Chapter 12
Knowledge Exchange and Application of Hydropower in Developing Countries

Christoph Rapp, Andreas Zeiselmairm, Emile Lando and Mfetoum Moungnutou

Abstract This paper presents some activities of the Munich University of Technology's *Fakultätsplattform Entwicklungszusammenarbeit* (Faculty Platform for Development Cooperation), an association that supports knowledge exchange with developing countries, focusing on a design project for a micro hydropower plant for a renewable-energy vocational school that is being carried out in collaboration with two Cameroonian partners. The power plant, which is situated in a remote area, will provide the school with electricity and serve as an example for the education of the students. During a two-week research stay in Foumban, close to Bafoussam, several possible sites were surveyed. The result of the trip was a feasibility study that examined four different layout options. Due to social and ecological reasons, a site was chosen where only part of the water discharge at a natural step is used. A head of 10.88 m is gained within approximately 100 m of $D = 0.5$ m penstock. The hydropower plant has an estimated output of 15 kW. A crossflow turbine, combined with a synchronous generator, will supply the island network. As hydrological data is scarce, the emphasis has been placed on ensuring flood protection.

Keywords Knowledge exchange · International collaboration · Hydro power · Regional involvement

Short Introduction

The Munich University of Technology, in collaboration with two Cameroonian partners, focused on a design project for a micro hydropower plant for a renewable-energy vocational school, which will provide the school with electricity and

C. Rapp (✉) · A. Zeiselmairm · E. Lando · M. Moungnutou
Department of Hydromechanics, University of Technology, Munich, Germany
e-mail: rapp@tum.de

W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_12,

serve as an example for the education of the students. This paper presents the activities during two weeks of site research, including the feasibility study for different options.

Preface

We can learn from history that engineering expertise to protect people from natural hazards and control water and food supplies paved the way to civilization. Nowadays, building infrastructure is the basis of a developed society, and civil engineers are therefore essential. This was the background thinking for the foundation of a platform for knowledge exchange at the Faculty for Civil Engineering and Geodesy at the University of Technology in Munich, Germany (www.ez.bv.tum.de).

The scope of the initiative is manifold. Lectures form its core, which have been held at Jordan University of Technology and Eduardo Mondlane University in Mozambique, where support is also being given to set up a hydraulics laboratory. These lecture courses comprise topics in renewable energy supply for buildings and hydraulics or hydraulic engineering. In the hydraulic laboratory, practical training is given to students and teachers, for which certain measurement devices are provided. The work has been recognised by the Mozambican Prime Minister, who even visited the hydromechanics laboratory of the TUM while on a state visit to Germany in May 2011.

Additionally to the academic exchange, joint projects between students from Germany and countries in Latin America and Africa are being realised with the involvement of local populations. For instance, the power supply for a medical care centre in Burkina Faso was designed; a primary school in Mozambique was electrified; and a kindergarten with autonomous power supply was planned and constructed near Cape Town. Various projects were conducted in the Ecuadorian rainforest, where, among other things, the drinking water supply of a village and a micro hydropower plant were designed (Zeiselmair et al. 2011; Hansinger et al. 2011).

In 2010 a letter of intent was signed by the association Green Step e.V (Green Step is the vocational school's implementation organisation) and TUM's platform for knowledge exchange, aiming to build a hydropower plant (approx. 15 kW) for the electrification of a renewable-energy vocational school in Foumban near Bafoussam in Cameroon. The power plant would serve not only as power supply, but also as an example for the students. During a research trip in May 2011, a possible site was located and two Cameroonian partners were identified:

Action pour un Développement Équitable, Intégré et Durable (ADEID), an organisation that builds different plants using renewable sources and operates several micro hydropower plants;

Institut Universitaire de Technologie de Douala, Cameroon.

Within this consortium, the partners have worked collaboratively on the survey of the site, the design of the plant and on clarifying legal issues.

Introduction

A vocational training school for renewable energies is being erected close to Foumban, Cameroon. Its focus lies on practical application, such that the students gather experience in production, distribution, installation and maintenance of these technical products, since such responsibilities are generally not taught in this country. Consequently, pico hydropower plants and solar thermal systems will be produced and sold in the school (Hertlein 2011). Therefore, power is not only needed to provide classrooms with electricity, but also to operate manufacturing machinery such as a lathe, welding rectifiers and drills. However, special emphasis is placed on ensuring that the facility fulfills its main function, which is to serve as an example to the students. Additionally to these conditions, the generated energy should be used to electrify the area in the vicinity of the plant. This issue will contribute to improving living conditions and enhancing development.

To successfully implement the scheme, local and international partners work in their particular fields of expertise under the general management of Green Step. The German association *Ingenieure ohne Grenzen* (Engineers without Borders) is working on the school's business plan, whilst the University of Applied Sciences in Regensburg (Germany) and the University of Guelph (Canada) are designing a pico hydropower turbine that will be produced and sold at the school. The *Fakultätsplattform Entwicklungszusammenarbeit* is constructing the hydropower plant in collaboration with ADEID and the University of Douala. ADEID is also responsible for legal issues (e.g. water rights), whereas the latter assists in providing hydrological data. Finally, Green Step coordinates the partners, handles the funding, deals with social aspects and runs the school.

An appropriate site for the hydropower plant was found in the proximity of the school. The constructional tasks include the overhaul of an already existing weir, integrating the intake structure with a sand trap (Fig. 12.1). An approximately 100 m long penstock, with a head of 10.88 m, will deliver the water to a crossflow turbine generating 15 kW. The power house is placed on the left embankment to ensure flood protection. The design of the structure minimises the ecological impact. An already existing channel on the right embankment serves as a fish pass.

Scope

The school's scope is to educate students in renewable-energy technologies, which makes it an obvious step to provide the school with energy from such sources. The poor reliability of the electricity supply makes the usefulness of an independent island grid evident. A feasibility assessment was carried out for various systems, whereby a high potential for hydropower was identified due to the reliable precipitation and topography of the area. Consequently, as a field trip, the school's hydropower supply was examined for possible installation sites in its proximity, and relevant data was collected for further analysis.

Fig. 12.1 Downstream view with weir overhaul and intake structure

Off-site tasks included negotiations with stakeholders and material suppliers, as well as gathering particular local know-how. Many examples showed that the sustainable development of comparable projects could only be realised in collaboration with future associates, local authorities and residents, who help with information and labour. Therefore, a fairly decisive concern is the legal and administrative part of the planning, to ensure that ADEID's experience and expertise in erecting locally built water turbines is a major benefit.

Hydrology

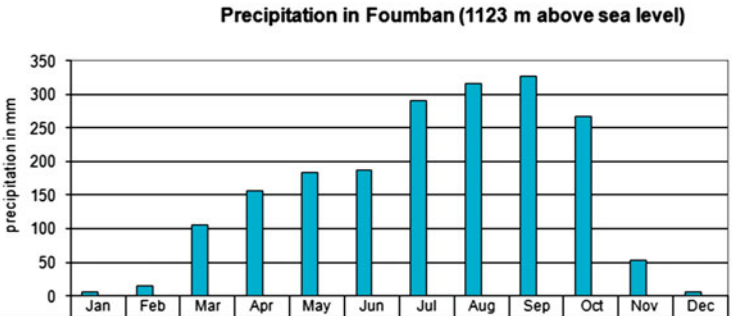
Climatic Boundary Conditions

Cameroon is characterised by a great variation in types of climate—this is why it has been called "Africa in miniature". The country ranges from the wet southern equatorial regions to the arid parts in the "extreme North". Cameroon can be subdivided into four climatic and geographic zones: the Sudano-Sahelian, the savanna, the coastal and the tropical forest zones (Molua and Cornelius 2011).

Foumban, the location of the hydropower installation, is located in the tropical forest zone, which has mostly wellwatered surface water (Atlas dupotentiel hydroélectrique du Cameroun 1983). The surface is mainly covered by metamorphic and igneous rocks. The type of climate in this area is known as "equatorial monsoon". It is determined by two distinct seasons. The dry season lasts from November to March; the rainy season from April to October. The precipitation maximum can be observed from July to September. The total annual precipitation in Foumban is around 1,908 mm (Fig. 12.2).

Hydrological Characteristics

Cameroon has two major catchment areas. The area around Foumban is part of the western highlands, also called the "Cameroon Volcanic Line". It is part of the Atlantic drainage basin, which is dominated by the Sanaga river system. The



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly precipitation in mm	5	14.1	105.7	155.8	182.6	187.2	290.3	316.4	326.5	266.1	53	5.5
Days with precipitation > 1mm	1.1	2.4	9.5	15.4	19.1	20.2	23.3	24.4	24.9	22.9	6.3	1.1

Fig. 12.2 Average annual precipitation in Foumban (Obermeier 2011)

catchment area of the river at the installation site is characterised by a longitudinal tributary area, which ranges around 11.5 km from the spring to the installation site. It has several smaller confluences (Fig. 12.3).

In order to obtain approximated discharge-variation values, comparisons to neighbouring river gauges were made. Figure 12.4 below shows the hydrograph of the rivers Noun and Mbam (Distances and directions of gauges from site; measurement period. Noun, Bamendjing, 43 km west, 1965–1973. Noun, Bafoussam, 48 km south-west, 1952–1975. Mbam, Mantoum, 36 km South–East, 1965–1980). The runoff has been normalised by the annual average, worked out from the monthly mean values. The red line indicates the base flow-reduced hydrograph of the Noun catchment area (excluding the outflow of Bamendjing reservoir). Through its very similar characteristics, this curve should fit the hydrograph at the site best.

The discharge measurements available have all been conducted during the dry season, so that they can be assumed as low-level discharges. This has also been verified by local residents. Currently, further data are obtained through two fixed-level gauges that have been installed and operated by ADEID. One is located

Fig. 12.3 Catchment area (*Source* Google Maps)

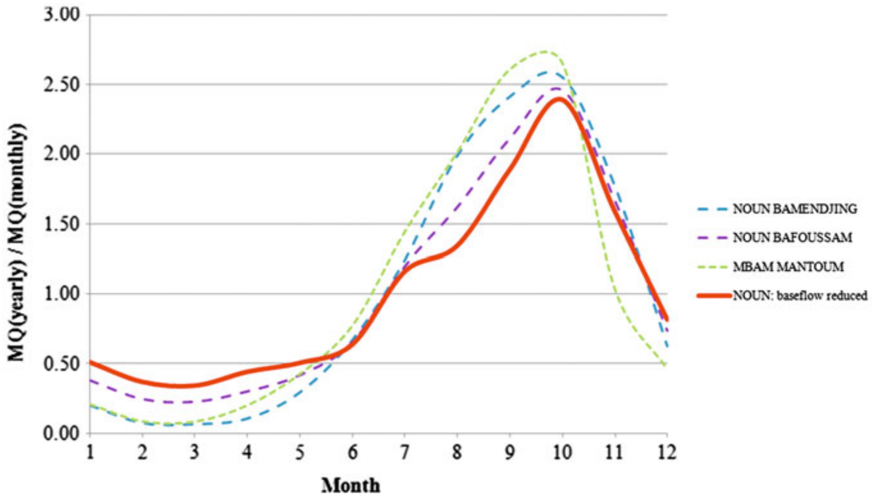


Fig. 12.4 Discharge hydrograph of gauges at comparable neighbouring rivers (The Global Runoff Data Centre 2011)

above the weir intake; the other one is placed close to the powerhouse installation site. A resident working close to the site will check the water level daily and hand the data over to ADEID.

Conclusions

Unfortunately, there is a major lack of hydrological data. However, the project is not endangered by this, as the site boundary conditions are nearly perfect. It should be mentioned that the power output requirement allows a comfortable safety margin—for low runoffs and for flood events. Due to the doubtful runoff data, special emphasis has to be placed on flood security. The discharge measurements were taken in May, which is at the end of the dry season (see Fig. 12.4). Hence, one can conclude that the measurements reflect runoff minima.

Site Survey

The first step of the on-site research was to get a better understanding of the geographical, hydrological and morphological situation in the school's surrounding area. Therefore, the most important task was to explore the water course of the nearby river and possible feeder streams.

Discharge Measurement

In order to get an estimate of current discharge at different parts of the river, several measurements were taken. The techniques used were based on flow velocity and cross-section analysis. At specific locations, hydrological methods were applied, e.g. flux approximation at critical-flow conditions. Subsequent to the on-site measurements, two fixed water gauges were installed by ADEID to assess the annual flow duration curve. The data is needed to estimate flood scenarios and energy yield.

Surveying Data

The possible sites were surveyed with a tachymeter. The exact head differences were of major interest, and the elevation and position of probable penstock tracks were also captured.

Flood Security and Occurrence

Assessing the difficulty of flood protection is a hard, but also an essential, task in the planning process in such areas. Due to the fact that there is almost no reliable river discharge or area precipitation data available for most parts of Cameroon, one has to rely on other sources. The most efficient and easiest method was to consult nearby residents and workers around the sites. As this information is rather vague and most likely to be biased, it is even more important to set a sufficient safety margin. For example, concerning the occurrence of floods, one statement from a local worker was “about two to three times a year; for about one week the water level is about here”. Historical maximum flood levels for this creek are essential for the design; however, information on these could not be collected.

Sites

The investigations resulted in two possible installation sites with quite different characteristics. Each site would further allow two different layout options each (see Figs. 12.5 and 12.6).

The following table gives a comparison between the two possible installation sites and their different layout options (Table 12.1).

Fig. 12.5 Overview of geographical position of different installation sites (GPS data on Google Maps)

Fig. 12.6 Possible installation sites. *Left* weir at Cascade 1; *Right* Cascade 2

Table 12.1 Comparison of different installation sites and layout options

Installation site comparison	Big waterfall with already existing weir (cascade 1)		Waterfall below local washing area (cascade 2)	
Head	10.88 m		3.71 m	
Discharge	Approx. 300–500 l/s		Approx. 1 m^3/s	
Power output	10–30 kW		15–25 kW	
Inlet structure	+ (integration into already existing weir)		− (to be built at left embankment)	
Water rights/usage	+/− (water partly used only by local water supply company SNEC—negotiations ongoing)		− (intensively used as the local washing and bathing area)	
Layout type	Layout 1 Penstock along embankment	Layout 2 Penstock on cascade course	Layout 1 Conventional turbine	Layout 2 Water wheel
Penstock length	○ approx. 100 m		+ approx. 10–15 m	+/
Flood safety	+	–	○/−	○
Overall result	+	–	–	○/−

Large Waterfalls with Already Existing Weir (Cascade 1)

At the grand cascade an output of 10–30 kW, depending on the method, can be generated. With a head of 10.88 m only a minor part of the water is needed to meet the required power output. The first layout (Cascade 1—Layout 1) marks the option where the penstock is aligned along the orographically left embankment of the waterfall (see Fig. 12.7). This is also the preferred layout. The advantage of this is a more or less constant penstock slope and therefore fewer pipe bends. A second central advantage is that it is less prone to damage caused by floods, since it is away from the main flow path and does not need to be fixed upright above the ground. The advantageous location of the intake structure, as well as of the powerhouse, makes this option the preferable one.

Another possibility for the penstock track would be to guide it along the course of the waterfall itself (Cascade 1—Layout 2). There are some islands along the waterfall, where fixing the pipe to the underground rock would be possible. The big issue here is the flood risk, since at higher flow rates this layout could be affected by floating debris. However, the underground conditions are clear and do not bear any risks.

Cascade Below Local Washing Area (Cascade 2)

Cascade 2 offers an output potential of 15–25 kW. One option for this cascade would be the use of a conventional turbine with a short penstock track of only around 10–15 m (Cascade 2—Layout 1). The intake could be placed on the orographically left side, right above the cascade, whereas the powerhouse would be located on a minor rocky spot. As the discharge is quite high ($Q \approx 1\ m^3/s$), the use of great pipe diameters or more than one pipe would be necessary.

Using an overshot water wheel is another option, although this brings a number of uncertainties (Cascade 2—Layout 2). The intake situation is similar to Layout 1. A channel will have to be constructed with a diameter of around 2.50 m to channel the water right above the wheel. The water wheel could be stationed as indicated in Fig. 12.8. The generator and electrical equipment could be placed on top of the

Fig. 12.7 Installation site Cascade 1, with two different layout options

Fig. 12.8 Two different layout options at Cascade 2

embankment. The power transmission could be realised with a gear belt. Here, difficulties arise, such as the high level of construction effort, especially concerning the fixing and foundations. The latter is also quite undetermined, due to the lack of investigation of the underground conditions. Another drawback is the safety issue, as the area above this site is intensively used by residents as their local washing and bathing area.

A comparison in terms of flood security leads to the observation that a conventional turbine with penstock has the advantage of being more hidden. The second issue is that a turbine/powerhouse can be easily fixed, and does not have to deal with dynamic forces as a water wheel does.

Conclusions

As the first option at the big cascade promises to be the most attractive, the main focus will be placed here. The second cascade, below the local washing area, would be an alternative to Cascade 1, although its power output is smaller. As the location is frequently used by locals, compensatory measures would be necessary.

Design

In the following, Layout 1 of the big cascades is described in more detail. Due to flood-security reasons the powerhouse will be placed 2 m above the regular water level of the plain. There, a perfect place was found, where the powerhouse can be anchored to the rocks and natural shelter is provided. Including the height of the powerhouse structure, the geodetic head reduces to 8.38 m (Fig. 12.9).

Fig. 12.9 Overview of intake situation at Cascade 1

Intake

The intake structure is placed on the orographically left side, and will be integrated into the weir (see Fig. 12.10). The tulip-like inflow opening is incorporated into locked housing, which also includes the sand trap. This structure guarantees the correct amount of water for SNEC and the slaughterhouse. Emphasis is placed on safety issues, as locals fish on the weir and children play or swim in its proximity. The opening of the whole structure is parallel to the main flow direction and equipped with a narrow rack. It should be noted that frequent rack cleaning will be necessary and will be conducted by the school staff.

Pipe Layout

As a constant pressure turbine is proposed the Darcy-Weisbach equation underlies the pipe design in the following notation according to the energy plan (Fig. 12.11).

$$H_{geo} = \frac{8Q^2}{D^4\pi^2 g}\left(\frac{\lambda l}{D} + \zeta_I + \sum \zeta_B\right) + \frac{Q^2}{A^2_{Nozzle\perp} 2g} \quad (1)$$

Applying Eq. 1, the pipe diameter was optimised using the data in Table 12.2 and a discharge dependent efficiency factor between 40 and 76 %.

Examining Eq. 1 for different pipe diameters and appropriate turbine layouts (see 6.3) yields Fig. 12.12. From the graph, it can be seen that a pipe diameter (PVC pipe diameters in Cameroon were considered only: d = 0.125 m, d = 0.25 m, d = 0.50 m) of 0.50 m is essential for a reasonable output, but also maintainable water-hammer pressure peaks. The nozzle area is subject to the turbine design in 6.3.

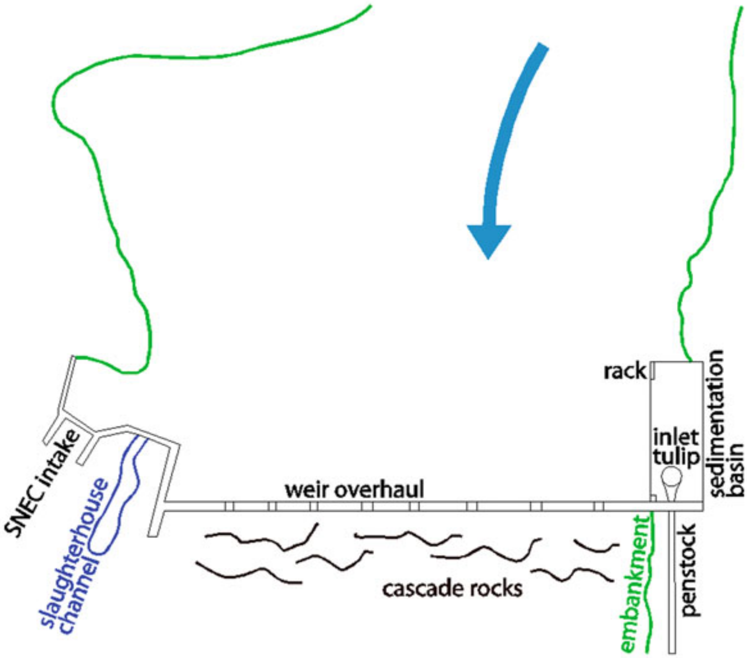


Fig. 12.10 Sketch of weir and intake situation

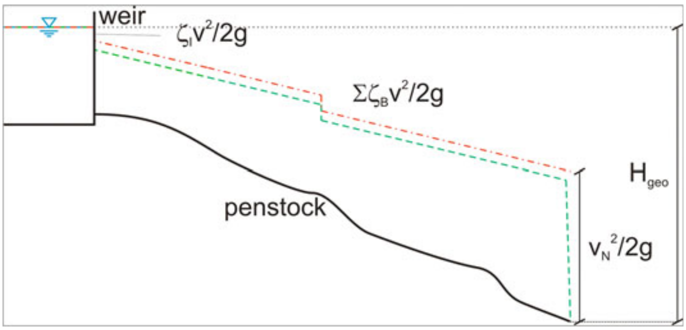


Fig. 12.11 Energy plan of the proposed layout

Table 12.2 Input data

Geodetic head	$H_{geo} = 8.38$ m	Kinematic viscosity	$v_{(25\ °C)} = 9E\text{-}7\ m^2/s$
Pipe length	$l = 100$ m	Inflow loss	$\zeta_I = 0.5$
Roughness	$k_s = 8E - 6$ m	Sum of bend losses	$\sum \zeta_B = 2.5$

The use of two or more smaller pipes is not an alternative, as can be seen from Fig. 12.12. The following specifications were obtained using a pipe diameter of 0.50 m (Table 12.3).

Turbine

A crossflow turbine has been chosen due to its robust construction and perfect applicability at the suggested site. Crossflow turbines, also called Ossberger or Banki turbines, are radial-flow impulse turbines. Because of their low maintenance requirements and simple construction, they are frequently used as small and micro hydropower plants in remote areas. As the mechanical system is not very sophisticated, repairs can easily be performed by local mechanics. The proposed discharge ranges from 0.025 to 13 m^3/s for heads of 1–200 m (NHT Engineering and IT Power Ltd 2004).

Although the peak efficiency of a crossflow turbine is somewhat less than other conventional turbines, it has the advantage of a flat efficiency curve under varying loads. This can yield better annual performance at variable discharge rates. To achieve good part-load efficiency it is possible to divide the split runner and turbine chamber at a ratio of 1–2 at varying flow rates (Giesecke et al. 2009). Since the turbine runs at low speed it is not severely affected by suspended solids. The

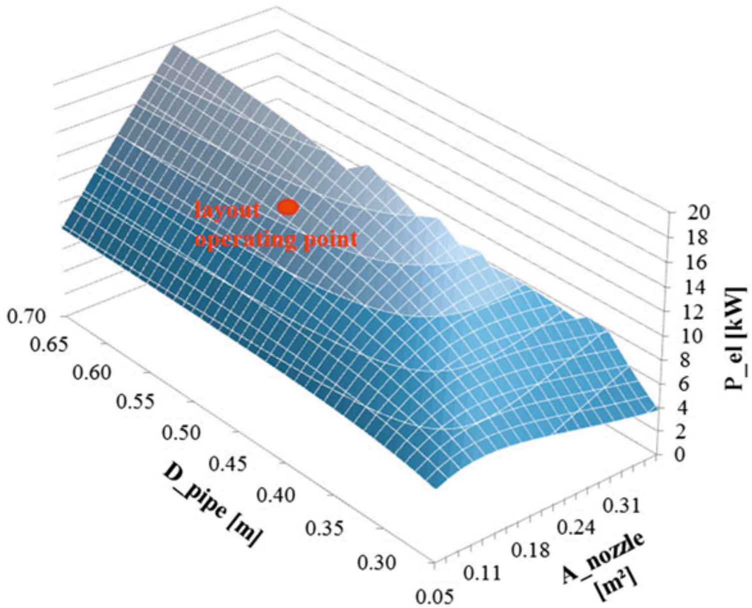


Fig. 12.12 Operating point of the system—pipe diameter dimensioning

Table 12.3 Hydro power plant specifications for different discharges

Q [m^3/s] (discharge)	A_{nozzle} [m^2] (adjusted nozzle area)	H_n/H_b (net head/gross head) in (%)	v_{pipe} [m/s] (pipe velocity)	v_{nozzle} [m/s] (velocity at nozzle)	Δp [bar] (Joukowsky hammer)	p_{total} [bar] (total max. pressure)	P [kW] ($\eta_{HPP} \cdot \rho \cdot g \cdot Q \cdot H_N$)
0.100	0.031	99	0.51	3.19	0.98	1.80	4.5
0.150	0.047	98	0.77	3.17	1.48	2.30	7.8
0.200	0.064	96	1.02	3.15	1.97	2.79	10.7
0.250	0.080	95	1.27	3.12	2.46	3.28	13.3
0.300	0.097	92	1.53	3.08	2.95	3.77	14.3

high durability, low price, simple construction and reliable operation make these turbines ideal for use in developing countries.

Constructional Tasks

Weir Overhaul/Intake Construction

The large amount of leakage that is currently experienced at the weir makes an entire overhaul mandatory. In order for the facility to be able to exploit a steady discharge, it is important to keep a constant water level above the weir. In the event of very high discharges, a secured HQ release will be provided on the top of the weir. The process of concreting the weir will be carried out section by section.

Penstock Fixation

The fixation of the penstock depends on the ground conditions. With Layout 1, there is a certain thickness of the topsoil layer. Below the soil, solid rock is expected, as it forms the basis of the whole cascade. At the current stage, it is assumed that the reinforcing steel can be anchored to these rocks. Further analysis is mandatory in order to give final instructions.

Powerhouse

The powerhouse contains the core of the whole facility and therefore requires special safety precautions. The first issue to be considered is flood protection. As the generator and further electric equipment is located in the powerhouse, it has to stay dry under any conditions. Further safety precautions against electric shock also have to be taken. In addition, all facilities must be inaccessible to any unauthorised persons (health and safety, sabotage, etc.) (Fig. 12.13).

Social and Ecological Impact Assessment

The main issue regarding the ecological consequences of the newly built hydropower plant concerns its impact on fish and riverine fauna. As the weir will be kept in its current dimensions, the construction will not cause any deterioration in the situation for organisms. Nevertheless, an improvement of the current situation will be aspired to. Harming fish with the turbine can be avoided by using a rack with narrow spacing at the intake; the velocity head is negligible anyway. Additionally, a channel supplying a slaughterhouse with water can be modified to serve as a fish pass. The site is ideal because already existing structures are used. The plant will therefore not have an impact on the flood security of the residents.

Education Concept

The hydropower education will focus on hydraulics, hydraulic engineering and hydrology. A concept for descriptive courses has been published in (Rapp 2006). However, an entire engineering course cannot be offered—and is not intended. Basic, applicable know-how will be provided so that the students are enabled to conduct similar projects. This prerequisite implies secure ground conditions and flood safety, both for the plant itself and the surrounding area. Ecological impact minimisation and awareness will be the principles to be taught.

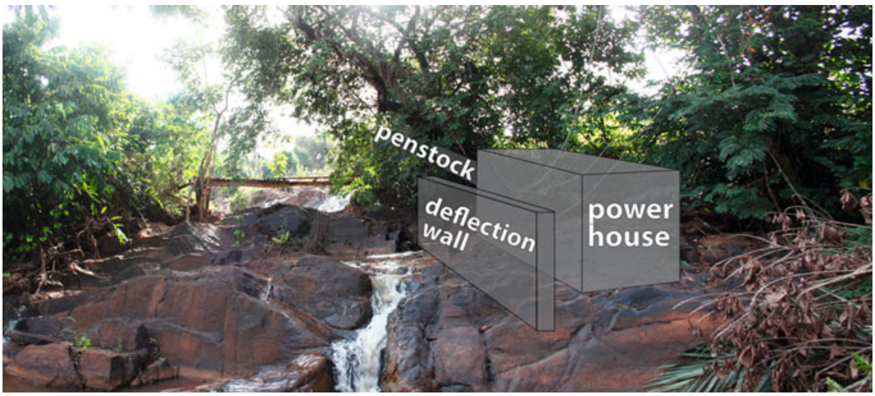


Fig. 12.13 Sketch of powerhouse construction and layout

Outlook

The result of this paper is that construction can be carried out very efficiently under the evaluated circumstances. With the examined site layout, the ecological impact can be minimised to an almost negligible value. The social impact on the local residents can be rated positively throughout. Long-term operational safety has a very high priority.

To be able to make a final proposal and determine all duties necessary, there is still research to be done, which is already in progress. For example, the recording of a hydrograph by installing a fixed water-level gauge is currently being organised by ADEID. The issue of electrical distribution, control and supplying energy consumers will be dealt with in another study. All in all, the proposed design serves as an example for a hydropower plant built in an area where hydrological data is scarce, but flood security can be guaranteed. It improves the quality of life of the locals, whilst causing no identifiable ecological deterioration.

Acknowledgments The authors gratefully acknowledge the contribution of the *Technische Universität München*, the *Verein zur Förderung des internationalen Wissensaustauschs e.V.* and Green Step e.V.

References

Atlas du potentiel hydroélectrique du Cameroun (1983) [Yaoundé]: Société nationale d'électricité du Cameroun

Giesecke J, Mosonyi E, Heimerl S (2009) Wasserkraftanlagen: Planung, Bau und Betrieb. 5., aktualisierte und erweiterte Auflage. Springer, Berlin, Heidelberg

Hansinger M, Rapp C, Botero A (2011) Planung der Trinkwasserversorgung für ein Dorf im ecuadorianischen Regenwald. Korrespondenz Wasserwirtschaft, Vola 12:630–634

Hertlein J (2011) Available at www.green-step.org

Molua EL, Cornelius M (2011) Climate, hydrology and water resources in cameroon. Department of Economics, University of Buea. Available at http://www.ceepa.co.za/docs/CDPNo33.pdf

NHT Engineering and IT Power Ltd (2004) HYDROPAK: concept design and analysis of a packaged cross-flow turbine. CONTRACT NUMBER: H/03/00078/00/00 URN NUMBER: 04/1885

Obermeier M (2011) Erstellung eines Konzepts zur Regenwassernutzung am Beispiel Erneuerbare-Energie-Schule in Kamerun. Technische Universität München

Rapp C (2006) Eduaction in hydraulic engineering. In: Rutschmann P (ed) Flood or draught? in the MENA Region, pp 98–103

The Global Runoff Data Centre (2011) German Federal Institute of Hydrology, Koblenz

Zeiselmair A, Konz A, Rapp C (2011) Kleinstwasserkraft zur elektrischen Versorgung eines Dorfes im Regenwald Ecuadors. Wasser Wirtschaft 5:28–32