challenging environments to install wind turbines, due to the medium-low wind source, the frequent lightning strikes, the

high salinity and humidity and the heat.

In addition, the communities revealed a lack of interest and discipline in performing maintenance and wind technology imports are not subsidized by the government [12].

5.4 Solar and wind: technology suppliers & maintenance

Imports of solar technologies are strongly subsidized by the Nicaraguan government, while wind and electronics ones are not, as shown in fig. 5.4.

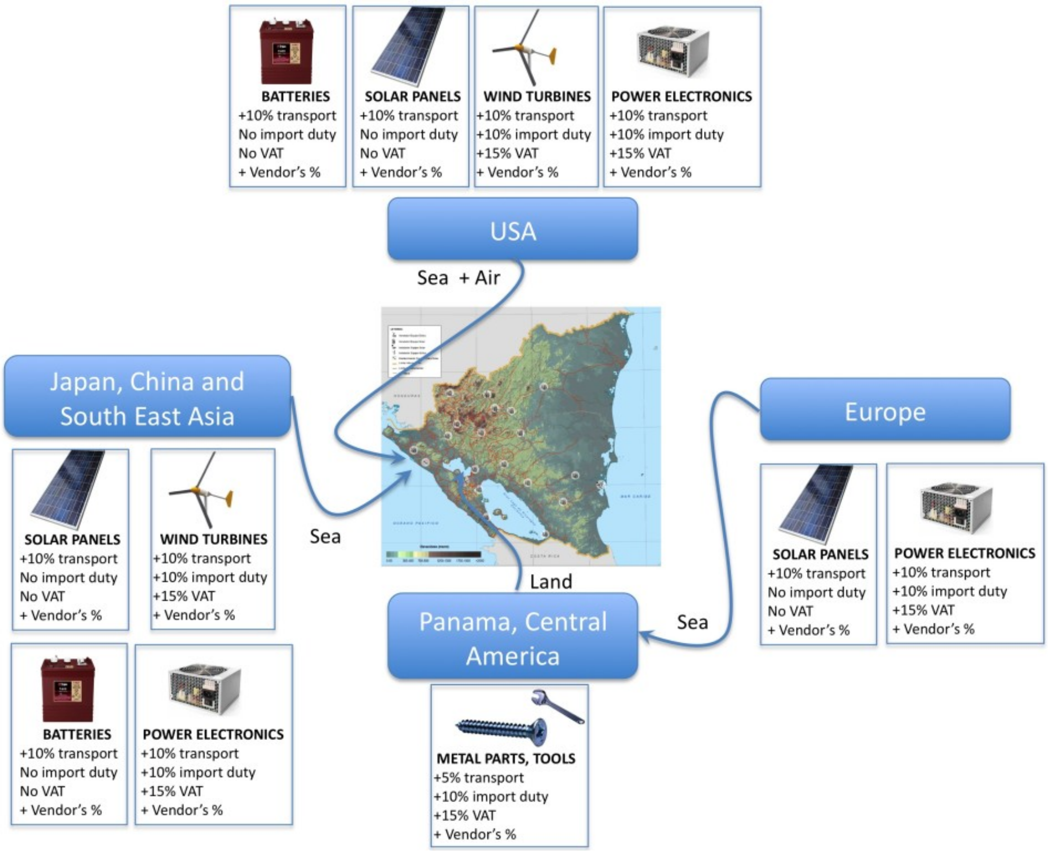


FIGURE 5.4: Supply chain of wind and solar technologies in Nicaragua [14]

Fig. 5.5 gives a more detailed overview of the solar and wind technologies suppliers and shows also installers and maintenance providers.

BlueEnergy is listed both among the installers and the maintenance providers of solar and wind technologies.

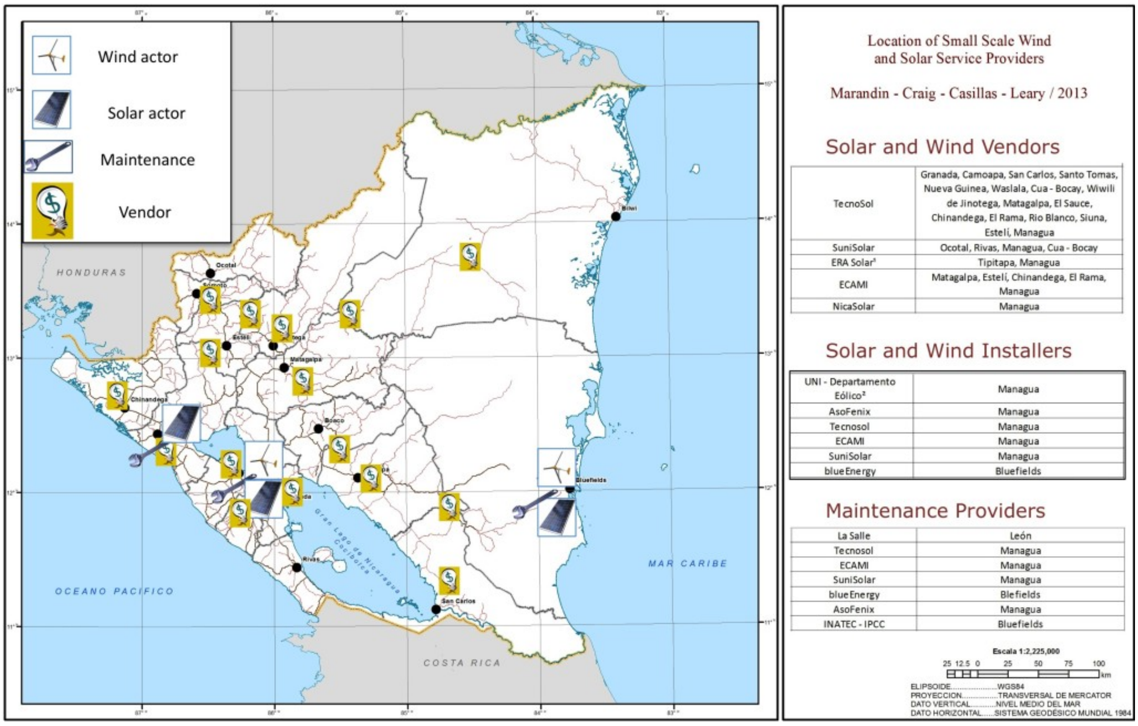


FIGURE 5.5: Suppliers, installers and maintenance providers [12]

5.5 Biomasses

The visit to Wawashang and conversations with BlueEnergy's technicians revealed that biomasses could be a potential resource for power generation in the Wawashang Agroforestal Complex. This could be done both through the use of residuals from crops and carpentry activities and waste from humans and animals. Some members of the BlueEnergy group are working on the design of two possible digesters: one using the manure of the pigs of the nursery and the second one for a project of collecting all the human waste waters of the Complex. Numbers and potential of this resource are not analyzed in this thesis work because BlueEnergy is already currently focusing on it.

On the contrary, the residuals from the crops and the carpentry workshop will be described, even if they do not represent the core of this project. This can provide

a starting point for further studies on the biomass potential.
The procedure applied in harvesting this potential follows the idea of a BlueEnergy engineer (Eng. Gilles Charlier).
The data were collected during the field trip in February 2013 and therefore are up to date.

The main solid organic wastes are from the woodworking of the carpentry.

Coconut husks and shells could be another source of energy, since coco is one of the main products of Wawashang. Fig. 5.6 shows coconut husks collected in Wawashang.

FIGURE 5.6: Coconut husks collected in Wawashang

However, both the coconuts produced by the Innovation Program ($10,000 cocos/month$ this year) and the ones produced by the school (low production planned for 2013, but production of $66 cocos/day$ in 2012) are not available for energy production at the moment, since destined to other purposes.
An electrical coconut processing facility could increase the amount of coconuts processed and consequently the amount of husks and shells available for energy generation.

The bagasse obtained from sugar cane could also be an interesting waste, but currently it is not produced due to the absence of an automatic processing system of sugar canes.
Both coconuts and bagasse should be considered as energy source in the future.

5.5.1 Wastes from the carpentry

The waste from the carpentry can be divided in sawdust and pieces of wood that cannot be used. The data were gathered during a conversation with Don Alvaro and another teacher of the carpentry in February 2013. They are based on estimates done by the carpenters' experience, since the production is variable.

Sawdust is measured in bags, each containing $200kg$ of rice and having a volume, according to Gilles Charlier, of around $0.6m^3$. The sawdust produced can be estimated between 1.5 and 2 $bags/day$. Therefore, considering 20 $working\,days/month$ and the density of sawdust $210kg/m^3$ [15], the monthly production yields:

$$M_{sawdust} = 1.7\frac{bags}{day} \cdot 0.6\frac{m^3}{bag} \cdot 210\frac{kg}{m^3} \cdot 20\frac{days}{month} = 4284\frac{kg}{month} \qquad (5.1)$$

However, the sawdust is partially used as bedding for pigs in the nursery. Assuming energy production as priority, another solution for the pigs' bedding should be found.

As far as the unusable pieces of wood are concerned, they can be divided in short ("tablas") and long ("tablones") pieces.
The unit of measure of this wood waste is a virtual board with the following dimensions: 12" x 12" x 1" ($0.304m$ x $0.304m$ x $0.025m$), that is equal to $0.0023m^3$.
This value has to be multiplied times the feet of waste produced.
According to the information gathered by Eng. Gilles Charlier, pino montero, santa maria, caoba, coyote are the types of wood usually used in the carpentry.
Only the density of santa maria and caoba were found: 650 and $560kg/m^3$ respectively [16][17].

Therefore, an average of $605kg/m^3$ is calculated and the production of pieces of wood can be estimated as follows:

$$M_{\substack{\text{wood}\\\text{pieces}}} = \left(7\frac{tablas}{day} \cdot 1\frac{foot}{tabla} \cdot 20\frac{days}{month} + 50\frac{tablones}{month} \cdot 2\frac{feet}{tablones}\right) \cdot \cdot 0.0023\frac{m^3}{foot} \cdot 605\frac{kg}{m^3} = 334\frac{kg}{month} \tag{5.2}$$

It should be pointed out that at the moment some of the pieces of wood are used in the kitchen as firewood. However, the carpenters' opinion was that using the pieces of wood for energy production would be the priority. In addition, the amount of wood needed by the kitchen might be lowered in the future, thanks to planned more efficient stoves.

5.6 Hydro Potential

This section shows the comparison between the expected hydro potential estimated before the trip and the effective one encountered during February 2013, in order to evaluate possible inaccuracies in the forecast.

5.6.1 Expected hydro potential

According to [1], the Atlantic Coast of Nicaragua has a high potential for hydropower generation, since the abundance of precipitations and the landform generate a great number of rivers. This is the reason why the decision of investigating mainly the hydropower potential was taken.
Unfortunately, the area around the Wawashang Complex is quite flat, while the rivers carry good amounts of water.
An estimate of the hydro potential was carried out before the field trip to Wawashang, since no data were available. This was done in order to find some potentially interesting sites to be inspected on the field.
As already mentioned, the hydropower potential is combination of head and water

flow. The head was estimated thanks to the topographies provided by INETER (*"Instituto Nicaragüense de Estudios Terriotoriales"*). These maps present contour lines by steps of $10m$.

An estimate of the average yearly water flow was calculated thanks to hydrological data from a study by MARENA[1], which provides values of surface runoff (SR) for all the watersheds of Nicaragua (unfortunately, the method used for the calculation of these runoff values is unknown).

The "SR" values were used to estimate the average water flow of the tributaries around the Wawashang Complex following the procedure described in Chapter 2.

The investigated tributaries were: Manwood Creek, Sabawas Creek, Camp Eight Creek and Mahogany Creek. Different intake locations were also tried in order to maximize the power output.

The estimates shown in table 5.1 have been selected among all the investigations, since they offer the highest potential and are the closest to the Complex.

The maximum power potential ($Pmax$) was calculated using the equation 2.1 with the gross head, assuming 100% efficiency of the turbine and not taking into account the residual flow.

Then an efficiency of 60-70% can be supposed to estimate the real power output ($Preal$), considering the loss of head in the pipes, the hydraulic, mechanical and electric efficiency.

A^* is the drainage area at the selected intake.

River	Q(m^3/s)	A* at intake (km^2)	Hgross(m)	Pmax(kW)	Preal(kW)
Mahogany Creek	0.83	36.45	10	81	49-57
Rio Wawashang	16.8	740	1.5	247	148-173

Table 5.1: Estimate of hydro potential of selected rivers

Rio Wawashang is the main river of the area and has available flow rate all year round.

The tributary Mahogany Creek has a big drainage area and therefore a good water flow.

The intake locations on Mahogany Creek and Rio Wawashang found during the

[1] Study performed with data by INETER of 1993 and by MAGFOR (*"Ministerio Agropecuario y Forestal"*) of 1990.

estimates were around $9km$ and $8km$ far away from the Wawashang Complex respectively. The possible turbine locations could have been around $6km$ and $5km$ far away from the Complex respectively.
Looking at the topographies, the head of $10m$ on Mahogany Creek is undoubtedly present and distributed in $3km$, while the head of $1.5m$ on Rio Wawashang is only estimated (because $10m$ is the minimum step between the contour lines) and distributed in $3km$ as well.

An average estimate of the water flow is of little use for micro hydropower design. According to [3], water flow records for at least a year needed to be gathered.

One of the goals of the field trip was installing a gauging station in State Creek (the tributary of Rio Wawashang flowing through the FADCANIC property), in order to know the variation of its water flow.
An estimate of the water flow of Mahogany Creek could have been done, using the flow rate of State Creek and the drainage area ratio (eq. 2.5).
The drainage areas of State Creek and Mahogany Creek are in the same range of magnitude ($12.12km^2$ and $36.45km^2$ respectively), making the estimate with eq. 2.5 reasonable.
The same estimate could not have been done for Rio Wawashang, due to its wide drainage area at the intake site ($740km^2$).

5.6.2 Actual hydro potential

The field trip revealed that the locations investigated in the estimates were in reality not offering a feasible solution.
The area around the Wawashang Complex, indeed, does not have such an interesting potential for hydropower generation. There are three main factors that make the estimates not practically feasible.
Firstly, the region revealed to be even flatter than expected. In particular, Rio

Wawashang does not offer any interesting head around the Complex and flows really slowly. Only more detailed topographical maps with contour line steps smaller than $10m$ would have given more accuracy in the estimate.
Second, it should be mentioned that the whole area is divided in properties. The FADCANIC property is confined to an area around State Creek. This would make any practical decision not easy to take.
Third, the deep forest around the whole area could contrast any civil work and makes exploring the sites a difficult task.
In addition, boats on Rio Wawashang are the main means of transport to reach the nearby village Pueblo Nuevo or Laguna de Perlas. Therefore, a massive hydropower installation in Rio Wawashang would influence strongly the habits of the people.

All these reasons made the installations planned in the estimates not attractive.

The exploration of the site on Mahogany Creek with $10m$ head was not done since a boat was required (due to the deep forest), with high gasoline expenses for FADCANIC. Moreover, Mahogany Creek is not in the property of FADCANIC.
Therefore, it is still unknown how the slope of Mahogany Creek changes: the head of $10m$ can be either mostly concentrated in one point or distributed equally in $3km$.
Though the whole area looked quite flat, as already mentioned, the hydropower potential on Mahogany Creek should be investigated in the future.

Even though the results about the hydropower potential were not as expected, as soon as a proper site for the gauging in State Creek was found, the measurement procedure started as planned. This was done for two reasons: first, in order to generate knowledge about the flow rate of one river of the area; second, FADCANIC members wanted to know the exact water flow value of State Creek, since its water is pumped for irrigation and sanitary purposes during the dry season.

Meanwhile, during the field trip, the whole area around State Creek was explored with FADCANIC members, reaching the source of one of the branches of the river, surrounded by a deep rainforest. During the survey, a site with a small potential was found and the feasibility of a possible installation will be discussed in Chapter 6 and 7.

The study of this site has become the core of this project.

Chapter 6

The micro hydropower potential of State Creek

6.1 The site with potential for power generation

6.1.1 Location

In this Chapter, the location for a possible micro hydropower installation is presented. It is located on State Creek, the small river flowing through the FADCANIC property.

The area of the micro watershed of State Creek is quite flat, with altitudes oscillating between 5 and $50m$ above the sea level [7].

State Creek is $3km$ long and maximum $5 - 7m$ wide. Nevertheless, it has a good water flow during the whole year, due to the heavy precipitations.

The path of State Creek, generated with ArcView, is shown in fig. 6.1.

Moreover, the four locations where the head was measured, the two pumping stations and the gauging station for the water flow are indicated with different symbols (red dots, purple squares and green triangle respectively). These will be described in the following sections.

As shown in the figure, State Creek originates from three branches and then flows into Wawashang river. The main branch of the river is the one dividing the property of the farmer Don Epifanio Vargas from that of FADCANIC.

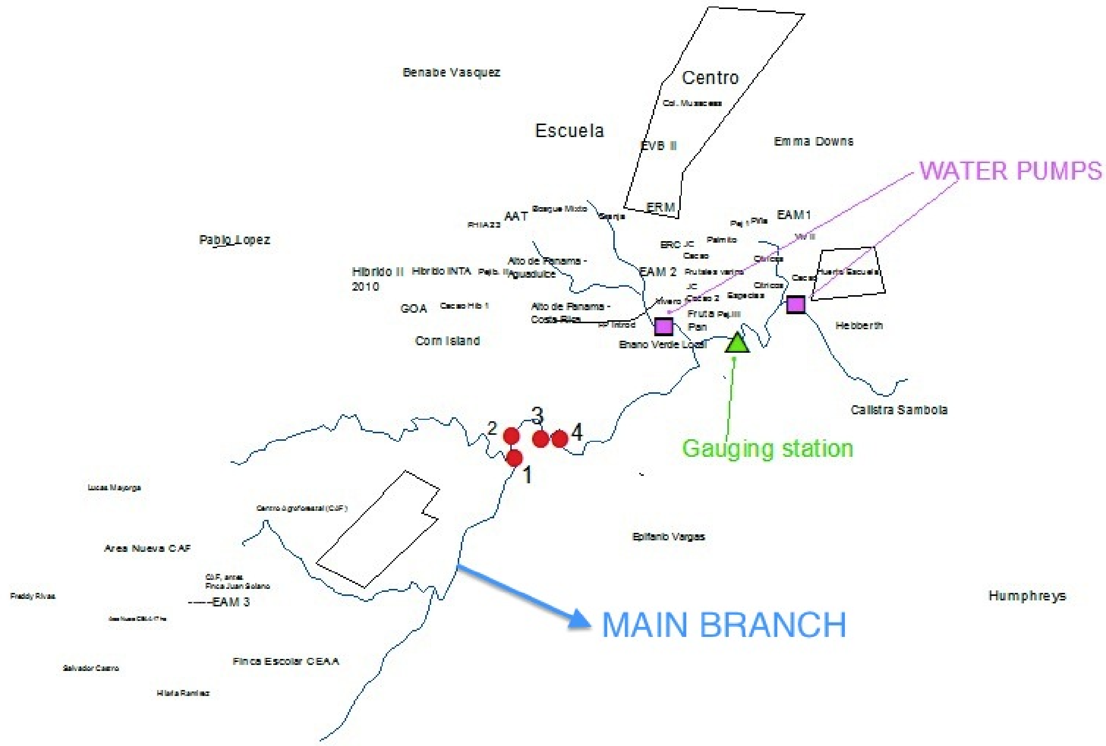


FIGURE 6.1: Map of State Creek

The water of State Creek is used by the people living around it for their personal hygiene and for the farmers' animals.
Moreover, water is pumped from State Creek for irrigation and fill the water tanks of the Wawashang Complex especially during the dry season.

The location was individuated during an exploration of the area with the members of FADCANIC. The exploration was conducted with a portable GPS that, according to people working in FADCANIC, is reliable in finding the location but not the altitude. Therefore, an iPhone with a GPS was brought on the field as well.
The site is around $1km$ from the buildings of the Complex and in-between the property of FADCANIC and the one of Don Epifanio Vargas. It offers a site with very low head, where the feasibility of a micro hydropower installation is under evaluation. The river is flowing in its bed on a level lower than the hill around it.

The first beneficiary of the micro hydropower plant could be the house of the farmer Don Epifanio Vargas that is not electrified at the moment. Don Epifanio is cooperating with FADCANIC in protecting the environment of the micro watershed of State Creek and therefore FADCANIC is interested in providing his house with power.
The second one could be a coconut processing facilities that FADCANIC might build next to the river.
The last beneficiary of the installation could be the Wawashang Complex itself, which requires a transmission line of at least $1km$ would be needed.

The following sections show the measurement of the potential available (head and water flow).

6.1.2 Measurement of the head

The method of the head estimate to apply to State Creek needed to be suitable for low head sites, inexpensive and simple.

A carpenter's spirit level and a straight planck of wood together with a wooden folding ruler were used. This method is quite straight forward and it is shown in fig. 6.2.

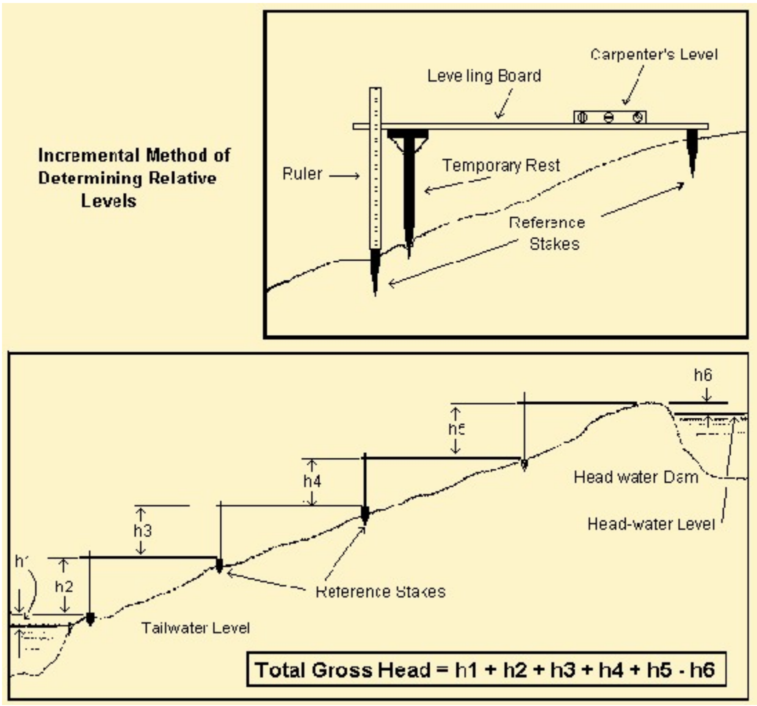


FIGURE 6.2: Carpenter's spirit level, plank of wood and folding ruler method

According to [3], this method can be reasonably accurate for low head sites, but it should be cross-checked with another method (like the water filled tube and pressure-gauge method, explained in Section 2.4 of [4]).

The head was measured together with a member of FADCANIC (Mr Yoel) using four different locations, as shown in fig. 6.3. Yoel showed a strong motivation, especially after the explanation of the purpose of the work.

A reference point was chosen on the top of the hill next to the river and the elevation of each location (1, 2, 3 and 4) was measured compared to this point. This reference point was tried to be kept constant for the four measurements, though some small inaccuracies could have occurred, since the top was not totally flat.

Figure 6.3: Measuring the head in State Creek

The reason of measuring in different locations can be explained as follows. The upstream locations (1 and 2) represent the two possibilities for the intake of the micro hydropower plant. They are located respectively before and after the small branch enters the main stream. Therefore, the first one will provide higher head, while the second higher flow. The other locations (3 and 4) are downstream and represent two possibilities for the micro turbine installation.

The results of the measurements at each location are depicted in table 6.1.

Location	To top in m (measured)	Altitude over sea level in m (iPhone)
1	3.6	28±4
2	5.2	28±3
3	7.5	25±3
4	8.3	23±6

	Distance (m)	Δh measured (m)	Δh iPhone (m)
4-1	207	4.7	5
4-2	206	3.1	5

Table 6.1: Head measurements on State Creek

Measurements of the elevation have been recorded both as difference from the top measured with the wooden folding ruler and as difference from the sea level measured with the GPS of an iPhone. The GPS has a range of uncertainty that is shown as well.

The bottom part of the table shows the gross head between 2 (intake location) and 4 (micro turbine location) and the one between 1 (intake location) and 4 (micro turbine location). These values, together with the water flow, allow to calculate the actual hydro potential.

In addition, also the minimum distance between the considered intake and the turbine locations is shown; the distance will be fundamental during the design and costing of the pipe system. These values were found by means of the geographical system ArcView, in which GPS data of the area are recorded.

As shown in table 6.1, the length of the pipeline will not be influenced by the choice of one of the intake locations (1 or 2). Therefore, the choice between intake locations 1 and 2 will depend on which one will maximize the power output.

Unfortunately, the deep rainforest represented an obstacle for the use of the carpenter's level, influencing the choice of the measurement locations. The locations 1, 2, 3 and 4, indeed, were also chosen because easily accessible from the river banks.

Therefore, it should be pointed out that nearby the locations 1, 2, 3 and 4, other ones could be found (for example downstream the small branch) with more water flow available and lower cost due to the shorter pipeline length. A different method (e.g. water filled tube or water filled tube and pressure gauge method, explained in Section 2.4 of [4] could allow to measure the head by walking in the stream.

This is an important part of the further work to proceed in this project.

Moreover, using pressure gauging, the head measurements will result more accurate and suitable [4].

Based on the above discussions and the head measurements, it can be stated that State Creek provides a head between 3 and $5m$ at the site chosen.

6.2 Measurement of the water flow

6.2.1 The method used: stage-discharge relation and the velocity-area principle

If appropriate stream flow time series about a river are not available as in the case of State Creek, the discharge should be preferably measured for at least one year. A single measurement of instantaneous flow in a watercourse is of little use for designing a hydropower installation, particularly in tropical areas like Nicaragua, where precipitations vary strongly throughout the year. However, daily water flow measurements are not feasible for State Creek, because of the distance from the site. In this case, the option of building a stage-discharge curve[1] was chosen as solution. Consequently, in order to get this relation, the water flow of State Creek was measured during the field trip.

Having the equation of the stage-discharge curve, allows to determine the water flow knowing only the gauge height. Automatic methods for stage measurement can be used; they consist of a structure housing instruments to measure, store, and transmit the stream-stage information. If an automatic gauging station is not economical, a person at the location has to check the height at the installed gauge every day.

Generally, according to [18], the stage-discharge relation can be expressed by the following curve equation:

$$Q = C\,(h + a)^n \tag{6.1}$$

Where Q is the discharge and h the gauge height. C and n are constants, while a is the value of stage at zero flow (or datum correction) that can be considered

[1] The stage, or gauge height, is the recorded water level at a streamflow gauge.

zero if not measured. The constant n reflects the shape of the channel of the river and is larger than 1, since the discharge should increase more than the height for high flows.

An example of the stage-discharge relation is shown in the fig. 6.4.

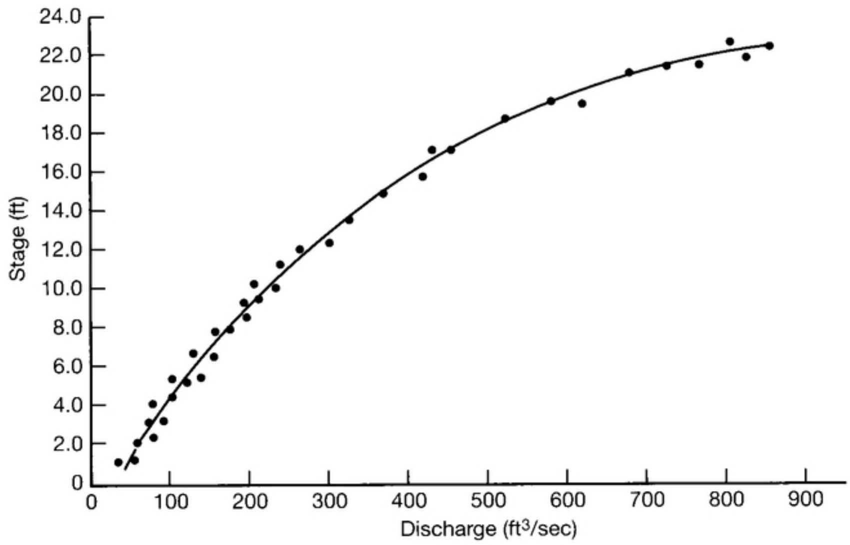


FIGURE 6.4: Example of stage-discharge relation [19]

Knowing the expected shape of the curve is important to analyze correctly the collected data. In literature, these graphs usually display the water flow (dependent variable) on the x-axis, while the stage (independent variable) on the y-axis. In order to build the stage-discharge relation of State Creek, the water flow was measured for several gauge heights.

The "velocity-area principle" was used for the water flow measurements.

The cross-section is divided into segments by spacing verticals in a sufficient number of locations across the channel. According to [18], the verticals can be chosen either equidistant or having segments with equal flow or spaced to accommodate abnormalities in the bed profile. Anyway, whatever principle is chosen, a general rule improving the accuracy should be to make the width of the segments lower as depth and velocity increase; in addition, as rule of thumb, the verticals should be spaced so that no segment contains more than 10% of the total water flow.

The velocity was measured at each vertical by the current-meter OTT C2, shown in fig. 6.5, borrowed from NTNU (*Norwegian University of Science and Technology*).

The total discharge of the stream was computed by summing the discharges of each segment.

FIGURE 6.5: OTT C2 current meter [20]

OTT C2 belongs to the class of propeller-type meters that have rotors with horizontal axis. This instrument was chosen for measuring the water flow of State Creek, because it is the easiest to carry in a backpack. Moreover, the OTT C2 current meter suits to shallow and small streams like State Creek in the end of February (the beginning of the dry season). Measurements with OTT C2 were, indeed, performed by wading.

The current meter transmits an electrical impulse to a counter at each propeller rotation; the number of rotations is then displayed on the screen of the counter. The operator chooses a time span in which the rotations are counted and then calculates the angular speed of the propeller. A relation between angular velocity and velocity of the stream, known as "current meter rating", is provided in the technical manual provided by the supplier. This relation depends on the size and shape of the propeller used.

Each measurement kit has usually more than one propeller available, each one with a maximum measurable velocity of the stream and its "current meter rating".

Knowing the velocity at each vertical, the discharge of each segment was computed by the "Mid-Section Method", shown in fig. 6.6, assuming that the velocity sampled at each vertical represents the mean velocity in a segment.

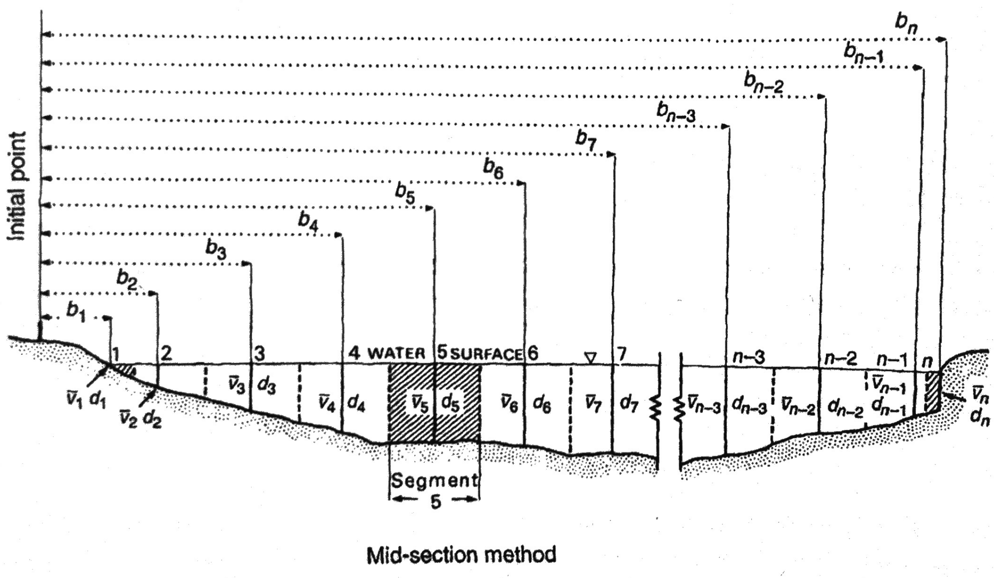


FIGURE 6.6: Stream cross section illustrating Mid-Section Method to determine the discharge [18]

According to [21], this is the most used method for computing the discharge of each segment. Accordingly, in the example shown in fig. 6.6, the water flow through segment 5 is determined by:

$$q_5 = v_5 \left(\frac{(b_5 - b_4) + (b_6 - b_5)}{2} \right) d_5 \tag{6.2}$$

With segments from 2 to $n-1$, where n is the number of verticals. The first and last water flows can be computed as follows:

$$q_1 = v_1 \left(\frac{b_2 - b_1}{2} \right) d_1 \tag{6.3}$$

$$q_n = v_n \left(\frac{b_n - b_{n-1}}{2} \right) d_n \tag{6.4}$$

The total discharge is calculated by summing all the discharges in each segment.

6.2.2 Application of the method to State Creek and challenges encountered

The first main challenge encountered in the measurement of the discharge of State Creek was finding a location with sufficient stream velocity, since the field trip was in the end of February, the beginning of the dry season. Moreover, the location needed to be close to the Wawashang Complex, in order to allow a local person to check the gauge height every day.
After talking with some FADCANIC members and after a field survey, an appropriate gauging site was individuated and the gauging station was set, as shown in fig. 6.7.

FIGURE 6.7: Gauging station in State Creek

Finding the exact position of the gauging station was not possible, since the GPS was not receiving any signal. Therefore the gauging station was located on the map in fig. 6.1 by an experienced FADCANIC member.
The wooden bar standing on the left of the figure is the main gauging staff, where the gauge height of the stream is monitored. The bar was set in the carpentry of

Wawashang and a measuring tape was screwed on it. Then, it was fastened to the trees along the river in order to resist the high water flows of the rainy season. The horizontal measuring tape was set to divide properly the cross section of the channel in segments.

A "sufficient" number of verticals was chosen in order to maximize the accuracy of the measurement of the discharge. According to [18], the recommended amount of verticals is between 10 and 20 for a river with a width in the range of $5-10m$. Since State Creek is around $5m$ wide, the channel was divided by 12 verticals at the beginning. In the following days, the number and the spacing were changed in order to obtain about 10% of flow in each segment. Accordingly, the last 4 measurements were performed with 14 verticals.

The velocity was measured only once at each vertical at a distance of 40% from the bottom of the water, since State Creek was less deep than $1m$ during the field trip. If it was deeper, an average between three different observations at different depths for each vertical should have been taken [18].

The time on the counter was set to $40s$ and therefore the angular velocity was calculated with the displayed number of rotations. Hence, the velocity could be computed, using the current meter rating associated to the propeller used. The data of the chosen propeller are shown in table 6.2.

Propeller #	v_{max}	Formula
3-45083	2.6	$v = 0.26 \cdot n + 0.005$

TABLE 6.2: Propeller chosen for the measurements through current meter

Fig. 6.8 shows a picture taken during the water flow measurement of State Creek. The current meter OTT C2 and the counter are shown in the picture, together with the main gauging staff and the gauging tape already described.

FIGURE 6.8: Measurement of water flow in State Creek (February 2013)

6.2.3 Results of the discharge measurements

Eight discharge measurements were performed in State Creek in eight days for eight different gauge heights. The results are listed in table 6.3.

Day	h(m)	Q(m^3/s)
19th February	0.285	0.219164375
21st February	0.28	0.172326475
23rd February	0.24	0.158028
25th February	0.23	0.1547682
26th February	0.218	0.14540715
27th February	0.206	0.140927688
28th February	0.21	0.149535075
1st March	0.208	0.131008375

TABLE 6.3: Results of the discharge measurements in State Creek

The results follow the rainfall trend (fig. 3.3), because February, March and April are considered dry months with progressively decreasing precipitations. The gauge height is increasing only on the 28th of February compared with the 27th of February, most likely because it rained. The higher water flow on the 28th compared with that of the 26th of February is another abnormality, since the gauge height is lower. This can be caused by small measurement uncertainties of the method used, occurring especially when the measurements of flow at gauge heights close to each other are carried out. According to [21], this finding does not imply that the value has to be excluded, because a curve built as best fit of the data is the goal of the measurements.

The first flow value is much higher than the other ones and could drag the best fit curve to the wrong direction. This was the first measurement taken by an inexpert operator, with flows in each segment far from the suggested 10% of the total water flow. Therefore, the first measurement can be excluded for technical reasons.

The main comment to the above results concerns the measurement period. The purpose of building a stage-discharge curve for a river is, as already mentioned, having a tool for knowing the discharge by only checking the gauge height. However, the measurements taken in State Creek are only confined to a period of one week during the dry season. Therefore, the gauge height-discharge relation like 6.1 that will be found with the available data is used only for the calculation of the discharge at gauge height readings on the wooden bar from the last day of measurement till the end of the dry season. When the gauge height will become larger than the largest of readings during the field trip, the relation will not apply anymore.

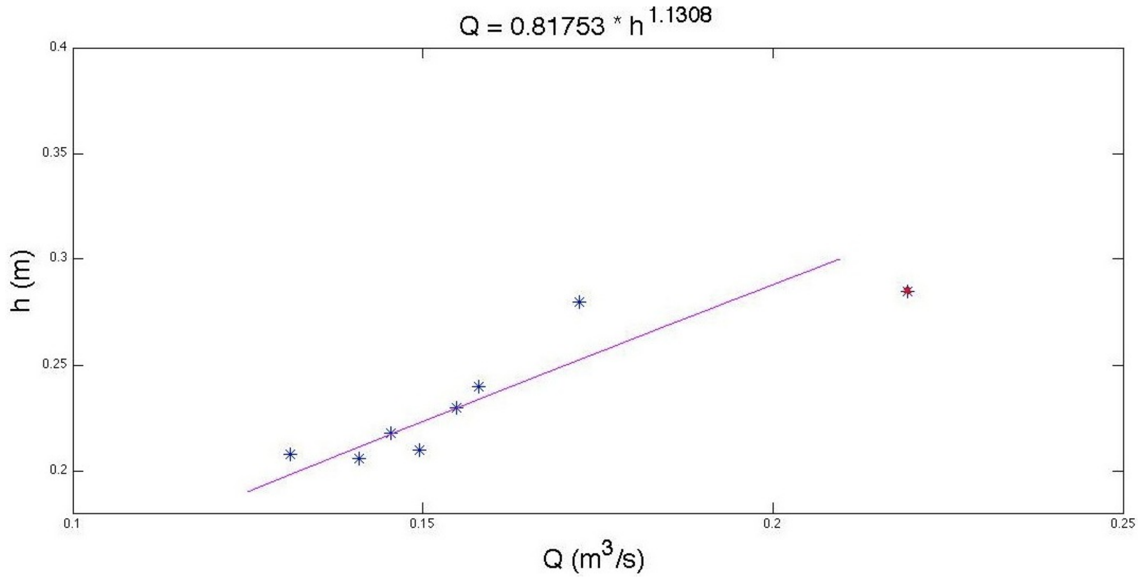
Further measurements have to be taken during the rainy season and combined with the already available ones, in order to find a stage-discharge relation valid for the entire year. This is part of the further work that has to be performed to complete this project.

Since water flow data are for the entire year are not available yet, only estimates can be made (described in 6.2.4).

Another comment about the measurements concerns the location of the gauging station that is different from the intake locations (1 and 2 discussed above). Compared to intake 2, the measurements at the gauging station are also including the water flow of one small branch (see fig. 6.1), while compared to intake 1, the measurements are including two branches. The water flow values of these branches are unknown. However, the main stream is carrying the biggest amount of water and a conservative approach will be used for the design of the plant components, taking these considerations into account.

6.2.4 Building the stage-discharge relation

As mentioned above, building the first part of the stage-discharge curve with the data available allows to find a relation between gauge height and discharge valid during the dry season. Finding the best fit curve for the measurements has been the challenge encountered in the processing of the collected data, since the curve has to be like eq. 6.1 and the constant n is constrained to be larger than 1.
For this purpose, the Matlab function *lsqcurvefit* was chosen, since it performs the "non linear curve fitting in least-squares sense" and allows to put boundaries on constants ($n > 1$). This function is not discussed any further, because the purpose of this work is providing a method and solutions for the analysis of the energy supply of the Wawashang Complex. The code written for finding the best fit curve is shown in Appendix C and additional details are on the webpage [22].
Fig. 6.9 shows the two stage-discharge relations, obtained with *lsqcurvefit*. The equations of the curves are written on the top of the graphs. The first curve includes the first measurement, marked with a red dot; the second excludes the first value from the vector of measurements.
Both graphs show a linear trend, since they describe only the behavior of the river in the first part of the curve.



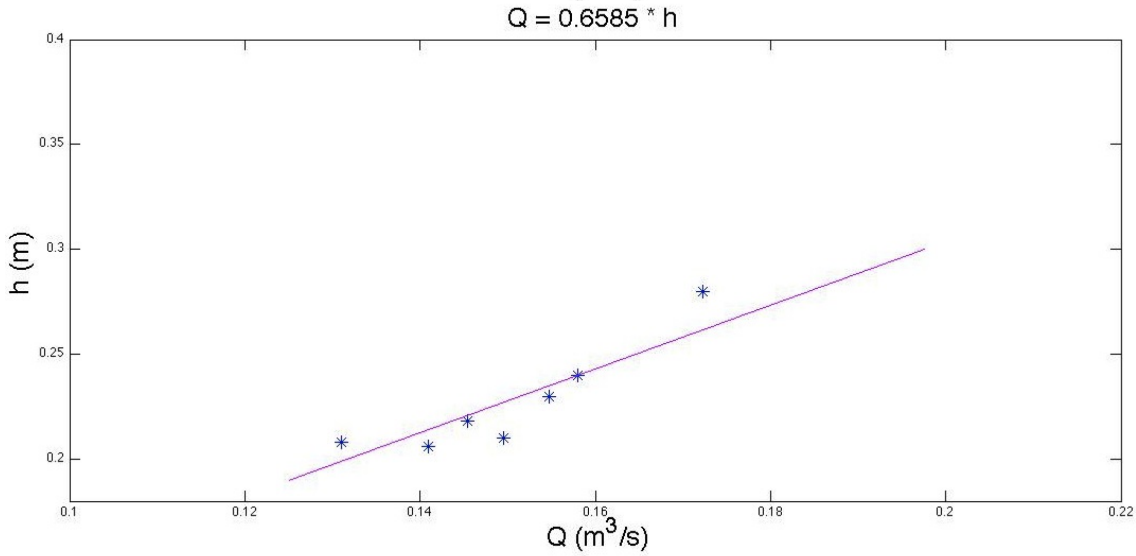


FIGURE 6.9: Stage-discharge relations of State Creek
Above: 1st measurement included
Below: 1st measurement excluded

The second curve is used in this work.

6.3 The water flow of the whole year

Generally speaking, a hydrograph[2] and an exceedance curve (FDC)[3] are needed to find the proper design flow for a hydropower plant. Data for at least one year

[2]Graph with water flow on the y-axis and time on the x-axis
[3]Graph with percentage of time on the y-axis and water flow on the x-axis

have to be collected in order to build these curves.

As already mentioned, the linear relation $Q(m^3/s) = 0.6585 \cdot h$ (fig. 6.9) can be used only for the calculation of the water flow during the dry season, more precisely for gauge heights lower than $h = 0.28m$; this represents the largest reliable value of the gauge-height observations.

Additional measurements should be carried out during the rainy season in order to complete the relation for high flow rates. Moreover, the stage data have to be collected for at least one year. This will be done daily by a member of FADCANIC (Yoel, already involved in the measurement of the head) for at least one year except Sundays. Gauge height data collected by Yoel until the 13th of June 2013 are shown in Appendix C, together with the respective discharge estimates.

In order to assess the feasibility for a micro hydropower installation, estimates of the water flow during the year are needed. After the field trip, two methods were for this purpose.

The first is the most commonly applied: a gauged river was found in the area and its water flow could have been scaled to State Creek (with eq. 2.5). The second one is based on the use of the precipitation data.

The former did not give the expected results, while the latter is unreliable for the design of a micro hydropower plant. Therefore other solutions for the choice of the design flow will be described in Chapter 7.

However, both methods are presented, since they can be used in similar cases.

6.3.1 Estimate using the water flow of Rio Escondido

Rio Escondido is a big river of the Atlantic Coast of Nicaragua, located in the water basin neighboring to Wawashang; it has a drainage area of $11,650km^2$. INETER owns a gauging station on Rio Escondido in the area of Rama. Unfortunately, discharge values are not available and only the gauge height of the river is monitored[4]. Daily values of gauge height from 2009 to 2012 were received from

[4]The gauge height is monitored because the region of Rama is prone to floods and Rio Escondido is crucial for the navigation to the Atlantic Ocean

INETER, together with the shape of the section of the river. No gauge height - discharge relation seems to be available.

Assuming a slope S of 0.1% (since the area is really flat, according to INETER) and a Manning coefficient n of 0.025 [23], the Manning formula is used for the estimate of the water flow:

$$Q_{Rio\,Escondido} = \frac{S^{1/2} \cdot \left(\frac{A}{p}\right)^{2/3}}{n} \tag{6.5}$$

Where A is the area of the cross section and p the wet perimeter, both varying with the gauge height. Therefore, the daily water flow of Rio Escondido was estimated with the Manning formula.

The drainage area ratio can then be used as in eq. 2.4 to estimate the water flow of State Creek throughout the whole year and corrected using the measured data. This is done under the assumption that Rio Escondido has hydrological, geological and watershed characteristics comparable to State Creek.

However, the average water flow of Rio Escondido estimated with Manning was two orders of magnitude different from its average calculated with the hydrological data from MARENA (see Chapter 5); the shape of the section of Rio Escondido might not respect the requirements needed for the use of the Manning formula. Based on these results, this method of estimate was dropped.

6.3.2 Estimate using the precipitation data

The water flow measurements performed in the end of February 2013 seem to be coherent with the precipitations: $0.282 m^3/s$ is the estimated average water flow of State Creek, while the measurements' range is between 0.131 and $0.172 l/s$; the estimated average water flow was calculated using the runoff data from MARENA, together with eq. 2.3 and eq. 2.4, with a drainage area A^* of $12.12 km^2$.

Runoff, derived from the precipitations, were used for the estimate of the water flow during the rest of the year [24]. Then, a hydrograph and an FDC could be built.

The FAO software (see Chapter 3) gives the daily precipitation values and therefore was used for the estimates.

The idea of the estimate is finding a vector of ratios between available water flow data and the precipitations. Then an average of this vector can be used to adjust the precipitations to find the water flow during the whole year.

The available water flow data are found inserting the gauge heights available so far (from the 19th of February till the 30th of April) in $Q(m^3/s) = 0.6585 \cdot h$.

Fig. 6.10 shows the hydrograph and the FDC found with this estimate.

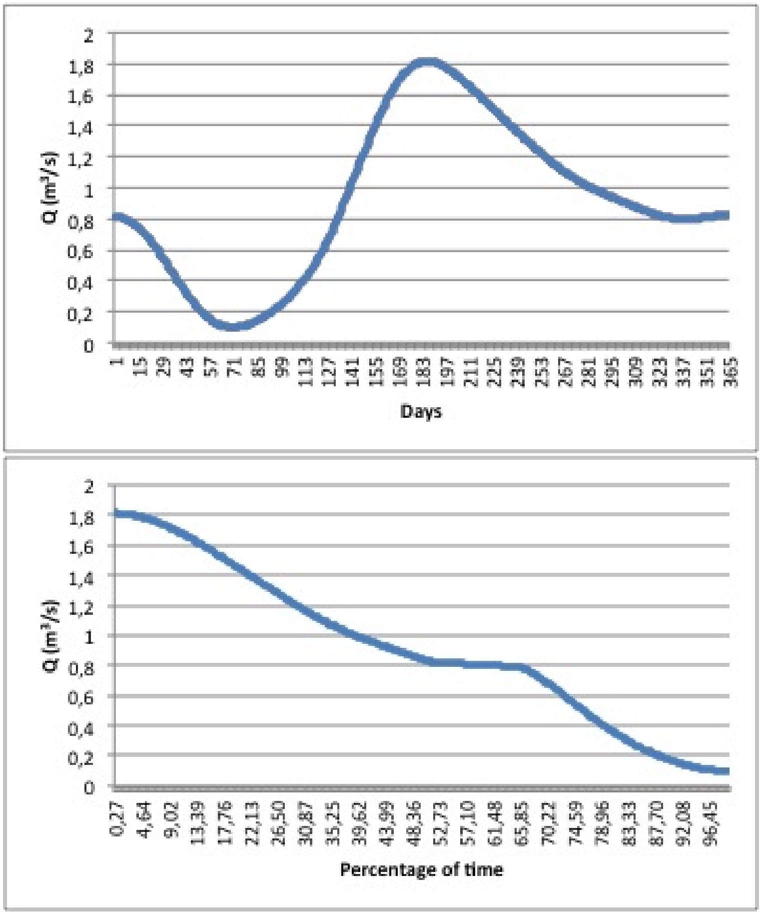


FIGURE 6.10: Estimate of hydrograph and FDC of State Creek using the precipitations

However, it must be pointed out that this estimate is of little use for a design since the rainfall and the discharge are not directly proportional: the relation is complex and changes throughout the year. In addition, the calculation method of the runoff data by MARENA is unknown.

Anyway, the results are presented because they will be used to support the feasibility study. In addition, once real data will be available, it will be interesting to compare them with the estimate.

6.4 Pumping water stations

As already mentioned at the beginning of this Chapter, State Creek water is sometimes pumped to irrigate the crops and fill the water tanks of the buildings of the Complex.

Crops watering is occurring mainly during the dry months (i.e. March, April and beginning of May). On the contrary, water is pumped to fill the water tanks also during the rainy season.

Water for irrigation and sanitation has the priority over power generation. Therefore these activities have to be taken into account in case of designing a micro hydropower installation.

As shown in fig. 6.1 and fig. 6.11, two pumps extracting water from State Creek are currently installed (called "Bombeo Rio" in fig. 6.11), both driven by gasoline generators.

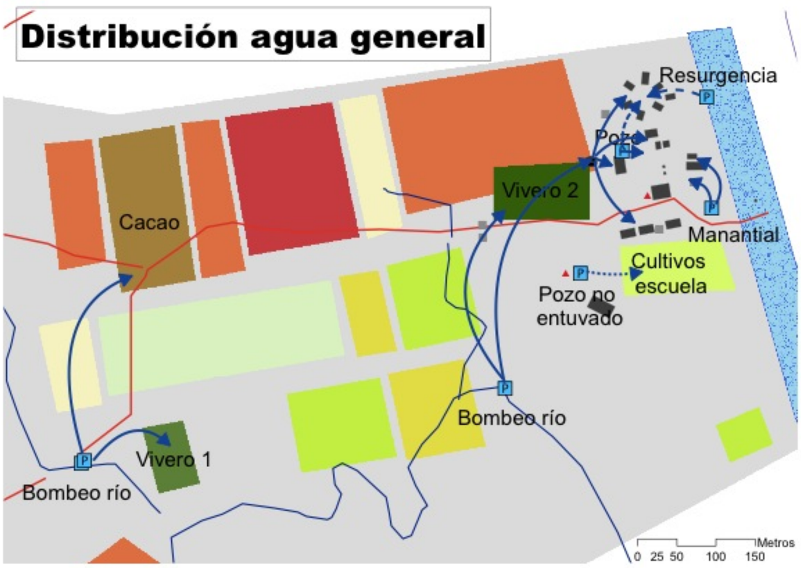


FIGURE 6.11: Water system in Wawashang [11]

Fig. 6.11 shows also two pumps extracting water from wells in the ground (two blue squares on the right of the map, next to the buildings of the Complex). These two pumps are powered by gasoline generators as well.
The analysis carried out in this project will only focus on the pumps on State Creek. The first one is downstream both the micro hydropower locations (1, 2, 3 and 4) and the gauging station. Therefore it will not affect either the measurements or the power output.
On the contrary, the other pump is located before the gauging station and will influence the measurements. As shown in fig. 6.11, this pump is providing water to Vivero 1 and the Cacao field (the latter only in very dry years).
There is no measurement of the pumping; only an estimate was done by an environmental engineer working for FADCANIC (Dr. Eng. Blunier Pascal). According to his estimate, an amount of water around 0.8-1l/s is pumped for 4-5h every day during the dry season.
Therefore, the impact of the quantity of water pumped for irrigation purposes can be neglected, because much lower than the water flow of State Creek (estimated to be 65l/s in the end of April).

If more water will be needed for irrigation, pumping at night would be a solution for preserving the water flow used for power generation.

Chapter 7

Design of a micro hydropower installation on State Creek

7.1 Preliminary discussion about the design

Before starting a micro hydropower design, common practice is discussing the available alternatives to the micro hydropower installation such as connection to the national grid, other renewable energy sources or diesel generators [4].

The purpose of this project is finding a way to improve the present system, not alternative to it, in order to maximize its efficiency, reduce the fossil fuel consumption and increase its power. Solar power and diesel generators, as discussed in the previous Chapters, are already used in the buildings of the Wawashang Complex. Therefore other renewable sources, like biomasses and micro hydropower, could be introduced in the system to support the installed power generation system to improve efficiency, sustainability and reduce the operating costs.
The design of a micro hydropower plant on State Creek and its feasibility are the focus in this project.

Regarding the grid connection, FADCANIC members consider it as a possible future project, but they suggested, for the moment, the development of an optimal “off grid” solution.

7.2 Considerations about the design flow

As mentioned in the previous Chapter, three potential beneficiaries of the micro hydropower plant in State Creek are considered in the design. This will result in three different design options, trying to forecast the needs of the users.
The design flow represents the main parameter influencing the design, because it will determine the power output and the period throughout the year when power is supplied, dependent on the water flow. In addition, the design flow will influence the size of the equipment and consequently its installation cost.

An FDC is usually used to get the design flow, since it shows the flow availability throughout the year.
Since no reliable FDC is available for State Creek, the design has been based on the measurements performed during the field trip, the values obtained thanks to the gauge height-discharge curve (only till the end of the dry season) and assumptions from the precipitation data (fig. 3.3).
In this project, the design flow will be constrained by the available technologies compatible with the head and the range of flow of State Creek, as described in the following sections.

A residual flow, considered in the design, has to be left in the river in order to preserve life in the stream. According to the approaches and references presented in Chapter 2 three different values can be used:

- around $30l/s$ is the 10% of the medium annual flow. The medium annual flow is $282l/s$ according to the estimate with the runoff.
- $50l/s$ was suggested by Katie Brown.

- $6l/s$ is the 15% of the minimum flow (the flow at the beginning of May is estimated to be around $40l/s$).

Considering all the different options, a reasonable and conservative choice of residual flow between 30 and $50l/s$ is used in this project.

7.3 Three different design scenarios

According to the three beneficiaries mentioned in Chapter 6, three design scenarios are considered, with different design flows and components:

- *Scenario A*: the house of the farmer Don Epifanio is the only beneficiary. The design takes into consideration the little power needs for domestic uses during the whole year ($0.2kW$-$0.5W$), as some lights and a few appliances. The house of the farmer is located nearby the possible location of the micro hydropower installation, allowing a short transmission line.

- *Scenario B*: the coconut grinding machine is the beneficiary. According to [10], the machine needs $1Hp = 0.746kW$ and will be bought soon. The machine could be located next to the river, reducing the transmission costs from the micro hydropower plant. It requires a reasonable higher power than the *Scenario A*, with no need of continuous supplying throughout the year. The power demand of the coconut processing might be higher if other processing machines will be bought in the future.
  Since the coconut grinder works during the day, the micro hydropower plant designed for this scenario could provide energy to the farmer's house at night.

- *Scenario C*: the Wawashang Complex is the beneficiary. The design of the micro hydropower plant should support the present installed energy supply (PV panels), providing the maximum possible power during the rainy season. The plant can then be shut off for some of the dry months.

This design scenario is therefore considering the micro hydropower installation as part of a micro grid together with solar and gasoline generators (and maybe biomasses in the future).
About $1km$ of transmission line is needed to connect the micro hydropower plant to the electrical system of the Complex[1].

The design will therefore be based on the previous considerations and on the available technologies that can be suitable for the site of interest.

7.4 Design of components

Civil work components (intake, settling basin, waterway, etc) and turbine are the main components that need to be purchased or designed.

The choice will follow the rule to purchase equipment in Nicaragua or, at least, in neighbouring countries, in order to reduce initial and maintenance costs. Unfortunately, this is not always feasible, since Nicaragua is poorly industrialized.
The shipping cost to Managua was obtained from Powerpal, one of the vendors of turbines presented in the next sections. This company informed that the shipping cost from Vietnam[2] is around 1,000 US$[3] per $1.5m^3$.
The manual labor of the skilled members of FADCANIC is supposed to be used as much as possible in case of installation.

The first big issue in the design was finding the starting point of the design. The turbine was chosen as beginning point, because the low head site and the small budget reduce the amount of suitable machines available on the market.
Once the turbine is chosen, the water flow and the head of the plant are also determined.

[1] BlueEnergy informed that $300m$ of AWG#6 wire for the micro grid in Kahka Creek cost 600US$. In addition the cost of the poles (one each 25-30m, free if in wood) and the one of the connectors to the posts (4-5US$ each) have to be added

[2] The Powerpal turbine is manufactured in Vietnam

[3] There is a minimum charge for $1.5m^3$ even though the equipment occupies lower volume

More than one turbine solution is proposed for each scenario (A, B and C), according to the different needs. Among all the possible solutions, a choice will be made.
A conservative approach will be used in order to forecast the time of availability of a certain flow rate, since no reliable flow rate estimate during the whole year was found (Chapter 6).

The waterway is then designed to match the requirements of the turbine. In this thesis work, the waterway design will be presented for only one turbine solution.

7.4.1 Turbine

The turbine needs to be chosen according to the available site head and flow. Fig. 7.1 shows the head-flow ranges for some turbine types for micro hydropower generation.

A head between 3 and $5m$ is considered available on State Creek, as explained in Chapter 6.

According to fig. 7.1, pumps as turbines (PATs)[4] are the only solution close to match the site requirements.
According to [25], the head range of PATs can be extended down to $5m$ by using a six pole generator.
However, after an email conversation with the author of [25] (Arthur Williams), the PATs option was dropped because the head available in State Creek is too low.
PATs would have been a really good solution for this project, because of the following advantages: for outputs below $10kW$ the cost of PATs is likely to be significantly lower than crossflow turbines or Pelton for heads less than $30m$. Moreover, turbines have usually to be designed for a certain site, raising the cost, while PATs

[4] End-suction centrifugal pumps can be used as turbines

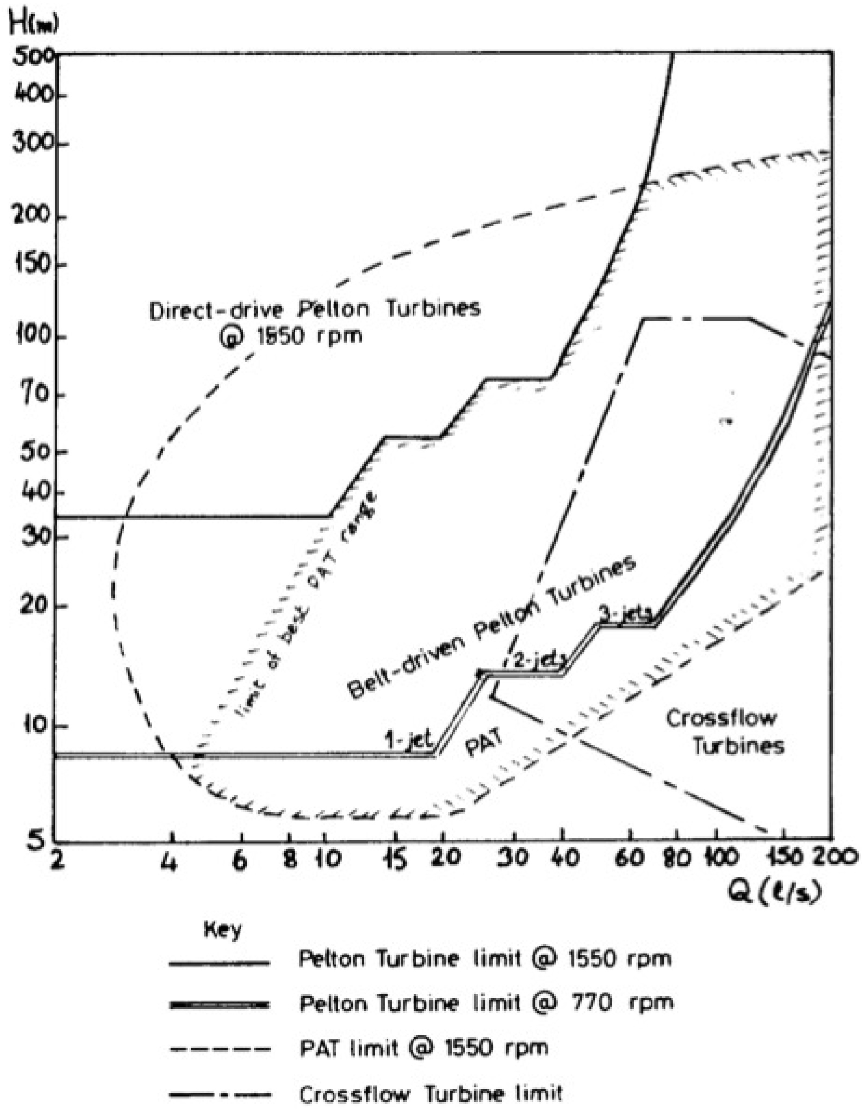


FIGURE 7.1: Head-flow ranges of some types of turbines [25]

can be chosen directly from the supplier's catalogue for a certain head and water flow. In addition, in many countries all over the world, there are many companies manufacturing pumps for water supply and irrigation purposes in large quantities, whereas there might be no local production of water turbines.

Several low-head turbine solutions suitable for the site requirements in State Creek exist on the market, even though they do not appear in fig. 7.1. They will be described in this Chapter.

During the turbine selection process, the head will be kept as low as possible in order to minimize the waterway from the intake to the turbine.

Seven different types of turbines are presented for the site. Each turbine is chosen to match the design requirements of one or more of the three scenarios (A, B and C).

After some research, only one turbine workshop was found in Nicaragua, where turbines are designed and constructed. Its name is ATDER-BL, located in the municipality of Cua/Bocay, where Pelton and Michell Banki turbines between 10 and 15kW are manufactured (according to a member of PCH, Elias Juarez Moya). Unfortunately, these turbine sizes are not compatible with the characteristics of the site on State Creek.
Anyway, the company's experience in micro hydropower installations could be an effective support for the development of the project.

7.4.1.1 MH (Medium Head) 3kW Exmork Tubular Turbine

Exmork New Energy Company (China) is selling tubular turbines for medium head power stations with heads of less than 20m and the diameter of the runner less than 3m.
The table in fig. 7.2 shows the turbine sizes for medium head available.

Model	Power (W)	Head (m)	Rate of flow (m3/s)	Rotational Speed (rpm)	Install tube diameter (mm)
→ MH-3KW	3000	4	0.136	1000	250
MH-6KW	6000	7	0.156	1500	300
MH-10KW	10000	11	0.165	1500	300

FIGURE 7.2: Medium Head Water Turbines [26]

The MH3kW indicated by a red arrow is one turbine solution chosen for *Scenario B* (coconut processing) and *Scenario C* (Wawashang Complex). It operates with a water flow of $136l/s$ and $4m$ of head, providing $3kW$ of power. The pipe diameter that has to be installed is $250mm$. The price of the unit is 6,679 US$. The turbine is coupled with a single phase neodymium permanent magnet generator; it provides power at $120V$-$60Hz$ and is sold together with the turbine.

Considering that a residual flow between 30 and $50l/s$ is left in the river as discussed above, this runner can operate only when the river flow is above 170-$190l/s$. According to the FDC estimate obtained from the precipitations (fig. 6.10), this water flow is available around 80% of the year. The estimate with the precipitations is, as already mentioned, full of uncertainties. Therefore, 7 months (between June and December) can be selected as a conservative forecast of the operation time of this turbine.
As a consequence, the coconut processing facility (*Scenario B*) can concentrate its automatic production during the 7 months; if additional production is needed when the plant is switched off, cocos can be processed manually as they are at the moment. If power was given to the Wawashang Complex (*Scenario C*), the micro hydro installation could integrate the other energy systems of the Complex in a micro grid. During the dry season, indeed, the power production by PV panels is at its maximum.

The MH 3kW, compared with the traditional vertical axial units, has simpler structure and larger volume of cross flow, less civil works are needed and maintainance is easier as well.
It is installed in an "S" type flow pipe and the axis of turbine pierces through the pipe wall, connecting then with the generator installed outside the pipe.
Between the turbine and generator there can be easily installed an accelerator in order to make the speed of the turbine out of the constraint of the synchronous speed.
The overall layout changes with the size of the unit, capacity and the specific circumstances of hydropower stations. For example, generators can be either installed in the upstream side of the turbine ("front axle stretch") or in the downstream

side ("rear axle stretch"); the axis can be either level ("level axle stretch") or tilted ("tilted axle stretch"); the "S" curve of the pipe can be both vertical and level, but it may also be tilted.

Fig. 7.3 shows a turbine application "front axle stretch" and vertical axis (on the left) and a "level rear axle stretch form" (on the right).

The latter, according to [26], having the generator horizontally installed above the draft tube downstream side of the turbine, is the most interesting design.

FIGURE 7.3: Medium Head Water Turbines
Left: "front axle stretch" and vertical axis [26]
Right: "level rear axle stretch form" [27]

The GD-LZ-20-3kW, sold by several Chinese companies, is a tubular turbine with the same design parameters as the MH 3kW. Suzhou Yueniao Machinery & Electronics Imp & Exp Co. (China) is selling it for 4,692 US$, while Fuchun Industry Development Co. (China) for 6,864 US$.

7.4.1.2 LH (Low Head) 500 Exmork propeller turbine

Exmork New Energy Company (China) is also manufacturing low head propeller turbines. The different sizes available are shown in fig. 7.4.

Model	Power (KW)	Water head (m)	Flow (m3/s)
LH-300W	0.30	1.8	0.04
LH-500W	0.50	2	0.045
LH-700W	0.70	2.2	0.05
LH-1KW	1.00	2.5	0.05

FIGURE 7.4: Medium Head Water Turbines by Exmork [26]

The LH-500W indicated by a red arrow is one turbine solution chosen for *Scenario A* (house of farmer). It requires a water flow of $45l/s$ and a head of $2m$.
The turbine is made to receive water through a channel and therefore no pipe diameter was recommended by the supplier. However, the water could be piped till a settling basin and then through channel to the turbine.
The price of this unit sold by Exmork is 585 US$. It is sold together with a permanent magnet generator, that produces power at $120V$-$60Hz$.
The turbine unit is shown in fig. 7.5.

FIGURE 7.5: Low Head Water Turbine by Exmork [26]

Considering a residual flow between 30 and $50l/s$, a river flow between 75 and $95l/s$ is needed to run this turbine. According to the FDC estimated with the precipitations this water flow could be available the whole year. However, the stage-discharge curve and the gauge height data revealed a lower water flow ($65l/s$) at the end of April. Using a conservative approach again, a water flow of 70-$90l/s$ could be considered available for 9-10 months, between May and January.

The $0.5kW$ installation could provide the farmer Don Epifanio Vargas sufficient power for lighting, some appliances, a fan and a fridge.

This solution might reduce the installation cost since it requires a head of only $2m$ and therefore shorter waterway.

7.4.1.3 LH (Low Head) 1kW by ES&D and Exmork

The company Energy Systems&Design (ES&D, Canada) and Exmork are manufacturing a low head turbine that gives $1kW$ output, the LH1kW. It could be a solution for the farmer (*Scenario A*) or the coconut processing facility (*Scenario B*).
However, it might offer more power than the amount the farmer needs resulting not economically convenient for *Scenario A*.
The best option would be using this turbine to grind coconuts during the day and provide power to the farmer at night.

As shown in fig. 7.4, the LH1kW by Exmork works with $50l/s$ and a head of $2.5m$.

The turbine specifications presented in the ES&D's manual are more detailed than the ones offered by Exmork.
Table 7.1 shows the power output chart taken from the manual, with varying performance at different water flows and heads and suggested pipe diameters.

Head (m)	Q (l/s)	P (W)	Minimum Pipe Diameter (mm)
0.61	28.35	70	203.2
0.91	34.65	150	254
1.22	40.01	250	254
1.52	44.73	350	254
1.83	48.83	465	304.8
2.13	52.92	585	304.8
2.44	56.39	715	304.8
2.74	59.85	850	304.8
3.05	63	1000	304.8

TABLE 7.1: Performance of LH 1000 by ES&D

The ES&D LH1kW can work in a head range of 0.6-3m and is equipped with a brushless permanent magnet generator. As shown in the table, the water flow is determined by the head, as there is no equipment that changes the flow.

More or less the same considerations about the water flow as for the LH500 by Exmork can be made for both the LH1kWs. Therefore a plant with LH1kW could run 9 months on State Creek.

A pipe can be used to lead water from the intake to a settling basin and then through a channel to the turbine, as suggested previously for the LH500 Exmork unit.

The ES&D and Exmork unit cost 2,975 US$ and 888 US$ respectively.

7.4.1.4 MHG-500LH, low head turbine by Powerpal

Powerpal (Canada) is manufacturing low head turbines as well. The different sizes available are shown in fig. 7.6.

	MHG-200LH	MHG-500LH	MHG-1000LH
Water head	1.5 m	1.5 m	1.5 m
Water flow	35 l / sec	70 l / sec	130 l / sec
Output Power	200W	500W	1000W

FIGURE 7.6: Low head water turbines by Powerpal [28]

MHG-200LH or MHG-500LH, providing $0.2kW$ and $0.5kW$ respectively, are possible solutions for *Scenario A* (house of farmer). The bigger unit MHG-1000LH was not considered, because a power plant needing $130l/s$ could operate only 7 months, while the farmer should have power for a period as long as possible.

MHG-200LH and MHG-500LH operate with $1.5m$ of head and require $35l/s$ and $70l/s$ of water flow respectively.
The waterway can be only a channel for both the units and its length (and costs) reduced significantly, due to the very low head.

The turbine units are sold together with the generator (single phase permanent magnet generator, $120V$-$60Hz$), the electronic load controller and spare lower bearings. The price of the whole kit is 343 US$ for MHG-200LH and 674 US$ for MHG-500LH. In addition, the required inlet canal and draft tube cost 113 US$ for MHG-200LH and 171 US$ for MHG-500LH.

Considering a residual flow between 30 and $50l/s$, a river flow of 65-$85l/s$ has to be available to run MHG-200LH and 100-$120l/s$ for MHG-500LH.
Using a conservative approach again, MHG-200LH could be operated for 9-10 months and MHG-500LH for 9 months.

The head of only 1.5m reduces considerably the investment costs, since the waterway will be shorter.

One of these two turbines can provide power to the farmer (*Scenario A*) in order to supply resistive loads. If some reactive loads[5] need to be powered, a cooling kit of the generator might be needed [29].

7.4.1.5 ZD series low head turbines by Yueniao

Suzhou Yueniao Machinery & Electronics Imp & Exp Co. (China) is also producing a series of low head turbines, shown in fig. 7.7.

MODEL	Runner Diameter	Water Fall (m)	Water Flow (m3/s)	Power (W)	Speed r/min	Price EX WORKS
ZD1.8-0.3DCT4-Z	120mm	1.7 ~ 2.0 (5~6feet)	0.04	300	1500	Sample USD388 >5 pc USD288
ZD2.0-0.5DCT4-Z	120mm	2.0 ~ 2.5 (6~6.6feet)	0.045	500	1500	Sample USD525 >5 pc USD425
ZD3.0-0.7DCT4-Z	120mm	2.5 ~ 3.0 (6.6~7feet)	0.05	700	1500	Sample USD604 >5 pc USD504
ZD3.5-1.0DCT4-Z	150mm	3.2 ~ 3.5 (7~8.2feet)	0.05	1000	1500	Sample USD754 >5 pc USD654

FIGURE 7.7: Low Head Water Turbines by Yueniao [29]

The unit providing 0.5kW at 120V and 60Hz is selected for *Scenario A*.
This turbine is working with 2-2.5m of head and 45l/s of water flow. The unit is sold with a simple single-phase brushless permanent magnet generator. The cost is 578 US$, including the generator.

The considerations about the water flow are the same as for LH500 by Exmork and LH1kW by ES&D and therefore a plant with this machine could run 9 months on State Creek, using a conservative approach.

[5] Battery chargers, low voltage lighting transformers, etc

Also in this case, the installation cost will benefit of the low head, that will reduce the length of the water way.

7.4.1.6 Summary of the possibilities and final choice

The possible turbine solutions for the three scenarios (Sc.) are summarized in table 7.2.

Sc.	Model	Vendor(s)	Q(l/s)	H(m)	P(kW)	Months	Cost(US$)
A	LH-500W	Exmork(China)	45	2	0.5	9-10	585
	LH1kW	ES&D(Canada)	63	3.05	1	9	2,975
	MHG-200LH	Powerpal(Canada)	35	1.5	0.2	9-10	343+113
	MHG-500LH	Powerpal(Canada)	70	1.5	0.5	9	674+171
	ZD2.0-0.5DCT4-Z	Yueniao(China)	45	2-2.5	0.5	9-10	525
B	MH3kW	Exmork(China)	136	4	3	7	6,679
	GD-LZ-20-3kW	Yueniao(China)	136	4	3	7	4,692
	GD-LZ-20-3kW	Fuchun(China)	136	4	3	7	6,864
	LH1kW	ES&D(Canada)	63	3.05	1	9	2,975
	LH1kW	Exmork(China)	50	2.5	1	9	888
C	MH3kW	Exmork(China)	136	4	3	7	6,679
	GD-LZ-20-3kW	Yueniao(China)	136	4	3	7	4,692
	GD-LZ-20-3kW	Fuchun(China)	136	4	3	7	6,864

TABLE 7.2: Summary of the possible turbine solutions

The final choices for each scenario are highlighted and can be justified as follows:

- *Scenario A (The farmer)*: MHG-200LH and MHG-500LH (output of 0.2kW and 0.5kW) by Powerpal (Canada) are chosen because the low head minimizes the costs of the waterway. These turbines are manufactured in Vietnam and the minimum volume for shipping to Managua is 1.5m^3, costing around 1,000 US$. The MHG-200LH and MHG-500LH shipping packages occupy 0.5m^3 and 1m^3 respectively. Therefore, shipping 3 pieces of MHG-200LH would be the most convenient option, if needed in other locations in Nicaragua. The choice between 0.2kW and 0.5kW depends on the amount of power needed by the farmer.

- *Scenario B (The coconut processing facilities)*: GD-LZ-20-3kW (output of 3kW) by Yueniao (China) and LH1kW (output 1kW) by ES&D (Canada)

are considered.
The LH1kW by ES&D is chosen in this project instead of the one by Exmork, because of the worldwide known Canadian expertise and product reliability in hydropower systems (the LH1kW by Exmork could also be chosen because less expensive, but taking into account possible lower quality and reliability in shipping).
The choice between $1kW$ and $3kW$ depends on the size of the facilities. LH1kW can be used if power is only needed for the coconut grinding machine.

- *Scenario C (The Wawashang Complex)*: GD-LZ-20-3kW (output of $3kW$) by Yueniao (China) because the least expensive one.

In the following section, a waterway preliminary design for LH1kW (by ES&D) is presented. This solution was chosen as example of civil works design, because it is the most useful solution, providing power both to the coconut grinder and to the farmer.
MHG-200LH and MHG-500LH, providing power only to the farmer, are less expensive solutions, because of the lower turbine and waterway costs. Therefore, they should be considered when taking the final decision.

7.4.2 Waterway design for LH1kW by ES&D

Civil works (intake, settling basin and waterway the most important) represent the costly and tricky part of the design, especially for the case considered in this project, since the head on State Creek happens over a long distance. Therefore, the following is only a preliminary design, while proper final design of the civil works should be done by a civil engineer.

According to the performed measurements, the heads of $3m$ and $5m$ on State Creek happen on a distance of around $200m$. Even though future measurements might reveal a shorter distance, the preliminary design will be based on these measurements.

A preliminary design of the waterway will be done, while intake and settling basin are part of further work. The waterway is the only focus of the design among all the civil works because it represents the highest investment cost. Fig. 7.8 shows an installation of LH1kW in an environment similar to the Wawashang area.

FIGURE 7.8: Installation of LH1kW [30]

Due to the long distance a lot of land works might be needed in order to reach a fall (an example is shown in the figure above).

All hydro systems require a waterway. A waterway usually consists of a channel and/or a pipe.
The use of water drainage pipes and/or open flumes is the most convenient option for such a low head system like the one in State Creek.
Low head systems, indeed, do not require a pressurized pipe, known as penstock, typical of high head schemes. Pressurized pipes are expensive and increase the investment cost significantly.

A possible system layout for LH1kW with pipe is shown in fig. 7.9, taken from its manual [29].

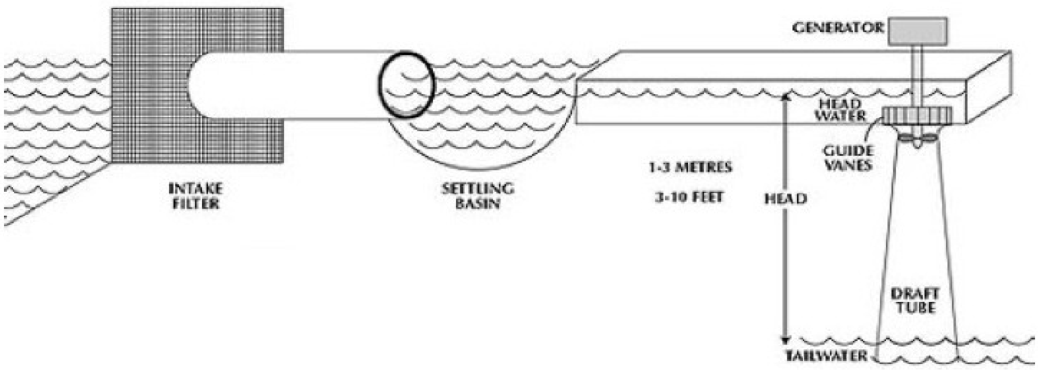


FIGURE 7.9: Installation of LH1kW [30]

An open flume made of wood, metal, plastic or masonry can be used instead of the pipe if labour is inexpensive.

A pipeline choice and open flume possible design are presented below.

7.4.2.1 Waterway with PVC pipe

PVC drainage pipes are the least expensive choice among the closed waterways. They can be chosen with thin walls in a low head system like the one foreseen in State Creek.

PVC pipes should be buried to be protected against damages, especially if the walls are thin. If the pipe is not buried, it needs to be painted on the external surface as protection against ultraviolet radiation.

In addition, pipes should be laid down with a slight slope, in order to avoid air blocks. In State Creek, it can be decided to have a fall of $1m$ over the total distance of $200m$ (that means $5cm$ every $10m$). This is one of the biggest challenge of the design, because it implies that civil engineering has to be quite precise, since the head happens over a long distance.

Durman is a company selling PVC pipes. It was founded in Costa Rica and

has a vendor in Managua. The single pipe unit sold by Durman is $6m$ long. Specifications of pipes sold by Durman are shown in Appendix D.
Four different thin wall pipes[6] by Durman with nominal diameters of $250mm$ and $300mm$ are compared below (smaller diameters would have led to high friction losses).

The assumptions in table 7.3 are used in the calculation of the head loss and SF (Safety Factor, to choose the proper thickness to withstand over pressures). The water flow ($Q_{net} = 63l/s$) follows the choice of LH1kW as turbine.

The calculation procedure used follows the method described in [4] (the equations are in Appendix E) and the results of the comparison are presented in tab 7.4.
Turbulence losses are neglected, since the exact path of the pipes is unknown.

Water Flow "Q_{net}" (l/s)	63
Gross Head "H_{gross}" (m)	5
Pipe Length "L_{pipe}" (m)	200

Table 7.3: Assumptions for the pipe calculations

	Pipe 1	Pipe 2	Pipe 3	Pipe 4
Nominal diameter "D" (mm)	250	300	300	300
SDR ("D/t")	32.5	32.5	41	64
Wall thickness "s" (mm)	8.41	9.96	7.9	5.05
Internal diameter "d" (mm)	256.23	303.93	308.05	313.75
Wave velocity "a" (m/s)	286.67	286.45	254.35	202.93
Total head "H_{total}" (mm)	40.65	30.35	26.86	21.86
Safety factor "SF"	4.52	6.05	5.35	4.12
Roughness "k" (mm)	0.01	0.01	0.01	0.01
Head loss (m)	0.92(18.4%)	0.42(8.4%)	0.38(7.6%)	0.34(6.8%)
Unitary cost $US\$/6m$	174.34	219	<219	<219

Table 7.4: Comparison of PVC pipe options sold by Durman

The costs do not include taxes and the labour cost needed to lay down the pipes. A contact person in Durman informed that, if more units will be purchased, a

[6] Thickness of pipes is determined by the SDR, ratio between nominal outer diameter (D) and thickness (t).

discount will be applied.

The cost of the Pipe 1 was obtained from the company, while the one of the Pipe 2 was estimated assuming the cost of pipes grows linearly with the diameter. The cost of Pipes 3 and 4 should be asked to the company because unknown. They are certainly less expensive than Pipe 2, due to the thinner walls.

According to [4], an SF factor higher than 3 can ensure that the pipe withstands over pressures.

Therefore, Pipe 4 is chosen, being the cheapest and the one with the lowest friction losses. Even though it has an SF higher than 3, valves should be shut off slowly during operation anyway. Due to the thin walls of this pipe, burying it would be the best solution.

7.4.2.2 Waterway with open flume

In countries where low-cost labour is available, an open flume can be a good alternative to the pipes.

An open flume in Rwanda is shown in fig. 7.10 and it could be an example for a similar one in Wawashang. The book [4] proposes an iterative method for channel

FIGURE 7.10: Open flume of a micro hydropower installation in Rwanda [31]

design; first, a suitable water velocity in the channel is chosen; then, size of channel and head loss are calculated. If the head losses are too high, the calculation can be repeated for lower velocity and therefore larger cross-sectional area. If the losses are very low, the velocity could be increased, reducing the costs to build up the channel.
This method is used for the channel design below.

The following principles regarding the choice of water velocity have to be remembered before starting any design procedure:

- Water velocity should be high enough to ensure that sediments do not settle on the bed of the channel.
- Water velocity should be low enough to ensure that the internal side of the walls of the channels are not eroded.
- The head loss grows with the velocity of the water.
- The lower the water velocity the larger the area, the higher the costs.

The channel design here presented is based on the assumptions in table 7.5.

Water Flow "Q_{net}" (l/s)	63
Gross Head "H_{gross}" (m)	5
Channel Length "$L_{channel}$" (m)	200

Table 7.5: Assumptions for the channel design

The channel materials considered are concrete and wood; the former because of the availability of skilled bricklayers in the neighbouring villages. The latter because of the availability of wood at the location and because of the skilled carpenters working at the Complex. In both cases, if the ground is excessively porous, the channel needs to be sealed, in order to reduce seepage.
The cost of a concrete channel is estimated to be around $50\$/m$, including materials and manual labour, according to the responsible of the Agroforestal Innovation Program (Mrs. Susanne Thienhaus [10]). On the contrary, the choice of a

wooden channel might imply no need to purchase materials, because available at the Wawashang Complex. In addition, the skilled carpenters know how to manufacture and join the boards. The only remaining cost would be manual labor for laying down the channel.

The design will give the same results for both concrete and wood, since the roughness, for channel heights lower than $1m$, depends only on the height (see Appendix F and [4]).

The cross section of the channel can be either rectangular or trapezoidal.
Fig. 7.11 shows the main dimensions of the cross section of a trapezoidal channel. The trapezoidal section would lead to lower head losses. However, a rectangular cross section is chosen for the channel ($N = 0$), because easier to build both by wood and concrete.

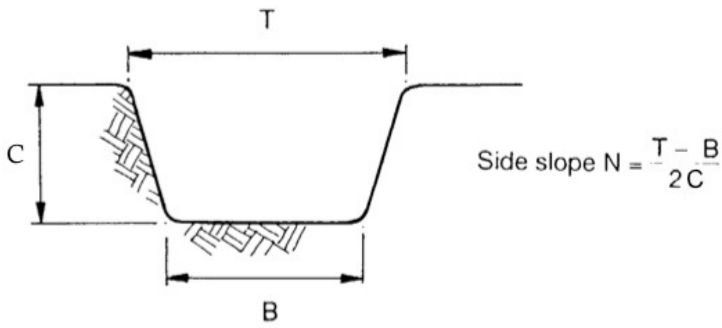


FIGURE 7.11: Channel dimensions [4]

The calculation procedure for the design is shown in Appendix F and the results are presented in table 7.6.

The chosen velocity gives a reasonable head loss of $0.2m$, with no need of repeating the calculation. Higher velocity ($0.3m/s$) was tried, but it led to high losses ($0.7m$).
As already mentioned, according to the theory the wooden channel and the concrete channel give the same design results for channels with heights lower than $1m$.

Material	Concrete/Wood
Water velocity "v" (m/s)	0.2
Side slope "N"	0 (rectangular section)
Freeboard allowance "F"	1.35
Cross section area "A" (m^2)	0.425
Channel height "C" (m)	0.461
Channel bed width "B" (m^2)	0.922
Channel top width "T" (m^2)	0.922
Corrected roughness "n" (C<1)	0.059
Hydraulic radius "R" (m)	0.23
Channel slope "S"	$9.89 \cdot 10^{-4}$
Head loss (m)	0.2

TABLE 7.6: Channel design results

Wood is preferred, because the initial and installing investment are supposed to be cheaper, due to the availability of wood and of skilled carpenters at the Complex.

7.4.2.3 Conclusions about the waterway

According to the waterway analysis between PVC pipe and open flume, the solution seems to be either the PVC Pipe 4 in table 7.4 (nominal diameter of 300mm and SDR 64) or the open channel made by wood.
It should be pointed out that the PVC pipe is more resistant to damages, especially if buried, but it is difficult to make inside inspection and its cost might be higher than the wooden open flume waterway, especially if wood is available in Wawashang.

In any case, for a final choice, the cost of Pipe 4 has to be requested as well as the labour cost to lay down 200m of PVC pipe and wooden channel.

Chapter 8

Conclusions

This project presents a proposal of micro hydropower installation on the State Creek river, which flows through the Wawashang Complex, in a remote area of the Caribbean Coast of Nicaragua.

The hydropower generation potential at the selected site was measured with low-cost methods during the field trip to Wawashang in February 2013.

The head was determined by a wooden folding ruler and a carpenter's level in four different locations, with the neighbouring hill as reference point. These measurements have shown that a low head of 3 to $5m$ over $200m$ is available in State Creek. Eight water flow measurements were also taken by means of a current meter borrowed from NTNU, resulting in water flow values between 100 and $200l/s$. The main purpose of the measurements was to find the relation between gauge height and discharge, which allows an estimate of the daily discharge after the gauge height is known. However, the 8 measurements were taken at the beginning of the dry season and only the first part of the relation curve is known. No reliable method was found to estimate the water flow for the rest of the year and therefore the design has been based on the dry season flow data, which is a conservative assumption.

Three different beneficiaries have been considered for the design. The first one being the farmer's house, which requires little power for a small number of appliances for as long as possible throughout the year. The second possible beneficiary of the micro hydropower plant is a coconut processing facility, which demands more power. The last beneficiary is the Complex itself: the micro hydropower installation could, indeed, support the PV system during the rainy season with the greatest possible amount of power.

The design has been limited to choice of the turbine and the waterway, being the components with the highest influence on the cost and feasibility of the project.

The choice of the turbine has been the starting point of the design, since the low head limits the possible solutions available on the market. Turbines in a head range between $0.2kW$ and $3kW$ have been considered and one (or more) solution has been selected for each power beneficiary.

A waterway has then been designed for LH1kW by Energy Systems&Design, being this the most satisfactory solution, as it could power the coconut grinder during the day and electrify the farmer's house at night. MHG-200LH and MHG-500LH by Powerpal, which can provide sufficient energy to the farmer, should also be considered good options, because of the low initial costs.

In this thesis, power consumption measurements of each building in the Wawashang Complex have been analyzed as well. The total current and forecast future power demand have also been generated. The present and future peak power required are about $17kW$ and $47kW$ during the week, while they are $2.5kW$ and $13kW$ during the weekend, respectively.

Harvesting natural resources at the location has also been part of this project. Besides solar irradiation and the low head hydropower generation in State Creek, the Wawashang Complex has potential to exploit the biomass resource. Waste wood, coconut husks and shells, human and animal excrements may be considered an interesting resource for power production; sugar cane will also be added to this list and the amount of coconut residuals will increase if food processing is electrified.

The main further work to this project is to complete the head and water flow measurements that were performed in February 2013. The head should be measured once more at the same location with one of the methods mentioned in Chapter 6,

in order to find the shortest possible waterway and minimize costs. More water flow measurements should be performed during the rainy season, in order to draw a correct gauge height-discharge curve. The measurement method could be the same as used in February 2013 and described in this thesis. The head measurement can be performed by a trained member of FADCANIC, while the water flow measurement, which requires the use of a current meter, might require another student from NTNU going to the field during the rainy season.
Once this is done, the assumptions made about the water flows and heads in the turbine choice can be verified.
The further step that FADCANIC should take is to select the beneficiary of the power produced. Knowing the labour costs, then, a choice between pipe and wooden channel waterways can be made. At this point, FADCANIC can estimate the total costs and come to a decision. A civil engineer can thus make the final civil works design after a survey of the site, including intake, settling basin and waterway.
The last step would be to purchase the components and plan the installation. The operation of installing low head turbines is fairly simple and can be made by following the manual.

Cooperation and human relationships have been fundamental to this project. A good interaction between IUG and FADCANIC made the trip to Wawashang pleasant and successful for the purpose of the project. Friendship with people in Wawashang made the work easier and more motivating for both parties. Particularly, sharing the purpose of the project with the locals aroused their interest and they helped with enthusiasm.
Altogether, this project has been a wonderful experience for professional, personal and cultural enrichment.

Appendix A

Present energy supply system

No	Description	PV panels/Generators	Batteries	Inverters	Charge controllers
B	**Carpentry**	-Diesel generator 440V: Perkins Renault, 26 kW -Diesel generator 220V: Kubota ASK R3100 ER 1400, 10 kW -Transformer for providing electricity to the 120V loads.	None	None	None
18	**Sport court**	None	None	None	None
14	**Computer room**	-SolarShell, polycrystalline, 28W x 5	Trojan 6V x 20	Magnum Energy, 1500W	Xantrex C35 12/24
14	**Library and teachers offices**	-Isofoton, monocrystalline, 55W x 13 -Trina Solar 225W x 4	4 in series, 5 parallels		VDC x2
1-2	**Kitchen and Dining room**	-GE, 20W x 6 -Isofoton, monocrystalline, 100W x 3 -SolarShell, polycrystalline, 85W x 4 -SunWize, 85W x 3	Trojan, 6V x 8 4 in series, 2 parallels	XPower, 1200 plus	Xantrex C35 12/24 VDC
15-16	**Classrooms**	None	None	None	None
3-9	**Professors' and students' dorms**	SunSwifer, 35W x 1 China, 18W x 4 ShellSolar, polycrystalline, 28W x 9 GE, 20W x 12	-Trojan 6V x 20, 4 in series, 5 parallels -Trojans 6V x 8, 4 in series, 2 parallels -Trojans 6V x 8, 4 in series, 2 parallels	Xantrex, 1500 W	Xantrex C35 12/24 VDC x 2
F	**USAID dorm**	EGE monocrystalline, 100W x 8=800, 12 VDC	Trojan 6V x 19, Crown Deep Cycle x 1, 4 in series, 5 parallels	Magnum Energy, 1500W	Xantrex C40 12/24 VDC x 2
C	**Water processing building**	Unknown brand, 2 x 50W	Unknown brand, 12V x 1	Samlex power, 450 W	Steca Solar charge controller 6A

Figure A.1a: Present energy supply installations in the Complex

No	Description	PV panels/Generators	Batteries	Inverters	Charge controllers
12	**Main offices**	Solar Shell, polycrystalline, 28 W x 24	Trojan 6V x 20 4 in series, 5 parallels	Xantrex, 1500W, 24 VDC	Xantrex C40 12/24/48 VDC x 2
10	**Auditorium**	GeEnergy, 20W x 8 ShellSolar, 85W x 14	Trojan, 6V x 18 Deka Pro Master 6V x 2 4 in series, 5 parallels Deka Pro Master 6V x 8 4 in series, 2parallels	Xantrex, 1500W	Xantrex C40 12/24/48 VDC Xantrex C35 12/24 VDC
17	**Guest house**	Kyocera, polycrystalline, 85W x 8 Isofoton, monocrystalline, 55W x 16	Crown Solar Deep Cycle 6V x 9 Deka Pro Master 6V x 1, 2 in series, 5 parallels,	IGTEC Flash Power, Model 1512FP, 1500W, 12 VDC VPS	Xantrex C35 12/24 VDC x2
-	**Irrigation system**	None	None	None	None
13	**Food processing building (backup generators)**	Gasoline Generator: Briggs & Stratton Elite Series portable generator, 10000W Gasoline Generator: Suzuki, 7500W	None	None	None
-	**Quality seed production facility**	None	None	None	None
-	**Forestal and Livestock farm**	None	None	None	None
-	**Street lights and wharf**	None	None	None	None
-	**Kahka Creek**	Kyocera, 130W x 5 Kyocera, 135W x 1 Photo Watt, 75W x 2 Kyocera, 65W x 2 Kyocera, 54W x 2 BPSolar, 230W x 4 Briggs & Stratton Elite Series portable generator, 10000W	Trojan x 28, 220Ah 6V	Magnum, 4kW	Xantrex C 35 Xantrex C40
iv	**Building for leisure activities**	None	None	None	None
A	**House of carpenters**	Unknown brand, 85W x 4	Trojan, 6V x 4, 2 in series. 2parallels.	WAGAN TECH AC, 1500W	Xantrex C35 12/24 VDC
11	**Laboratory**	Kyocera, polycrystalline, 136W x 6	Crown Deep Cycle 6V x 20	Inverter being repaired in Managua	Xantrex C40 12/24/48 VDC
	Unattached Inventory	Trina Solar, 225W x 2	-Willard 12V x 2 -Trojan 6V x 4 -Crown Deep Cycle, 6V x 9	Xpower 1200 Plus	Controller: C 60 12/24 VDC

Figure A.1b: Present energy supply installations in the Complex

Appendix B

Gasoline consumption of the Complex

The gasoline consumption of the Complex between January and March is shown in fig. B.1. An average 50 gallons per month for fueling the tractor has to be added. The price of gasoline is between 5 and 6 $US\$/gallon$.

Nº	Purpose	Gallons
	JANUARY 2013	
1	Boat transport between the Complex and Pueblo Nuevo	30
2	Chainsaw for cutting wood	15
3	Pump for Irrigating Vivero I	10
4	Pump for Irrigating Vivero II	12
5	Compacter, maintenance of chimney	5
6	Complementary energy for the Complex	7
7	Water purification system	5
	Total	84
	FEBRUARY 2013	
1	Boat transport between the Complex and Pueblo Nuevo	27
2	Chainsaw for cutting wood	17
3	Pump for Irrigating Vivero I	20
4	Pump for Irrigating Vivero II	20
5	Boat trip	13
	Total	97
	MARCH 2013	
1	Internal transport	30
2	Chainsaw for cutting wood	20
3	Pump for Irrigating Vivero I	20
4	Pump for Irrigating Vivero II	20
5	Trip to Bluefields, Laguna de Perlas and Kukra Hill	50
6	Gasoline generator in food processing building (SUZUKI 7.5 kW)	9
	Total	149

FIGURE B.1: Gasoline consumption of January, February and March 2013

Appendix C

Water flow measurements

C.1 Matlab code for obtaining the gauge height-discharge relation

```
%Code for non linear curve fitting of the measurements

clear
clc
format short

q1=[0.131 0.150 0.141 0.145 0.154 0.158 0.172]; %Water flows
h1=[0.208 0.21 0.206 0.218 0.23 0.24 0.28]; %Gage heights

x=h1;
y=q1;
beta0=[2 2]; %starting vector
modelfun=@(b,h)b(1).*(h).^(b(2)); %Setting the type of curve wanted
lb = [0 1]; %lower boundary of b(2) set larger than 1
ub = [inf inf];
options=optimset('TolFun',1e-6); %setting tolerance
[beta,resn,resid,f]=lsqcurvefit(modelfun,beta0,x,y,lb,ub,options);
coeff=beta

%Displaying results
days=[1.3 28.2 27.2 26.2 25.2 23.2 21.2]; %days of measurements
qest=[days' h1' q1' (coeff(1).*h1.^(coeff(2)))']

%Plot
plot(q1,h1,'*','MarkerSize',10);
hold on
xfit=linspace(0.19,0.3,1000);
yfit=coeff(1).*(xfit).^coeff(2);
plot(yfit,xfit,'m');
axis([0.1 0.22 0.18 0.4]);
ylabel('h (m)')
xlabel('Q (m^3/s)')
title(['Q = ' num2str(coeff(1)) ' * h^{' num2str(coeff(2)) '}']);
hold off
```

FIGURE C.1: Matlab code for obtaining the gauge height-discharge relation

C.2 Gauge height collected data

The table in fig. C.2 reports the gauge heights collected by a member of FADCANIC (Mr. Yoel).

The gauge height-discharge relation was used to estimate the discharge from the gauge height.

On the 9th of June the gauge height was 34*cm*, higher than the last gauge height record during the field trip (28*cm*). Therefore, the obtained gauge height-discharge relation could not be used to estimate the discharges after the 9th of June, as explained in Chapter 6.

March			April			May			June		
Day	Height (cm)	Q(l/s)	Day	Height (cm)	Q (l/s)	Day	Height (cm)	Q(l/s)	Day	Height (cm)	Q(l/s)
1			1	13	85,61	1	6	39,51	1	21	138,29
2			2	13	85,61	2	6	39,51	2	D	
3	D	D	3	13	85,61	3	6	39,51	3	21	138,29
4	20	131,7	4	13	85,61	4	6	39,51	4	21	138,29
5	20	131,7	5	13	85,61	5	D	D	5	21	138,29
6	20	131,7	6	13	85,61	6	6	39,51	6	20	131,7
7	19	125,1	7	D	D	7	6	39,51	7	20	131,7
8	19	125,1	8	12	79,02	8	6	39,51	8	20	131,7
9	19	125,1	9	12,3	81	9	7	46,1	9	D	D
10	D	D	10	11	72,44	10	7	46,1	10	34	
11	19	125,1	11	11	72,44	11	7	46,1	11	113	
12	18	118,5	12	10	65,85	12	D	D	12	56	
13	18	118,5	13	10	65,85	13	8	52,68	13	60	
14	18	118,5	14	D	D	14	8	52,68	14		
15	17	111,9	15	10	65,85	15	8	52,68	15		
16	20	131,7	16	10	65,85	16	9	59,27	16	D	D
17	D	D	17	10	65,85	17	10	65,85	17		
18	17	111,9	18	10	65,85	18	10	65,85	18		
19	17	111,9	19	10	65,85	19	D	D	19		
20	17	111,9	20	10	65,85	20	11	72,44	20		
21	16	105,4	21	D	D	21	11	72,44	21		
22	15	98,78	22	9	59,27	22	12	79,02	22		
23	15	98,78	23	9	59,27	23	13	85,61	23	D	D
24	D	D	24	9	59,27	24	14	92,19	24		
25	15	98,78	25	10	65,85	25	15	98,78	25		
26	15	98,78	26	9	59,27	26	D	D	26		
27	13	85,61	27	9	59,27	27	16	105,4	27		
28	13	85,61	28	D	D	28	17	111,9	28		
29	-	-	29	10	65,85	29	18	118,5	29		
30	13	85,61	30	10	65,85	30	21	138,3	30	D	D
31	D	D				31	21	138,3			

FIGURE C.2: Gauge heights and discharge estimates of State Creek between the 4th of March and the 13th of June 2013

Appendix D

Specifications of the pipes by Durman

Durman Costa Rica. Aseguramiento de Calidad (MAAA 10 / 98)										
Especificaciones tubos PVC según norma ASTM D 2241								Código: DI.CRI.EP.08.01.CC.22-01		
Diá. Nom.	Diám. Prom. Externo	Oval. Máx. (mm)		Espesor Mínimo de Pared (mm) (Tolerancia positiva equivalente al 6 % del espesor mínimo)						
		SDR		S D R						
(mm)	(mm)	64 a 21	17 y 13,5	64	41	32.5	26	21	17	13.5
12	21,34 ± 0,10	0.76	0.41	---	---	---	---	---	---	1,57+0,09
18	26,67 ± 0,10	0.76	0.51	---	---	---	---	1,52+0,09	1,57+0,09	1,98+0,12
25	33,40 ± 0,13	0.76	0.51	---	---	---	1,52+0,09	1,60+0,10	1,96+0,12	2,46+0,15
31	42,16 ± 0,13	0.76	0.61	---	1,18+0,07	1,52+0,09	1,63+0,10	2,01+0,12	2,49+0,15	3,12+0,19
38	48,26 ± 0,15	1.52	0.61	---	1,18+0,07	1,52+0,09	1,85+0,11	2,29+0,14	2,84+0,17	3,58+0,21
50	60,32 ± 0,15	1.52	0.61	---	1,47+0,09	1,85+0,11	2,31+0,14	2,87+0,17	3,56+0,21	4,47+0,27
62	73,02 ± 0,18	1.52	0.76	---	1,78+0,11	2,24+0,13	2,79+0,17	3,48+0,21	4,29+0,26	5,41+0,32
75	88,90 ± 0,20	1.52	0.76	---	2,16+0,13	2,74+0,16	3,43+0,21	4,24+0,25	5,23+0,31	6,58+0,39
100	114,30 ± 0,23	2.54	0.76	1,78+0,11	2,79+0,17	3,51+0,21	4,39+0,26	5,44+0,33	6,73+0,40	8,46+0,51
150	168,28 ± 0,28	2.54	1.78	2,64+0,16	4,11+0,25	5,18+0,31	6,48+0,39	8,03+0,48	9,91+0,59	12,47+0,75
200	219,08 ± 0,38	3.81	2.29	3,43+0,21	5,33+0,32	6,73+0,40	8,43+0,51	10,41+0,62	12,90+0,77	---
250	273,05 ± 0,38	3.81	2.54	4,27+0,26	6,65+0,40	8,41+0,50	10,49+0,63	12,98+0,78	16,05+0,96	---
300	323,85 ± 0,38	3.81	3.05	5,05+0,30	7,90+0,47	9,96+0,60	12,45+0,75	15,39+0,92	19,05+1,14	---
375	388,62 ± 0,41	7.47	---	---	9,47+0,57	11,96+0,72	14,94+0,90	18,49+1,11	---	---
450	457,20 ± 0,48	9.14	4.57	---	11,15+0,67	14,07+0,84	17,58+1,05	21,77+1,31	26,90+1,61	---
Presión nominal de trabajo a 23 °C			**lb/pulg²**	**63**	**100**	**125**	**160**	**200**	**250**	**315**
			kg/cm²	**4,46**	**7,03**	**8,93**	**11,25**	**14,06**	**17,58**	**22,15**
			kPa	**434**	**690**	**862**	**1103**	**1379**	**1724**	**2172**

Ovalamiento es absoluto / Diámetros de 31 a 62 mm en SDR 41 no pertenecen a esta norma

FIGURE D.1: Specifications of the pipes sold by Durman

Appendix E

Calculations for the choice of pipes

Knowing the water flow piped to the turbine (Q_{net}) and the length of the pipe (L_{pipe}), the steps presented in this Appendix allow the calculation of the friction losses and SF (Security Factor). These steps are taken from the book by Adam Harvey [4].

The calculation example shown is performed under the assumptions in table E.1. In addition, the turbulent losses are neglected, since the path of the pipe is still unknown.

Water Flow "Q_{net}"(l/s)	63
Internal diameter "d" (mm)	256.23
Wall thickness "s" mm	8.41
Gross Head "H_{gross}" m	5
Pipe Length "L_{pipe}"(m)	200
Assumed roughness "k" (mm)	0.01
Young's modulus "E" (N/m^2)	$2.8 \cdot 10^9$
Ultimate tensile strength "U" (N/m^2)	$28 \cdot 10^6$

Table E.1: Assumptions for the calculations

1. Estimate or use values from tables for the inside wall roughness "k". $0.01mm$ can be used for PVC pipes with an age of 5-10 years[1] [4].

[1]Roughness becomes worse when time passes. The design has to take into account that.

2. Calculate:

$$\frac{k}{d} = \frac{0.01}{256.23} = 3.9 \cdot 10^{-5}; \qquad \frac{Q}{d} = \frac{0.063}{0.25623} = 0.246 m^2/s \tag{E.1}$$

With these ratios read the friction factor "f" on Moody chart, shown in fig. E.1. f=0.016 with the calculated ratios.

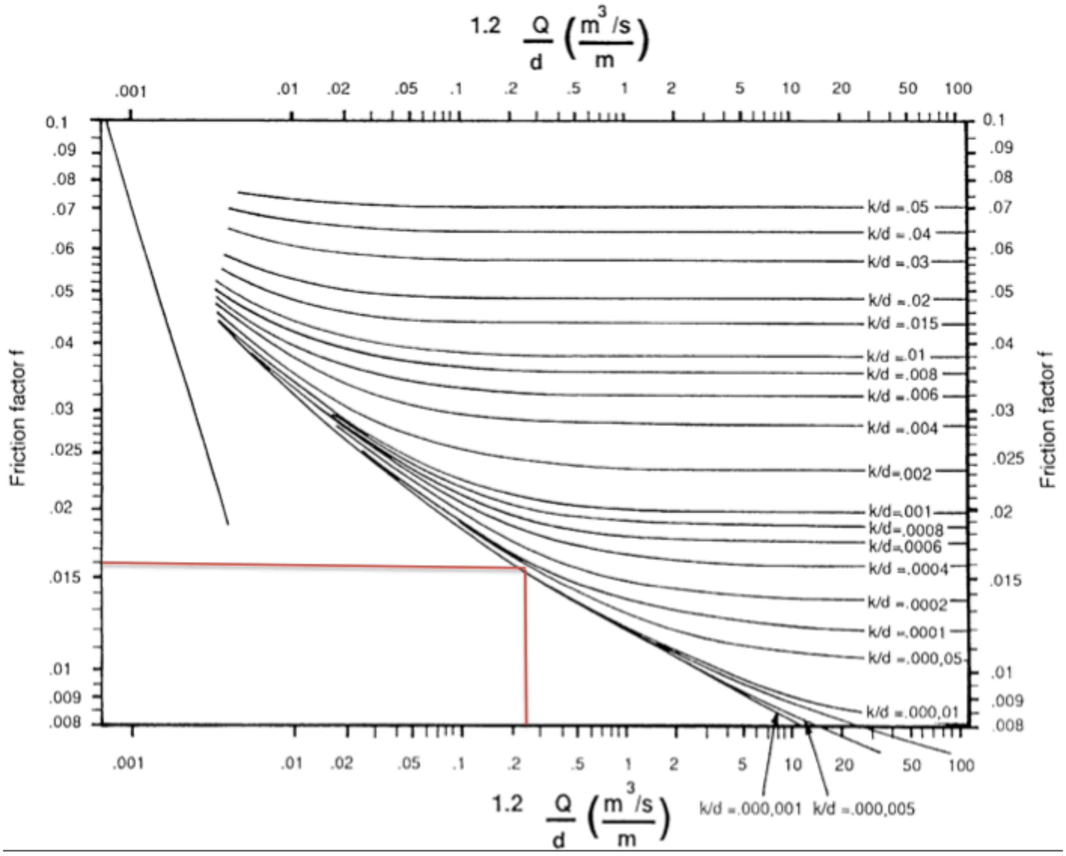


FIGURE E.1: Moody chart for friction losses in pipes [4]

3. Calculate the head loss due to pipe friction:

$$h_{wall\,loss} = \frac{f \cdot L_{pipe} \cdot 0.08 \cdot Q^2}{d^5} = \frac{0.016 \cdot 200 \cdot 0.08 \cdot 0.063^2}{0.25623^5} = 0.92 m \tag{E.2}$$

4. Calculate the pressure wave velocity "a":

$$a = \frac{1400}{\sqrt{1 + \left(\frac{2.1 \cdot 10^9 \cdot d}{E \cdot s}\right)}} = \frac{1400}{\sqrt{1 + \left(\frac{2.1 \cdot 10^9 \cdot 0.25623}{2.8 \cdot 10^9 \cdot 0.00841}\right)}} = 286.67 m/s \tag{E.3}$$

5. Calculate surge and total head:

$$v = \frac{4 \cdot Q}{\pi \cdot d^2} = \frac{4 \cdot 0.063}{\pi \cdot 0.25623^2} = 1.22m/s \tag{E.4}$$

$$H_{surge} = \frac{a \cdot v}{g} = \frac{286.67 \cdot 1.22}{9.81} = 35.65m \tag{E.5}$$

$$H_{total} = H_{gross} + H_{surge} = 5 + 35.65 = 40.65m \tag{E.6}$$

6. Calculate the SF:

$$SF = \frac{s \cdot U}{5 \cdot H_{total} \cdot 10^3 \cdot d} = \frac{0.00841 \cdot 28 \cdot 10^6}{5 \cdot 40.65 \cdot 10^3 \cdot 0.25623} = 4.52 \tag{E.7}$$

Appendix F

Calculations for channel design

This Appendix shows the procedure of channel design presented in [4].

Before starting the channel design, the water flow (Q_{net}) has to be known, while the length of the channel ($L_{channel}$) and the material of the channel have to be decided.

The design procedure uses an iterative process, in which an initial guess about the channel velocity is made. If the head losses are too high, the calculation is repeated with a lower velocity.

The assumptions taken for this example design are shown in table F.1.

Water Flow "$\mathrm{Q_{net}}$" (l/s)	63
Gross Head "$\mathrm{H_{gross}}$" (m)	5
Channel Length "$\mathrm{L_{channel}}$" (m)	200
Freeboard allowance "F"	1.3
Channel material	Concrete (tamped with smooth surface)

TABLE F.1: Assumptions for the channel design

The following steps present the calculation of the cross section area and the head losses for a concrete channel for one velocity value. The channel is supposed to be sealed.

1. Choose a suitable velocity in the channel. The book [4] suggests maximum and minimum velocities for different materials. $v = 0.2m/s$ is chosen.

2. Choose the shape of the cross section of the channel (rectangular or trapezoidal) and therefore the side slope N. Wooden and concrete channels are easier build with rectangular section and therefore $N = 0$.

3. Choose a roughness value n. A value of $n = 0.016$ is estimated for tamped concrete with smooth surface [4].

4. Calculate the cross sectional area A:

$$A = Q \cdot \frac{F}{v} = 0.063 \cdot \frac{1.3}{0.2} = 0.410m^2 \tag{F.1}$$

5. Calculate the channel height (C), changed bed width (B) and the channel top width (T) for rectangular channel:

$$X = 2 \cdot \sqrt{1 + N^2} - 2 \cdot N = 2 \tag{F.2}$$

$$C = \sqrt{\frac{A}{2}} = \sqrt{\frac{0.410}{2}} = 0.453m \tag{F.3}$$

$$T = B = H \cdot X = 0.906m \tag{F.4}$$

6. If $H < 1m$, the roughness should be corrected through:

$$n = \frac{0.04}{\sqrt{C}} = \frac{0.04}{\sqrt{0.453}} = 0.059 \tag{F.5}$$

7. Since the cross section is rectangular, calculate:

$$v_c = \sqrt{A \cdot \frac{g}{T}} = \sqrt{0.410 \cdot \frac{9.81}{0.906}} = 4.44m/s \tag{F.6}$$

   and reset v<$0.9 \cdot v_c$.

   This is already satisfied in this case.

8. Calculate the hydraulic mean radius (R):

$$R = \frac{A}{p} = \frac{0.410}{0.453 \cdot 2 + 0.906} = 0.226m \tag{F.7}$$

   where p is the wetted perimeter.

9. Use the Manning formula to calculate the channel's slope:

$$S = \left(n \cdot \frac{v}{R^{0.667}}\right)^2 = \left(0.059 \cdot \frac{0.2}{0.226^{0.667}}\right)^2 = 1.01 \cdot 10^{-3} = 0.101\% \tag{F.8}$$

10. Calculate then the losses:

$$H_{loss} = S \cdot L_{channel} = 0.00101 \cdot 200 = 0.2m \tag{F.9}$$

11. Calculate the freeboard height: $C \cdot (F - 1)$. If lower than 0.15, increase F. In this case the freeboard height is 0.14. The calculation could be repeated with a slightly higher F.

It can be noted that, if the hight of the channel is lower than $1m$, the kind of material does not influence the calculations. Therefore, the same calculation gives the same results for both concrete and wood channels.

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