NTNU – Trondheim
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Drinking Water Safety in African Countries

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Master of Science in Product Design and Manufacturing
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MASTER THESIS SPRING 2012
FOR
STUD.TECHN. FRIDA D. HYLIN

DRINKING WATER SAFETY IN AFRICAN COUNTRIES
Drikkevannstilgjengelighet i afrikanske land

It is well known that contamination of drinking water is a major problem in African countries causing serious diseases with numerous deaths. In some countries, the water supply situation is difficult because of increasingly dry climate. In the countryside, village citizens have to spend several hours pr. day for bringing water. If water could be distributed to villages, the life situation for women would be improved. Several aid programs are trying to improve the water supply in African cities and in the countryside, for example the Norwegian organisations NORAD and Church Aid, but numerous international aid partners are also active.

In her previous project work, the candidate has given a general overview of the water supply situation on the southern outskirt of Sahara, in rural villages, chosen a rural district for closer examination, and suggested ways to improve the situation for the villagers.

The aim of this project is to study the situation in the Mpaih village in Cameroon. Opportunities and bottlenecks for establishing a sustainable water supply should be studied based on principle technological schemes develop in the previous project task by the candidate submitted in December 2011. The master thesis should comprise a more detailed study of these technologies, evaluation of the current work executed by the French Foreign Aid organization ASCOVIM and a site visit to Mpaih village.

Specified tasks

1. Present a theoretical approach to sustainable water supply in African rural districts, based on existing literature
2. Present, based on previous project work, current water supply situation and discuss selection of new sustainable water sources for Mpaih village with regard to fulfillment of water quantity and quality needs.
3. Explore and if necessary redefine criteria for sustainable water supply in Mpaih (social, economic, organizational).
   Develop a questionnaire and provide field trip discussions with inhabitants of the village to explore practical opportunities and limitations. Discuss in particular how

existing organizations can be used in operation of water supply and how the establishment of water supply can impact in building of societal institutions in the village.

4. Make a detailed description of technologies needed for new water supply and corresponding use and robustness of materials and energy systems (e.g. solar energy).
5. Discuss how the technical solutions can be implemented in Mpaih (transport to site, building process, operation, operational organization etc.)

In addition to the report, a PU journal in A3 format shall be handed in. This should be a chronological collection of material found or developed in the course of the project.

The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.

Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Undervisning". This sheet should be updated when the Master's thesis is submitted.

The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's thesis.

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Professor/Supervisor

Changes in Frida D. Hylin's master assignment

The current text includes the phrase: "evaluation of the current work executed by the French Foreign Aid organization ASCOVIM".

In the course of the project, we have found that this point is irrelevant. The organization has not done significant work that influences what Frida Hylin should do.

The supervisor and the candidate have therefore agreed that this point will not be answered in the master report.

Trondheim, May 30 2012

Knut Aasland

supervisor

Preface

This report represents the work done in my master thesis "Drinking Water safety in African Countries" at the Department of Engineering Design and Materials at the Norwegian University of Science and Technology. The master thesis has been carried out as a follow-up of the project work related to the same topic completed during the fall of 2011. A brief, yet fruitful field trip the Mpagne village, Cameroon, in March 2012 has contributed to an enhanced understanding of the issues related to the water supply sector, which again has resulted in a more realistic discussion and generation of possible solutions. Working with this project has been an interesting and challenging process, where theory has been studied, practical applicability of previous courses has been tested, and multiple disciplines have been combined. In total, seven professors at four different departments and two faculties have, through contributing with their guidance, helped in developing this report.

First and foremost I would like to thank my supervisors Sveinung Sægrov and Knut Einar Aasland for valuable and helpful guidance. I am grateful for your support. A thank you also goes to:

Aksel Tjora, Professor at the Department of Sociology and Political science
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Helge Brattebø, Professor at the Department of Hydraulics and Environmental Engineering
Stein Wold Østerhus, Professor at the Department of Hydraulics and Environmental Engineering
Bjørge Brattli, Professor at the Department of Geology and Mineral Resources Engineering

for contributing with guidance on subjects from your respective fields. Further, I would like to thank Issa Nyaphaga and Georges Bwelle for making the field trip to Mpagne possible, and for contributing with important information and good spirit. Last, but not least, I would like to thank my family, mom, dad, Louise and Hannah, for supporting me through this process. You are awesome.

Frida Douglass Hylin
NTNU, June 2012

Introduction

This report covers the current theoretical approach to sustainable water supply in African rural districts, with special attention given to the countries in Sub-Saharan Africa. Cameroon has been a focus country, and the village Mpagne in the Mbam-et-Kim region in Central Cameroon has been studied to present the situation on a specific level and to discuss the selection of appropriate water supply. A field trip to the village reviled that this is a community who has been subject to a previously failed water supply project. This led to a shift in the focus of the master thesis to also cover theory of project failure in the rural water supply sector. Ideally an evaluation of the organization who implemented the previous water supply project should have been carried out. However, the attempts of contacting the organization have not been successful, and due to lack of comprehensive and reliable information this has not been possible. The scope of the report is focussed around the water supply itself. However, it is necessary to mention that hygiene and sanitation awareness and improvement are integral aspects of such a project. They have not been thoroughly covered in this report, due to time-constraints and the task defined in the problem text.

The work has been carried out as a continuation of the project work completed during the fall of 2011. To further study and possibly redefine the criteria for sustainable water supply in Mpagne, it has been important to scrutinize the current situation and the technical and social aspects of the previously implemented project. This, in combination with a study of published literature has served as a base for the development of a thorough background analysis on which the generation of possible technical solutions has been based. To support the decision making process the indicator comparison methodology developed during the fall project has been further improved in terms for more reliable input data. This methodology was developed based on elements from standard life cycle assessment and sustainability analysis from the field of industrial ecology.

Lastly, it has been important to study and discuss an implementation strategy, as this is a crucial phase for the sustainability of a water supply project. This covers the stages planning, construction, operation and maintenance, as well as follow-up and evaluation. In addition a discussion regional, national and international administrative changes required to increase the success rate of the water supply sector is presented, based on information gathered in Cameroon as well as published literature. This is an out of scope activity, but has been included to demonstrate a better picture of a local water supply project in a proper context, as it cannot be treated as a problem on an isolated village level only.

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Abbreviations and vocabulary

External agency	Entities such as donors, NGO's, International Governmental organizations which interact with communities and the water supply sector in general without being under its direct control
Hardware	Technical and human resources
Improved drinking water source	Tubewell or borehole, protected dug well, protected spring, rainwater
Mpagne	Actual name of Mpaih
m.y.	Missing Year, Bibliography
NGO	Non-Governmental Organization
O&M	Operation and maintenance
PD	Product development
Previous project work	Drinking Water safety in African Countries, project completed fall 2011
RWH	Rainwater harvesting
Software	Social structure, attitude and behaviour
SWOT	Strengths, Weaknesses, Opportunities and Threats
Unimproved drinking water source	Unprotected spring, unprotected dug well, cart with small tank/drum, tanker-truck, surface water (rivers, dams, lakes, ponds, streams, canals, and irrigation channels), bottled water
UNICEF	United Nations Children's Fund
VLOM	Village-Level Operation and Maintenance
WATSAN	Water and sanitation
WHO	World Health Organization
WSS	Water Supply and Sanitation

Recommended reading: Drinking Water Safety in African Countries, Project Work, fall 2011, Frida Douglass Hylin, attached in the digital submission of the master thesis.

Abstract

The following report is the result of a literature study of published documents presenting the current water supply situation in Sub-Saharan Africa, in combination with a field trip to the Mpagne village in Cameroon. The objective of the project has been to study and discuss the current theoretical approach on sustainable water supply, as well as to generate possible technical solutions and present administrative changes required.

A thorough background analysis demonstrates the need for improvement on a local village level as well as on a regional, national and international level. Key findings are high failure rates as a consequence of the absence of evaluation of past projects, as well as the fact that many agencies do not work in line with existing policies and theoretically developed approaches to solve the problem. Further, there is a general need to cultivate local political will for long-term commitment and funding of the sector. Although some of the organizations engaged in the sector have started to realise that there is a need for an alteration of approach angle, thus far there is little evidence of the change required to move towards universal coverage.

A needs assessment and a requirement specification were developed based on the findings in the background analysis. This was then used to generate possible technical solutions to be further studied. In the process of deciding upon technical solutions, the information gathered in the village, especially that related to the previously implemented system, has been important. After analysing the data collected in Mpagne and studying available technology the following alternatives were developed:

Alternative 1

Groundwater exploitation with flywheel handpump, elevated storage tank and gravity based distribution to community tap stand

Alternative 2

Rainwater harvesting with swale-trench filtration and flywheel handpump, elevated storage tank and gravity based distribution to community tap stand

Alternative 3

Combination of groundwater exploitation and rainwater harvesting, similar to alternative 1, with the addition of RWH at the village school.

In order to systematically compare these options and decide upon a best suited solution, the indicator comparison methodology developed during the fall project was used in combination with a SWOT-analysis of each concept. The final results obtained indicate that alternative 3 was slightly better than the other two alternatives. A description of the technology required for the new water supply facility in Mpagne was then presented to the level it is possible with the information available at this stage. The intention is for this to serve as an initial suggestion to be presented to the villagers for further discussion.

The report continues with a discussion of an implementation strategy with an enhanced focus on how the technical system can be installed in Mpagne in a social, economic and environmentally sound context. The discussion covers the following four phases:

1. Planning
2. Construction
3. Operation and maintenance
4. Follow-up and evaluation

This process will be especially important considering the past failed project in Mpagne, and an agency should give special attention to including the villagers in all levels from an early stage. This to avoid the deficiency between the solution implemented and the actual needs resulting from the past project.

Further findings are the current situation of downgrading external factors such as the availability and reliability of spare part supply networks as well as lack of general technical support. This is a primary cause of project failure today. The lack of coordination amongst the sector operators, including NGO's, donor agencies, and local and international government entities, is also an important factor which slows down the progress of developing an efficient and effective water supply sector.

Lastly, until internal village level factors as well as external regional and national aspects are adequately satisfied, the agencies operating in the rural water supply sector today have a great responsibility in terms of creating an enabling environment for sector development. Project conduction should be done in adherence with existing policies until the local governments and/or private partners have succeeded in developing an institutional framework to support a well-functioning water supply sector.

Sammendrag

Den følgende rapporten er resultatet av en studie av publiserte litteratur som presenterer dagens vannforsyningssituasjon i Afrika sør for Sahara, i kombinasjon med en ekskursjon til Mpagne i Kamerun. Formålet med prosjektet har vært å studere og diskutere den aktuelle teoretiske tilnærmingen til bærekraftig vannforsyning, samt å generere mulige tekniske løsninger og presentere administrative endringer som kreves.

En grundig bakgrunn analyse viser behovet for forbedring på et lokalt landsby nivå så vel som på regionalt, nasjonalt og internasjonalt nivå. Viktige funn er en høy andel av feilslåtte prosjekter som følge av fravær av evaluering av tidligere prosjekter, samt det faktum at mange organisasjoner ikke opererer i tråd med eksisterende politikk og teoretisk utviklede tilnærminger til å løse problemet. Videre er det et generelt behov for å dyrke lokal politisk vilje til langsiktig satsing og finansiering av sektoren. Selv om noen av de organisasjonene som er engasjert i sektoren har begynt å innse at det er behov for en endring av tilnærmingsmetode, er det så langt lite synlig bevis på endringene som kreves for å bevege seg mot universell dekning.

En behovsanalyse og en kravspesifikasjon ble utviklet basert på funnene i bakgrunnsanalysen. Dette ble videre brukt til å generere mulige tekniske løsninger for ytterligere undersøkelse. I prosessen med å velge tekniske løsninger, har informasjonen som ble samlet inn i landsbyen vært avgjørende, særlig informasjon relatert til det tidligere implementert systemet. Etter å ha analysert de innsamlede dataene fra Mpagne og studere tilgjengelig teknologi ble følgende alternativer utviklet:

Alternativ 1	**Alternativ 2**	**Alternativ 3**
Grunnvannsutnyttelse med manuell svinghjulpumpe, forhøyet lagringstank og gravitasjonsbasert distribusjon til vannposter i landsbyen	Regnvannsoppsamling i kunstig våtmarksgrøft (swale-trench) med manuell svinghjulpumpe, forhøyet lagringstank og gravitasjonsbasert distribusjon til vannposter i landsbyen	Kombinasjon av grunnvannsutnyttelse og regnvannsoppsamling, tilsvarende alternativ 1, men med regnvannsoppsamling ved landsbyens skole.

For å systematisk sammenligne disse alternativene og avgjøre hvilken av dem som er best egnet, ble den kvalitative indikatormetodikken utviklet i løpet av høsten prosjektet

benyttet i kombinasjon med en SWOT-analyse av hvert enkelt konsept. De endelige resultatene viste at alternativ 3 var litt bedre enn de to andre alternativene. En beskrivelse av teknologien som kreves for installering av dette alternativet ble deretter presentert, i den grad det er mulig med informasjonen som er tilgjengelig på dette stadiet. Intensjonen er at dette skal fungere som et innledende forslag som kan presenteres for landsbyboerne for videre diskusjon.

Rapporten fortsetter med en diskusjon av en implementeringsstrategi med spesielt fokus på hvordan det tekniske systemet kan installeres i Mpagne i en sosial, økonomisk og miljømessig forsvarlig sammenheng. Diskusjonen omfatter følgende fire faser:

1. Planlegging
2. Anlegg
3. Drift og vedlikehold
4. Oppfølging og evaluering

Implementeringsprosessen vil være spesielt viktig med tanke på det tidligere feilslåtte prosjektet i Mpagne, og en implementeringsorganisasjon bør spesielt fokusere på i inkludere landsbyboerne i alle nivåer av prosjekt prosessen fra et tidlig stadium. Dette for å unngå store avvik mellom implementert løsningen og beboernes faktiske behov, hvilket var resultatet av det forrige forsøket på å forbedre situasjonen.

Ytterligere funn er den nåværende tendensen med å undervurdere eksterne faktorer som tilgjengelighet og pålitelighet av distribusjonsnettverk for reservedeler, samt mangel på generell teknisk støtte. Dette er en av hovedårsakene til at prosjekter mislykkes i dag. Mangelen på koordinering av aktører som opererer i vannforsyningssektoren, herunder frivillige organisasjoner, donorer, og lokale og internasjonale offentlige enheter, er også en viktig faktor som hindrer utviklingen av en effektiv vannforsyning sektor.

Avslutningsvis, bør det fokuseres mer på at prosjekter gjennomføres i henhold til eksisterende politikk, der engasjerte aktører må koordineres for å sammen danne et muliggjørende miljø, inntil det foreløpig unge og umodne institusjonelle rammeverket i utviklingslandene er utviklet til et nivå som tilsier at lokale myndigheter og private sektor er i stand til å støtte vannforsyningssektoren.

Chapter 1 – Methodology

The traditional product development process model serves as a base for the overall project methodology, with a stepwise progress through important project phases.

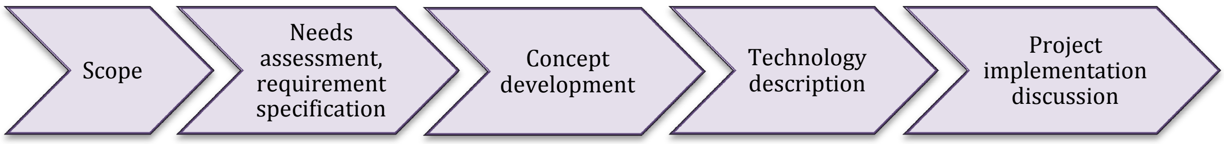


Figure 1 – PD-methodology (Hildre 2004)

Due to the nature of the project, the phases are generally more theoretically determined than a traditional product development project. The existing technical solution in Mpagne is presented as one of two background chapters as this includes preliminary information of importance for the needs assessment. Step four will be an in-depth description of required technology, based on available technology, rather than a detailed structure design. Step five in the original PD-model, “production preparation”, is replaced with a discussion of an implementation strategy, where the phases planning, construction, operation, maintenance, and follow-up are included.

1.1 Project scope

Study and propose a strategy for sustainable water supply intended for rural villages, with an enhanced focus on affordability, accessibility, as well as social and technical appropriateness.

1.2 Preliminary mapping and evaluation of social and technical aspects

The complex inter-linkage of the social and technical factors of a water project is evident through documentation from years of both successful and failed WATSAN projects. Preliminary theoretical mapping of social and technical aspects of such projects was therefore an integral part of the preparatory work for the field trip. A study of published literature was carried out to determine social and technical subjects and questions which needed to be determined during the field trip. The result of this study was the development of interview questions, and a technical note intended to serve as a base for mapping the practical opportunities and limitations through interviews and observation in the village. See appendix I for interview questions, and appendix II for the technical note.

1.3 Research methods

As the objectives of this project include generating detailed criteria for sustainable water supply in Mpagne and a thorough description of an appropriate solution, an in-depth understanding of the social structure in the village and the actual needs is of outmost importance. Generally, qualitative research methods emphasise insight and understanding while quantitative methods give an overview and seeks explanations(Tjora 2012). A qualitative approach was therefore chosen when the interview questions were developed in cooperation with professor in sociology Aksel Tjora at the Department of political science and sociology, NTNU. Further, a focus group discussion was chosen as interview type. This is an efficient form of group interview where several informants are gathered to discuss one or several subjects. In this case, with limited time in the village, it was considered as suitable due to the fact that it develops data from several sources at the same time. In addition, this interview type may come across as less threatening than individual interviews, making the informants more comfortable when discussing ideas and opinions, and might thereby result in a more fruitful data collection.

1.4 Processing and evaluation of collected data

The data collected served as a base for the needs assessment and requirement specification, which in turn were used to develop technical concepts and to determine strategies for the operation and maintenance organization of the technical facility. Factors affecting the validity and reliability of the data collected during the field trip:

- Language barrier. Initially the interviews were supposed to be carried out with a French-English interpreter present. However, this did not happen, and the interviews were carried out in French. Some of the women only spoke Balom, in this case one of the male inhabitants translated to French.
- Time shortage. Delayed departure from Yaoundé resulted in 24 hours in the village instead of 48 hours. Ideally this type of study should have been carried

out over a period of several weeks, in cooperation with anthropologist and/or sociologist. Yet, this was not possible due to a variety of factors.

- Semi-structured interviews/focus group discussion with two groups of men, only one woman was interviewed. The idea was to conduct interviews with one group of men, one group of elders, one group of women, and one group of school children. This was not possible due to cultural factors, and the resulting data are therefore less diversified than desired.
- Examination of only one of the three broken hand pumps. The mechanical failure analysis is therefore solely based on the incident of pump one. The general validity of the failure theories developed is therefore uncertain.

1.5 Concept development and selection of technical solution

Concepts of possible technical solutions have been developed based on published theory, available technology, the results from the previous project work, as well as the needs assessment and requirement specification. To support the decision making process, a SWOT-analysis has been carried out to categorize opportunities and limitations of each of the technical concepts, beyond the ones included in the indicator comparison decision support tool, which is also used to support the decision making process. This indicator comparison is a sustainability analysis, based on qualitative indicator comparison, which was developed during the previous project work. This has been further improved based on new information gathered during the field trip, and used to systematically compare the alternative concepts to decide upon a best suited solution.

1.6 Project implementation

Lastly, the implementation strategy discussion treats the planning, transportation, construction, operational and maintenance organization. As the time spent in the village was limited and the information gathered therefore to some extent incomplete, this section is largely based on the current theoretical approach to sustainable water supply. However, the data collected through observation and interviews is of vital importance and was utilised in developing an initial frame for the project implementation.

2.1 The current theoretical approach to sustainable water supply

Deprivation of access to safe drinking water causes 1.4 million child deaths every year(Ross-Larson, Coquereaumont et al. 2006). As the majority of infectious diseases prevalent in the developing parts of the world are directly or indirectly related to the consumption of unsafe drinking water, the water crisis is holding back human development. The current situation causes severe maladies with ripple-effects all the way from the micro-levelled village society up to national macro-economy. Sub-Saharan Africa accounts for one third of the world's population in need for improved access to safe drinking water, and is, contrary to other under developed regions, lagging behind in the progress toward reaching the UN Millennium Development Goals (MDG)(WHO and UNICEF 2010).

Substantial efforts have been made over the past 50 years to improve the water situation of the world's deprived population, yet little success has been seen in setting and achieving the goals of accessible, affordable and reliable water for all(Gleick 1999). The agencies engaged in the process towards gaining universal access range from large international and well known organizations like the UN, the WHO and the World Bank, to small NGOs and voluntary organizations initiated by local or foreign private individuals. The strategy applied by these organizations to seek to alleviate the water crisis has been extensively discussed over the years. Initially, aid organizations had an output oriented approach with little focus on recipient capacity, O&M and community ownership (Tranor 2007). Their focus was limited to the technical systems and the infrastructure required for access to clean water. Subsequently predominantly technical solutions were chosen as a means of overcoming the limitations in availability of water. When primary access was achieved the focus turned to enhancing technological and economic efficiency, making the solutions affordable for everyone(Keast and Gray 1999). However, a technical solution in itself is but one of many aspects of a successful implementation of a new technology into a community with a well-established social structure. Independent of the size, location and general nature of the community, the following are aspects of major importance:

- Existence of local institutional capacity
- The availability and level of skilled personnel

- The local economic situation
- The existence of knowledge and understanding of the problem being addressed

(Szyliowicz and Frenierre 2008)

The need for technical facilities remains significant, however, it is now seen as an integral part of a whole in which both hardware and software aspects of water supply are considered to be of equal importance for the success of a water project.
Today the focus lies on enabling communities to independently manage their water resources(Keast and Gray 1999). Community participation is a concept where the beneficiaries are involved in the planning and implementation of water projects, to develop a sense of "ownership" of the installed system. The idea is that this then contributes to a sense of responsibility by the community to carry out operation and maintenance themselves. Community participation has been classified in several categories, depending on the degree of involvement of the end-users.

Table 1 - Examples of categories of community participation(Keast and Gray 1999)

Categories of community participation	
1. Consultation	A basic means of giving communities a voice in decision making to meet community needs and facilitate implementation
2. A financial contribution by the community	Usually a contribution to capital cost, to increase the community's "ownership" feeling of a project
3. Self-help projects by groups of beneficiaries	A group of local inhabitants provide labour in the implementation phase assisted by external parties. Those who contribute usually get some sort of economic compensation.
4. Self-help projects involving the whole community	Everybody in the community is expected to contribute, in combination with input from external agencies.
5. Endogenous development	Self-directed generation of ideas and drive for improvement of living conditions, contrary to encouragement by external agents
6. Autonomous community project	Projects under community control. External agencies are hired for support and are paid for with internally raised funding.
7. Approaches to self-sufficiency	Needs are satisfied by using local materials and manpower. The objective is for the community to be self-reliant. The external agency has a facilitating, supporting and consulting role.

The table shows various levels of community participation and coinciding involvement by external agencies.

The next evolutionary step was to promote community management (Keast and Gray 1999). An ideal result of any water project should be a self-reliant community, with full responsibility for operation and maintenance of a technical water facility to include community involvement and commitment, in all stages form initial planning to final installation, operation and maintenance, and general system management. The various types of water systems, requires different types of management. However, the idea is that the beneficiaries are regarded as informed consumers, rather than passive receivers, and for the external organizations to serve as project facilitators instead of service providers.

This is done by:

- Provide technical advice and training during planning and implementation
- Encourage and create an understanding of community responsibility for the water supply for it to be used and maintained efficiently
- Assist in training of water committees in subjects such as financial accounting, record keeping, planning and management
- Ensure that operators and caretakers are in possession of proper technical skills
- Encourage community self-help spirit
- Empower people to make decisions and cope with possible problems such as unforeseen break-down and lack of spare parts

(Davis, Garvey et al. 1993)

If successfully carried out, the community will be self-sustained in terms of operations, maintenance and management of the water system upon project completion.

The current trend is a combination of the abovementioned levels of community participation. The international agencies have altered their focus towards establishing competence and improving skills at the institutional and governmental level. The objectives of the latter are to create an institutional capacity in terms of human and financial resources, as well as monitoring systems to locally support the communities in managing their own water facilities. Such an enabling and supporting environment is of vital importance for the sustainability of water supply systems. Some initiatives taken by the international community is to encourage standardization of technical solutions to decrease the variety of spare parts, and to initiate the establishment of reliable spare part supply networks. (Barbotte 2011) In addition, this strategy is intended to strengthen local institutions and authorities in the process towards creating mechanisms to hold implementation agencies accountable for failed projects (RWSN 2010).

2.2 The failure of rural water supply projects

During the research for this report little information was found on the failure of water supply projects. Ideally, the following section should have been based on several sources, however as this has not been obtainable, it is therefore to a large extent based on one relevant report published by the Rural Water Supply Network (RWSN 2010).

Despite the considerable efforts made to improve the situation for the rural dwellers, progress is slow. On a global basis 80 % of the people without access to safe and sufficient water supply live in rural areas. The rural-urban disparity is even greater in Sub-Saharan Africa, where between 1990 and 2006 one experienced an increase in the population without access to improved water supply in the region(RWSN 2010). Not only is the progression slow-paced, but between 20 and 30% of the technical service systems implemented in the Sub-Saharan region are out of service(RWSN 2010).
In other words, regardless of good intentions, foreign aid projects too often fail, leaving already deprived communities in a state of regression instead of progression. The reasons behind the project failures are complex. In recent years this has been a much discussed subject, and as stated by (RWSN 2010)the aid agencies have slowly started to reflect upon the underlying details of their strategies and the actual results of their well-intentioned projects. Studies have shown that very few organizations are willing to admit that they have failed. Despite years of experience, many carry on as before, and thereby continue to commit the same mistakes over and over(RWSN 2010). The recent report from the Rural Water Supply Network, RWSN, presents and evaluates different myths from the rural water supply sector. Their findings show a variety of factors contributing to repeated project failure:

- Too much focus on subsidising hardware, favouring construction of infrastructure rather than institution-building on a national, regional and local village level

- A quantitative instead of a qualitative approach in terms of installing as many technical facilities as possible, and not focussing on the factors and conditions required for the long-term operation and management of these systems
- Too high expectations regarding independent community management and self-reliance to be realised within a short time perspective
- Failing to consider further development requirements, in terms of for example increased demand, when choosing a technical solution
- Underrating the importance of cultural mores and social realities
- Not taking the financial capacity of the beneficiaries into account when an appropriate solution is to be selected
- Lack of spare part supply and technical support
- Neglect of the private sector as a potential partner in the rural water supply sector, for example in terms of spare part supply and technical support
- Mechanisms do not exist for holding the implementing organizations accountable for their failures and there are no incentives for project follow-up, hence it is rarely carried out
- The assumption that there exists a quick fix solution to the rural water supply issue
- Agencies do not adhere to approach strategies or existing policies

(RWSN 2010)

The theoretical principles presented in the preceding section have evidently not yielded the intended results, and poor implementation is one of the explanations. Initiating self-reliance projects does not replace the long-term commitment required to provide the support which is essential for the communities to eventually become independent. The result is communities who are dependent on external agencies, either in terms of supply of technical spare parts, in relation to social aspects, or even in terms of a subconscious psychological dependency. Raising awareness among project beneficiaries to enhance their understanding of the problems being addressed has long been an integral part of WATSAN projects. Maybe it is time to raise awareness among project organizations of the actual effect of their actions (RWSN 2010).

An overall lesson to be drawn from this is that experience based learning through admitting failure, creating incentives for project follow-up, and evaluation of past mistakes are key factors to future success in the rural water supply sector. Even though some of the organizations engaged in the rural water supply sector have started to realise that there is a need for an alteration of their approach, thus far there is little evidence of the change required to move towards universal coverage.

2.3 Current water supply situation in Mpagne

In terms of technical planning there are certain factors which need to be determined in order to create a solid base for the technical concept generation. The field trip to the Mpagne village showed a somewhat different picture of the situation than what was discussed in the previous project work. The following section will present findings based on the interviews and observations in and around the village.

2.3.1 The people

The population in Mpagne belong to the Balom tribe. The isolated nature of the village's location is primarily due to the fact that the people settled there as they were fleeing from tribal wars some 200 years ago. The rich soil in the area made it favourable to settle down on a permanent basis. The level of education is restricted to primary education at the local village school. Only a few privileged make it to the city for secondary and higher education. The level of technical skills is therefore limited to self-taught maintenance and repair of motorcycles used for transportation to other villages, as well as operation and maintenance of a small diesel-driven corn grinding mill for corn flour production. Heavy rain during the months of September and October gives ideal conditions for cocoa bean farming, which is the village's main source of income. Besides this, agriculture is seasonally based and mainly aimed at their own consumption. Some vegetables and fruit are transported to the closest city for sales on the market. The livestock in the village is not herded. Goats, pigs and poultry are free-range and mostly feed and drink of whatever they can find.

2.3.2 Topography, geology and climate

The topographical characteristics of the area were initially thought to be mostly flat, with some hills and smaller mountains. This is correct to a certain extent. More precisely, the village is situated along the flat ridge of a small mountain, with steep hills down on both sides. The area of the village stretches about two to three kilometres along the ridge, which is about 500 metres wide on average. At the bottom of the small valleys on each side of the village there are several small open water sources, which are fed from small streams and seepage from the surrounding area. Four open, dirty sources of this kind currently serve as water collection points for the villagers' all-purpose household usage. One of the sources, at the bottom of the steepest hill, has been slightly improved. The villagers have inserted two small corrugated iron sheets in the muddy hillside above the pond, draining somewhat cleaner water directly from the hillside, see figure 2.

Figure 2 – One of four water sources in Mpagne

Due to the cleaner nature of this water, it is primarily used as drinking water. However, it is not sufficient to serve the entire village population throughout the year. As discussed in the previous project work, the village is situated in a region dominated by Precambrian basement. The characteristics of such geological basement indicate that long-term reliable aquifers develop at a depth ranging from a few meters up to 90meters (MacDonald and Davies 2000). Nonetheless, the drainage of water from the hillside is evidence that the soil is rich on water, and that the possibilities to exploit this in a more efficient way than what is currently done might serve as a possible solution.

Further, Mpagne is situated on the border between tropical rainforest and the savannah. The climate is therefore dominated by characteristics from both. This indicates heavy rain in the rainy season and harsh drought during the dry season. The year is divided into four seasons as shown in table 2.

Table 2 - Seasons in Mpagne

Seasons in Mpagne	
Long dry season	December – March
Short rainy season	April – July, two weeks in August
Short dry season	Two weeks in August
Long rainy season	September – November

The average precipitation level in the region is estimated to 1500-2000 mm/year (DR 2006). The villagers reported of continuous rainfall during September and October. During the long dry season the sources close to the village dry out, and the already heavy burden of collecting water gets even tougher as the women have to walk back and forth to a river five kilometres away to fetch the water their families need. As this traditionally is women's work, they carry out most of it. However, during the harsh period at the end of the long dry season the men contribute to the water collection.

2.3.3 Infrastructure

The climatic and geological preconditions for large-scale farming of cocoa beans, fruits and vegetables are good. However, lack of basic infrastructure such as roads and reliable water supply impedes the village in exploiting these conditions. A bumpy cart road is the only connection to other villages and cities, and motorcycles or sturdy four-by-four cars are the only transportation alternatives. During the rainy season, when the conditions are good for cocoa bean farming, the soil turns into slippery mud, making the drive practically impossible for trucks required to transport larger amounts of cocoa beans out of the village. This is one of the reasons why the villagers haven't expanded their agricultural production, and the general income in the village remains at a marginal level. In terms of buildings, the village consist of a combination of masonry and concrete houses and some small mud huts. Bricks are produced locally, whereas the concrete has been bought in the closest city. The situation regarding the water infrastructure in the village turned out to be different than what was expected based on the information obtained for the project work. What was thought to be a village completely ignored by government and aid organizations turns out to be a community who has been subject to a failed rural water supply project as discussed in the previous section. The people, who once benefited from safe water supply, have now had to go back to collecting water from the contaminated water sources they used prior to the water supply project – with three broken handpumps rusting in the background. The current water supply situation will be further elaborated in the next chapter.

3.1 Previous attempt to improve the situation

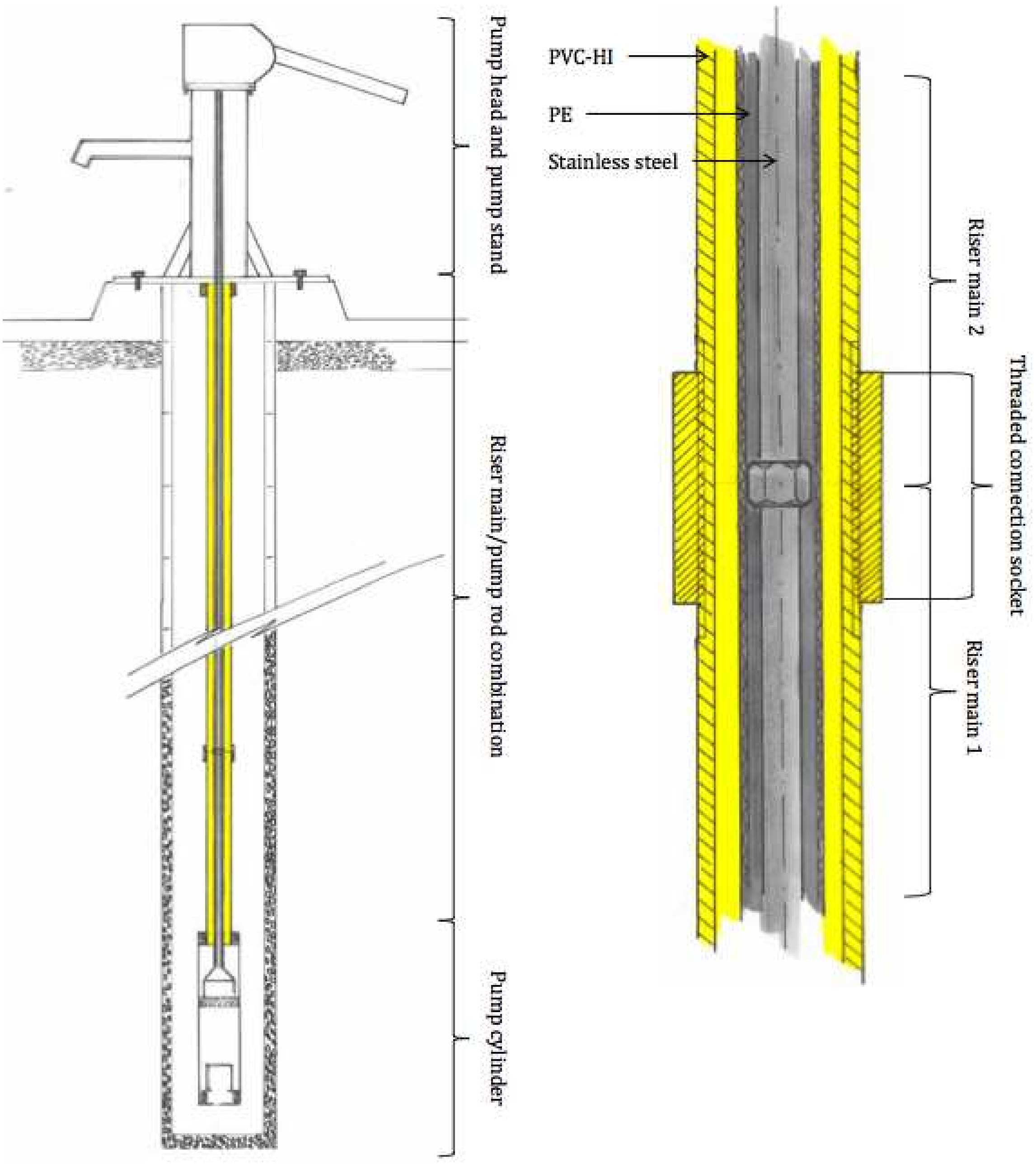
Appropriate technology is often defined based on parameters such as technical simplicity and low-cost. However, as previously discussed, water supply projects repeatedly fail due to a variety of reasons. The neglect of factors like social and cultural mores, as well as downgrading the importance of the technical competence and financial capacity of the beneficiaries are among the main factors contribution to project failure. In Cameroon, for example, the rural coverage is at 41%; however, 25% of the implemented systems are non-functioning (RWSN 2010). This is a striking example of the current success rate of water supply projects. This section will present the current technical solution in the Mpagne village, demonstrating the above mentioned theory resulting from the background analysis. Information regarding the implementation strategy of the previous water supply project has been gathered from the organizations' web-page. Sufficient information has not been obtainable in order to conclude on any level as to why the implementation was not carried out according to the plan or why the project objectives were not achieved.

In an attempt to improve the water supply in Mpagne, a Cameroonian organisation, in cooperation with consultants from a German research and development institute, initiated a water project covering the region in which the village is situated. The project funding was split between a German financial institution and the village inhabitants. The project objectives were to improve the health conditions through hygiene awareness, improvement of sanitation condition, and provision of access to clean water. With an idea of establishing a self-help initiative, the objectives were to be reached through training in community organization, operation and management of the water infrastructure, as well as the implementation of an appropriate technical solution through community participation. The technical solution implemented was the construction of three wells fitted with handpumps. These pumps, the SNW80, are of solid construction, manufactured by the Dutch company VRM. With over 30 years of experience, the company has a long list of references. Among others the International Red Cross, UNICEF and Oxfam(VRM 2011), as well as the Swiss organisation St. Martin Foundation, who initiated the "Water for Life" project in 1989 and who to date has constructed 1200 wells in Cameroons southern region (SMF m.y.). With low technical complexity, easy transportability, simple operation and little need for maintenance these pumps are designed in compliance with the appropriate technology idea(VRM m.y.). However, the inhabitants in Mpagne experienced that the three pumps installed in their village broke down after only a short period in operation. No one in the village were able to fix them, and the result is therefore that they had to go back to the traditional collection of water from open, contaminated sources and springs in the area.

As a means of understanding the cause of the project failure, and learning from it, the following sections presents a technical description of the pump, a failure analysis, and an examination of the overall project conduction. This is based on observations and information obtained during the field trip to Mpagne, as well as public information from the pump manufacturer.

3.2 Technical description of implemented solution

The villagers had disassembled one of the pumps, and a closer study of the components showed a simple yet solid technological solution, theoretically fit for the rural village purpose. Divided into four main components, the pump consisted of a pump head, a pump stand, a riser main/pump rod combination and a submersible piston pump cylinder. The riser main/pump rod combination was attached to the pump cylinder through a simple threaded screw-fix mechanism, and to reach the desired depth of the well, several of these were connected to each other. This was done with a threaded socket attaching the riser mains to each other and a nut-connection between the pump rod segments. The last raiser main was screw-fixed to the pump stand. The pump rod was threaded through the pump stand before it was attached to a swivel and lastly to the pump head, see figure 3. The pump system consisted of 9 riser mains à 4 metres each, plus the pump cylinder à 1 metre, which gives a 37 metres long construction, and probably a 38-40 metres deep borehole.



a. b.

Figure 3 – a. Sketch of pump design b. Sketch of riser main and pump rod connection

The materials applied in the construction, as given by the producer, VRM Apeldoorn:

Pump head, pump stand – stainless steel
Pump rod – stainless steel, protected by a polyethylene, PE, sleeve
Riser rod – high impact polyvinyl chloride, PVC-HI

(VRM m.y.)

It is not known which materials are used for lining the well, however they are not directly relevant to this case and are therefore excluded. The critical part here is the riser main/pump rod combination. What seemed to have caused the technical pump failure was a fracture in the threaded section of a PVC-HI pipe just below one of the sockets attaching two riser mains together, see figure 4.

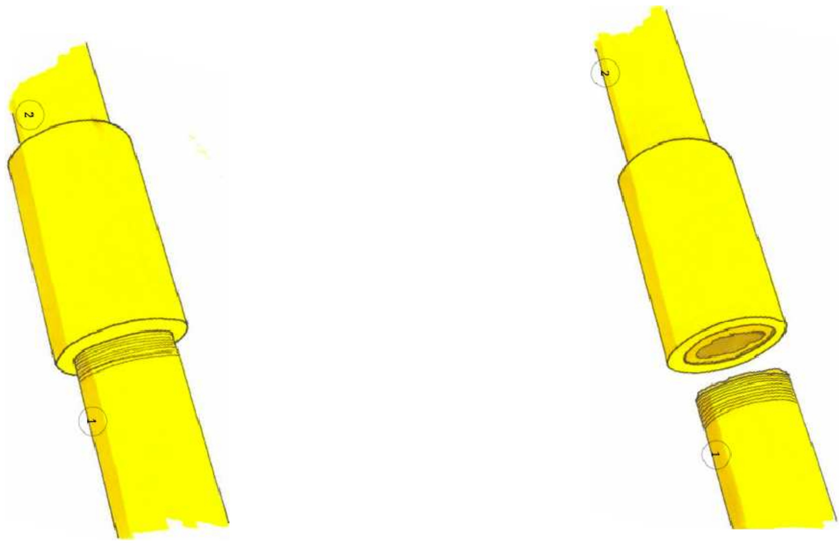


Figure 4 – Sketch of ruptured rising main

3.3 Failure analysis

The nature of the fracture surface observed on the component from the PVC-rising main indicated some sort of brittle fracture. As testing could not be carried out on-site, and components could not be transported to Norway for further evaluation of the fracture characteristics, the failure analysis will be based on a visual impression of the fracture surface, as well as knowledge of the system design and the mechanical properties of PVC.

PVC is an inexpensive plastic extensively used, largely due to its versatility. HI-PVC is characterized as a material with many favourable mechanical properties in relation to water supply application, such as resistance to corrosion, as well as its mechanical strength, tensile strength and hardness. However, its impact strength is low. This is a measure of the amount of energy required to fracture the material, or in other words, the material's ability to resist shock loading(MatWeb 2012). See table 3 for more details on material characteristics.

Table 3 - Relevant material data for HI-PVC (MatWeb 2012)

Material data, HI-PVC	
Mechanical properties:	
Tensile strength at yield, σ_y	49 MPa
Elongation at yield, ε_y	10%
Tensile strength at break, σ_R	30 MPa
Elongation at break, ε_R	30%
Modulus of elasticity, E_t	2600 MPa
Thermal/physical properties:	
Max/min service temperature	60 ° C/-40 ° C

The physical deformation mechanisms which are most often considered to cause polymer failure, according to (Brinson and Brinson 2008) are:

1. Atomic bond separation mechanisms
2. Shear bands
3. Crazing

Rupture or fracture of PVC must involve the separation of individual atoms and molecular chains. Atomic bond separation occurs due to the fact that an external force exceeds the internal forces between molecular chains. For solid thermoplastics like PVC, the presence of external forces can cause internal shear stress large enough to cause permanent deformations in the molecular structure, causing points of weakness exposed to further and critical deformation if external loading persists.

Shear bands are normally initiated at a point of stress concentration and develop due to large movements of molecular chains caused by application of external forces. This causes permanent deformations after load removal, affecting the original mechanical properties of the material. Generally, deviatoric stress is what causes shear bands.

The last deformation mechanism, crazing, occurs due to the formation of micro-voids at points of high stress concentration, as a consequence of dilatational stress. Points of high stress concentration arise in relation to for example surface scratches or internal micro-flaws and defects from processing. A multi-axial stress field around an existing micro-crack can cause the initiation of new micro-cracks. If a larger amount of micro-cracks are generated these can merge due to stress and thereby from a large crack, which can be the initiation of complete mechanical failure(Brinson and Brinson 2008).

Based on this information, some possible initiating causes of system failure in Mpagne could be:

- Production flaw such as dust particles or air bubbles in the components
- Damage during transportation causing surface scratches
- Material failure in terms of inadequate initial material robustness
- Material failure as a consequence of installation mistake

The general material characteristics indicate that the HI-PVC pipes are fit for the purpose in terms of material robustness. During operation the rising main is subject to stress fluctuations as the water is being pumped from the bottom of the well up to the pump stand above ground. The pump cylinder was not attached to anything at the bottom of the well. Operation therefore causes larger vibrations in the riser main/pump rod combination than if the cylinder would have been attached to a bottom supporter. The implementation of such a cylinder supporter usually depends on the depth of the well, and has evidently not been thought necessary in this case. The operation-induced vibrations are most likely taken account for in the pump design and should therefore in itself not be enough to cause system failure of the kind seen in Mpagne. Based on the design of the technical solution, the superficial nature of the fracture, knowledge of common polymer failure mechanisms, as well as general material characteristics of PVC-HI, the following two failure theories have been developed:

1. The system was not properly installed to begin with. As the pictures of the broken pipe shows, the fracture occurred in the threaded section of riser main 1. This indicates that riser main 1 might not have been screwed properly into the threaded socket connection between pipe 1 and 2. Stress fluctuations can have caused crazing and further crack propagation in the vulnerable threaded section of pipe 1, eventually leading to system failure.
2. Vibrations from operation can have caused the riser main to unscrew itself from the threaded fastening socket, altering the force distribution over the threaded area. Stress fluctuations can have caused crazing and further crack propagation in the vulnerable treaded section of pipe 1, eventually leading to system failure.

Both these theories are based on the fact that the fracture occurred in the threaded section of rising main 1, as shown in figure 4.The length of the connection socket and the threaded area of the PVC-HI pipes observed indicated that the socket is intended to completely cover the threaded section of the riser mains, as long as they are screwed properly in place. If pipe 1 would have been properly fastened into the connection socket, the forces present during operation would have been evenly distributed over the threaded section, minimizing the force concentration and stress fluctuation per thread. The theory indicates that this was not the case, and the forces acting during operation has led to stress concentrated over a smaller area than accounted for in the pipe-design. The threaded section is a vulnerable area, as this basically is an area of surface scratches. Normally, it is not a source of complications, but as the system structure presumably was not entirely in line with the directions from the producer, the threaded area beneath the fastening socket is a point of weakness with regards to the vibratory and tensile forces acting on this system. The initial material robustness was reduced – in this case to a critical level.

These theories are supported by results from a study by Tranor International carried out to evaluate NORAD's support to the WSS sector in Tanzania and Kenya in the 70's, 80's and 90's (Tranor 2007). This study shows that most non-working boreholes in the regions covered by NORAD's work were originally fitted with SWN pumps. Further, the report concludes that the major problem was the threaded and screw-fixed design of the PVC rising mains. This design makes the pipe prone to bursting from operation-induces movements and vibrations. The result seen in Tanzania and Kenya was that the pipe had dropped to the bottom of the well in many cases (Tranor 2007). As for the case observed in Mpagne, further investigation is required in order to be able to confirm the actual technical cause of the system break-down, and I will therefore leave the discussion with the two theories presented above as possible failure causes.

3.4 Project conduction and social aspects

Information about the general project conduction and the social aspects related to the implementation of the pumps was obtained through interviews with the villagers. The intention was to carry out focus-group interviews with representatives from different social groups in the village – women, men, school children, and the board of elders. However, culturally determined conditions, language barriers and time limitations led to a semi-structured interview setting, primarily focussed around the men, as well as a short interview with one woman. Nonetheless, the interviews gave an impression of the project implementation process, which to a large extent was based on community participation and village financial contribution. These are two elements regularly discussed in water project related reports, which, as previously mentioned, are emphasized as of major importance for the long-term success of the projects.

Pursuant to the men who were interviewed, community participation was carried out in the form of labour during construction. The technical solution was already decided upon by the external agencies, and the villagers had little or no saying in this decision making process. Given that the project failed despite the technical simplicity of the pumps, there is reason to believe that there were fractures also in the social frame required for the technical understanding, financial insurance, and general care-take of the water supply system. Results from the interviews show different factors affecting the sustainability of the project. The most important being:

- No personnel with sufficient technical skills in the village
- No spare parts available to replace the broken components
- No cost recovery system established to ensure that the village could afford maintenance and repair costs
- Low level of self-help spirit
- No contact with the organization who implemented the pumps
- No support from national or regional governmental bodies

When asked, the villagers expressed satisfaction towards the technical solution which had been implemented. It had largely improved the burden previously associated with water collection, and it had provided clean water almost all year round. However, one of the village mayors stated a desire for a storage tank to better make use of the heavy rainfall during the rainy season. Further, he also uttered a desire for the village inhabitants to be given the chance to participate in the decision process of a future technical solution, and had a desire that ideas from possible external agencies would be presented to them, so that they could have a saying in the decision making.

Several of the men commented upon the improvement they had experienced in the state of health in the village after the hand pumps had been installed. They also stated that they had experienced a health-related relapse in the years after the pumps broke down, with increased and more severe cases of illness and a higher death-rate. Even though this change has not been statistically determined, it shows that there exists a basic understanding of water related issues and the need to improve the situation. The villagers' overall conclusion was dissatisfaction with the fact that their money and hours of hard work in the end had led to nothing.

These findings leave the impression that the actual project implementation process was not carried out in line with the organizations' own objectives, and certainly not in line with the theoretical approach previously presented. In particular, it seems that the project was carried out with a short-term perspective, without a plan for operation and maintenance of the facilities, evaluation and follow-up, and without providing the villagers with neither the proper software nor hardware tools they need to be independent.

3.5 Lesson learnt

The lessons to be learned from this are many. In large, this case demonstrates two important aspects. The first is the lack of adherence to developed approach strategies and existing policies from the organization's side, and the second being the failure of the government to engage in and follow up rural water supply projects. There is a need for long-term commitment from a supporting party in order for rural water supply projects to be well-functioning on a long-term basis. Normally, aid organizations operate on a short-term perspective, and there are little incentives from them to change this approach. This enhances the importance of institution-building on a national and regional administrative level, as the government should be the main body in charge of follow-up and evaluation of these projects. Further, the example also enhances the need for the establishment of reliable district spare part supply networks and the importance of proper technical training of a system maintenance team.

The technical solution implemented was a theoretically appropriate solution. While working, the pumps provided water at a qualitatively satisfactory level. However, quantitatively speaking, the project did not satisfy the needs in Mpagne. And, as stated by several of the villagers, the massive rainfall during the months of September and October can be exploited in a way which contributes to the quantitative needs being met. This inconsistency between the actual needs and the solution provided might be the result of the fact that the villagers presumably were not included in the decision making process or the initial planning phase of the project implementation. The bottom line and main lesson to be drawn from this example is therefore that the simplest of technologies cannot be implemented without ensuring that the social and organizational structure around it is of a solid and sustainable nature, enabling villagers to be as independent as the external agencies leave them to be.

Chapter 4 – Needs Assessment

An integral part of the initial stages of this type of project is a thorough evaluation of the beneficiaries' actual needs and desires. To conclude the background study, the following section will present the project needs assessment, and thereby determine the gaps between the current and desired situation. The assessment is carried out based on information collected during the field trip to Mpagne, information acquired through the background study, and results from the previous project work. The study has led to identification of the following issues needing to be addressed:

Village level

- Lack of well-functioning basic infrastructure
- Lack of adequate access to safe drinking water, qualitative and quantitative
- Severe health problems as a direct or indirect consequence of consumption of contaminated drinking water
- Lost education due to high illness rate/health problems related to consumption of unsafe water, as well as time spent on collecting water to meet the needs of the village population
- Enhanced gender inequalities as the women are traditionally responsible for the time-consuming work
- Lack of technical competence for operation, maintenance and larger repairs
- Lack of access to equipment and spare parts
- Lack of a cost recovery system to ensure the ability to pay for necessary maintenance and possible larger repair operations
- Lack of a distinct institution responsible for operation and maintenance of a technical facility
- Low level of self-help spirit

Regional, national and global level

- The isolated village location poses challenges with regards to transportation of material and equipment, as well as it causes difficulties in communication with regional and national administration
- Lack of local or regional technical support, suppliers and a reliable spare part supply network
- Lack of political will to engage in small-scale projects on a national as well as regional level
- Lack of a systematic, sustainable, and practically applicable approach for gaining access to safe drinking water on an overall administrative aid level

- Lack of follow-up and evaluation of previous projects, neither by aid organizations nor by governmental agencies
- Lack of mechanisms for holding aid organizations accountable for failed projects

The findings reflect challenges directly related to the Mpagne village, issues correlated with regional and national level administration and business environment, as well as inadequacies in today's foreign aid strategy. The two latter are not issues only related to Mpagne in particular, but general challenges in the rural water supply sector on a global level. The need for improvement is evident. The description of the failed technical solution, in combination with the above needs assessment, will serve as a base for the requirement specification generated to set the framework for possible technical concepts. In prioritizing the needs, the village level issues are the main needs to be satisfied through the implementation of an appropriate technical system, and are therefore the key subjects to be studied in what follows. The challenges related to regional, national and global administrative factors will be further deliberated in the discussion of the implementation strategy in chapter 9 and in the concluding parts of the report.

Chapter 5 – Requirement specification

The criteria for sustainable water supply are more or less the same as those defined in the previous project work. These were based on basic information regarding the current situation in Mpagne, as well as published literature covering the water supply crisis on a general level. The field trip to the village led to a better understanding of the situation as it is today, and it gave an impression of what the villagers themselves see as future solutions. The result is a list of requirements for a possible technical solution which is an elaborate version of that presented in the fall project. Criteria have by and large not been redefined, as many of the predefined criteria corresponded with the actual conditions. However, information from observations and interviews underlined the importance of several of the criteria, and the list of requirements has therefore been supplemented with further details.

1. Health and safety requirements
    a. Must provide water of adequate quality in compliance with government standards, or WHO guidelines for drinking water quality to achieve ideal health effects (Ross-Larson, Coquereaumont et al. 2006)
    b. Must be designed to minimize the risk of harming operators and end users
2. Social requirements
    a. Must be possible to implement within the existing social structure, or with a minimum of reorganization of existing social structure
    b. Must be designed in compliance with the villagers actual needs and requirements
    c. Should be designed with an intention of easing the workload for the women and children responsible for water collection
    d. Should be in compliance with local cultural mores
3. Functional requirements
    a. Must yield the daily water need to the community of 600 inhabitants. In line with the WHO poverty-threshold (Ross-Larson, Coquereaumont et al. 2006), this indicates 20 l/person/day, rendering 12 000 litres of drinking water per day, excluding spillage

    b. Should be suited for further capacity development to keep up with possible population growth or other expansion needs
4. Reliability requirements
    a. Operation and maintenance requirements must comply with local level of technical competence
    b. Must be designed with a minimum requirement for maintenance
    c. Must be designed in compliance with availability of spare parts
    d. Long system life-time should be a priority
5. Financial requirements
    a. The capital and O&M cost must comply with the beneficiaries' financial capacity, both in terms of ability and willingness to pay, on a long-term basis
6. Transport related requirements
    a. Must be possible to transport on a sturdy four-by-four car, helicopter is also a possibility, however this would increase the capital cost to an unacceptable level
7. Environmental requirements
    a. Should comply with local climate, topography and geology
    b. Must be designed to avoid overexploitation of available water resources
    c. Land degradation as a consequence of construction work should be minimized in order to avoid harming arable land

6.1 System of interest

Determining an appropriate technical solution requires a solid base of information in order to ensure compliance with the given requirements. The necessary technical systems already exist; however, it is the way in which these are combined and implemented which to a large extent determines the long-term sustainability of the facilities. An optimal solution is one commensurate with local needs, one which is in compliance with the community's financial and technical capacity, and which efficiently exploits the available water sources in an environmentally sound context.

The results from the previous project work led to the selection of groundwater exploitation or rainwater harvesting (RWH) as possible technical solutions. More specifically, the two technical concepts proposed were:

1. Groundwater extraction with a submersible solar-driven pump and an elevated storage tank for gravity-based piped distribution to community tap stands.
2. RWH in a swale-trench, with a submersible solar-driven pump and an elevated storage tank for gravity-based piped distribution to community tap stands.

Of these two concepts, alternative one was seen as the most viable based on the results from a qualitative indicator comparison methodology(Hylin 2011). However, the generation and evaluation of these concepts were strictly based on published theory, with only limited input of information regarding the village of concern.

In the preparatory work for the field trip a technical note was generated, creating an overview of components required for the two concepts from the project work presented above (see appendix II). This again contributed in setting up important technically related inquiry subjects to be determined during the field trip. The following factors were seen as important in relation to a technical solution, and set the frame for the system of interest:

- Available technology options, favour standardized technical solutions
- Available water sources
- The need for treatment of available water
- Appropriate technology applied in an appropriate way

Further, the table below shows an overview of important technical information gathered in the village.

Table 4 - Technical mapping

Technical inquiry	
Number of inhabitants	Approx. 600 spread between four neighbourhoods
Area and distances within the village	Total area of village: 0,5 x 2-3 = ~1,5km^2 3 neighbourhoods 500 m apart from each other, 1 neighbourhood about 1 km down the road
Topographical characteristics, especially height differences	30-50 m difference in height between village level and water sources
Superficial soil characteristics, composition	Muddy when wet, no visible large rocks
Intended use of the water	First priority is drinking water, but clean water for all-household purpose is highly desirable
Draw-off pattern in the village	Three times per day, morning – midday – afternoon
Level of local technical skills	Limited to self-taught maintenance and repair of motorcycles and a diesel powered corn-mill
Existence of electricity	Limited to one solar panel producing electricity for lighting in the Chief's house (installed during the field trip)
Distance to and relationship with other villages in the area	2 km to closest village, good relationship, no conflicts, little trade
Distance to closest city w/possible spare part supply	20 km
State of village economy	Marginal
Applicability of locally available materials	Low, only materials available in village: wood and locally produced bricks
System borders	Including the people and animal in the four neighbourhoods of Mpagne, agricultural activities are not included at this stage, interaction with other villages is negligible

With this in mind, combined with general results from the data collection in Mpagne, the two solutions suggested in the previous project work are highly inappropriate at this point. The technical complexity is not in line with the level of local technical competence. The training required to reach a satisfactory level should take the form of stepwise introduction to technology, and therefore start with creating an understanding of simpler technical systems. Further, it has also been argued that systems based on photovoltaic power generation are not economically feasible for communities with less than 2000 inhabitants(Barbotte 2011). The following section will thus present a generation of more appropriate alternative solutions, with groundwater and rainwater as suitable sources.

6.2 Groundwater

The exploitation of groundwater aquifers, where available, is considered to be a stable and reliable means of water supply. Hand-dug wells and boreholes are two alternatives for gaining access to the groundwater, and the variety of sustainable top-side solutions fit for small-scale water supply range from bucket and rope to more technically advanced mechanical pumps(Baumann and Erpf 2005). As wells already have been constructed in Mpagne, the top-side solution is of main interest here. Figure 5 shows concept sketches of a selection of existing hand pumps. The table below shows an overview of the different alternatives, and some benefits and drawbacks with each of them.

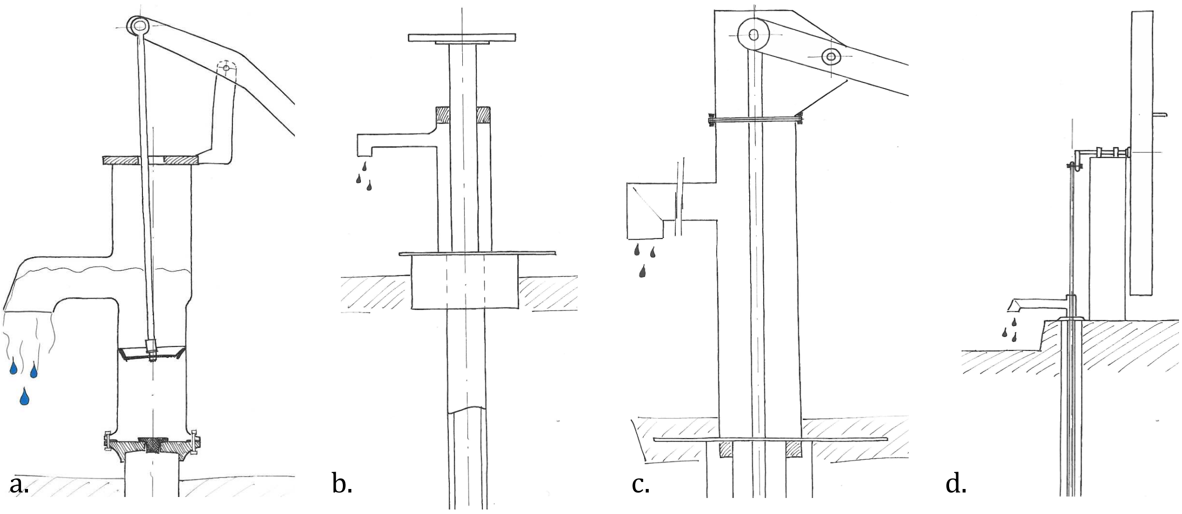


Figure 5 – Sketches of handpump technologies
a. Suction, b. Direct Action. c. Lever Action, d. Flywheel

Table 5 - Groundwater technology options(Baumann and Erpf 2005)

Top-side technology for groundwater exploitation		
Technology	*Benefits*	*Drawbacks*
Reciprocating pumps		
Suction pumps	The pump cylinder is normally mounted in the pump body above ground. This facilitates maintenance. Simple installation.	Can only be used to lift water 7-8 meters, as this is the limit to which atmospheric pressure can push water. The pump needs to be full of water before operating. Normally the priming is done by an operator who fills the pump head, whenever it is empty. In this lies the risk of contaminating the well with dirty priming water. Suitable for serving only 50-100 people.
Direct action pumps	The pump rod is made of plastic pipes and is designed in such a way that it floats in the water of the rising main. This reduces the force required for the up-stroke. Narrow clearance between pump rod and rising main allows for water delivery during both up- and down-stroke. Easy to install. Suitable for serving populations up to 300 people.	Operation limited to lifting water 15 meters. Recommended operation depth is 12 meters. For maintenance of pump cylinder the entire pumping element (pump rod, riser main and cylinder) must be lifted out of the well in one piece.
Lever action pumps	The lever eases the operation of pumping water from deep wells. The lever can be replaced with a flywheel operating a crank shaft which transforms the rotation into a reciprocating movement, increasing the pump lift potential. The flywheel is especially suitable for lifting water to elevated storage tank. Pumping lift ranges from 2 to 80 meters depending on the type. Suitable for serving populations up to 300 people.	Not all lever action pumps are fit for local manufacturing. This makes the communities dependent on imported goods and reliable spare part supply networks. Maintenance and repair might be difficult for VLOM (depending on the type)
Rotary hand pumps		
Rope pumps	Simple design and easy maintenance. Pumping lift: 0-30 meters. Good potential for local	Suitable to serve populations of less than 70 people. Not designed for high daily output. Application range

	manufacturing.	recommended for up to 15 meters.
Motorized pumps		
Submersible pumps	Efficient, can serve larger populations.	Maintenance requires thoroughly trained technical personnel. Requires steady supply of energy (diesel, petrol, electricity)
Line shaft pumps	Driving element of pump is above ground. This eases the maintenance. Efficient, can serve larger populations.	Maintenance requires thoroughly trained technical personnel. Requires steady supply of energy (diesel, petrol, electricity)
Jet pumps	Does not have any working parts and is therefore easy to operate and maintain.	Relatively inefficient, as half of the drawn water is used to drive the pump. Maintenance requires thoroughly trained technical personnel. Requires steady supply of energy (diesel, petrol, electricity)

In addition to traditional energy sources, the motorized pumps can also operate on solar or wind power. A storage tank is then required to generate a water buffer for days with little sun or wind, and to balance out demand fluctuations.

Given the approximate depth of the existing well (38-40 m), the quantity requirement to satisfy the village need, and the present level of technical competence, some of the above alternatives are more appropriate than others. As previously mentioned, the solar powered solution suggested in the fall project is of too high technical complexity, and the above presented motorized pumps are therefore also regarded as inappropriate at this stage. They will, however, be included in the discussion of implementation strategy in chapter 9 as possibilities for the process of stepwise introduction of technology in the village. Of the handpump alternatives, the lever action pump is the only one with a pump lift capacity exceeding the required depth in Mpagne, which at the same time is suited to serve up to 300 people. This reduces the number of pumps required to meet the needs in the village, and thereby also the total capital cost of the project. The SWN80 handpump installed in the village today is a lever action pump, which the villagers were satisfied with while it was functioning. However, it did not meet the quantitative need at all times. One cannot exclude the fact that the reason behind the shortage of water is because the aquifer accessed with the boreholes might not be a long-term reliable source, or that it might have been affected by harsh droughts. However, demand fluctuations can also be the cause, where periods of greater demand poses a risk of over-extraction from the groundwater reservoir. The latter cause can be avoided through implementing a storage tank, which is dimensioned to serve as a buffer balancing out these variations in demand for water. If the tank is elevated, further distribution can be gravity-based, and thereby exclude the need for additional technical appliances to distribute the water from the tank to a community water stand post. If an elevated storage tank is to be implemented, a lever action pump with a flywheel is a suitable choice as the pump lift potential of this type of pump is 80 meters.

The concept which seems most suitable of the possible combinations presented above is a flywheel lever action pump fitted on the existing wells, and an elevated storage tank with gravity based distribution to community tap stands. This is based on the assumption that water can still be found in the existing wells, and that they can function as long-term reliable sources given that the implementation of storage tanks balances out the demand fluctuations. The main argument for this choice is that the concept complies with the requirement specification, in terms of technical requirements, water quality and easing the women's work load. In addition, using a manual hand pump to fill the storage tank allows for the creation of income-generating jobs. This is in turn an incentive for the hired facility manager(s) to make sure the system is in operation at all times. The sustainability of the concept is further enhanced as the flywheel also can operate on solar power. As a local technical team develops their competence, the solar-panel power generation can be expanded to also provide electricity for lighting in the village. This concept will therefore represent the groundwater exploitation in the qualitative indicator comparison in the next chapter. See table 6 at the end of the chapter for an overview of the chosen concepts. The variety of storage tanks will be discussed later in this chapter.

6.3 Rainwater

The heavy rainfall during the long rainy season in the area is a primary source of clean water of a large volume, which should be taken advantage of to meet the needs of the community. On a village or single household level, rainwater harvesting is normally done on roof-tops or tilted large-surface ground catchment areas. The run-off water is guided to gutters which leads it to storage tanks. To enhance the cleanliness of the water, it can also be led through a collection box with for example a sand filter, before it is drained into a storage tank (WaterAid m.y.). Other types of water treatment are solar disinfection in PET-bottles, UV-radiation and chlorine (Aristanti m.y.) and (Burch and Thomas 1998)

Efficient traditional RWH requires large catchment areas, as the run-off from the roof is directly proportional to the amount of rainfall and the size of the catchment area. Ideally 1 mm of water per square meter of roof area yields 1 litre of water. However, in practise this is an underestimate due to factors such as evaporation, wind and spillage losses (WaterAid m.y.). As of today some of the houses in Mpagne have corrugated iron sheet roof-tops, while the majority of the houses have roofs made of palm tree leafs. Both are suitable as rainwater catchment surfaces, however, a palm leafed surface is harder to clean, can taint the run-off and may contain dust or debris. The corrugated iron roof-tops in the village are therefore more appropriate as they are easier to clean. Gutters are normally placed along the eaves of the buildings, and can be made from galvanized steel sheets, wood or a hard plastic if this is available. Rainwater storage tanks are normally constructed of PVC or Ferro-cement, and are built either above, below or partially below the ground. The specific capacity of a storage tank depends on factors such as pattern and volume of yearly rainfall, duration of periods without rain, and an estimate of demand (WaterAid m.y.). The climatic preconditions in Mpagne indicate, as mentioned, that large volumes of water can be collected. However, the length of the dry season, the relatively small total area of existing catchment areas, and the population size, makes it questionable as to whether RWH is a feasible water supply solution for the entire community.

The WHO suggests 15-20 litres per person per day as a lower poverty threshold(Ross-Larson, Coquereaumont et al. 2006). In Mpagne, with a population of roughly 600, this implies a need for 4.4 million litres of water per year. An estimate of the existing total area of suitable roof-tops is about 360 m^2. This is the area of the roof-tops of the school buildings, the chief's house and a few other residential houses. With an average yearly rainfall of 1500-2000 mm/year (DR 2006), this yields 540 000 litre of water per year, without taking losses into account. If this kind of rainwater harvesting is to serve as a sustainable solution, the total catchment area has to be significantly increased, or RWH has to be combined with water supply from a different source.

An alternative to the traditional method for RWH is the swale-through-trench presented in the previous project work. The concept is based on on-site storm-water treatment technology from Germany, but can with a few adjustments serve as an artificial groundwater reservoir. The idea of fitting the trench with a PV-driven submersible pump to lift the water to an elevated storage tank is, however, not a suitable solution for the same reasons as for the inappropriateness of the solar-pumping of groundwater concept discussed in the preceding section. A solution which complies with the requirement specification is a manual pump of the kind presented in the groundwater section. In this case, though, the water reservoir will not be as deep as a natural aquifer, and the alternatives of suitable pumps are therefore many. However, it is also here desirable with a storage tank to reduce the risk of over-extraction. There is thus a need to lift the water from the lowest point of the trench to the top of the tank – a height difference exceeding 10 meters. The alternatives are therefore narrowed down to a direct action or lever action pump. The excavated swale-through-trench requires a lot of space to ensure a sustainable water supply. The specific size and number depends on the volume and pattern of yearly rainfall, the size and porosity of the matter used to fill the trench and an estimate of the actual water need in the village. The structure of the village and the topographic characteristics of the area indicate that fertile soil and arable land has to be removed at the expense of possible swale-through-trenches. It is not known whether this is acceptable for the villagers or not.

Similarities to the natural purification resulting in high-quality groundwater, the ease of the women's work load, as well as the concepts compliance with other technical requirements are benefits which led to the decision of this being the alternative concept representing RWH in the qualitative indicator comparison.

6.4 Combined solution

A combination solution will also serve as one of the alternatives for the indicator comparison methodology. This concept involves groundwater exploitation through improving the existing wells by fitting them with flywheel pumps, elevated storage tanks and gravity based distribution to community tap stands. In addition, rainwater harvesting can be implemented at the village school. The roof serves as catchment area and a storage tank can be constructed beside or between the two school buildings. This is suggested as a suitable solution, as it is an overall efficient and sustainable way of exploiting the available water resources in the village. Further, it can serve as a means of creating awareness around water related issues among the children in the village. The development potential of this solution is also beneficial, as the initial introduction to RWH at the school will ease a possible expansion of rainwater harvesting at a village level.

6.5 Storage tank

All three alternatives include storage tanks. As it is a means of constantly ensuring availability of water, it has an essential function in the water supply system. There exists a variety of storage tanks, and the most commonly used are masonry or reinforced concrete tanks, collapsible fabric tanks, pre-fabricated steel or plastic tanks and ferro-cement tanks(UNHCR 2006). On a long-term perspective there are certain criteria which are to be satisfied, including affordable capital and O&M cost, easy operation and maintenance, long system lifetime, local availability of materials, as well as compliance with beneficiaries' know-how in terms of construction, operation and maintenance. Research carried out by the United Nations refugee organization, UNHCR, shows that the ferro-cement storage tank technology satisfies the abovementioned parameters (UNHCR 2006), and is therefore a preferred choice in many water supply projects. Benefits such as light weight, toughness and durability, combined with easy construction and repair, as well as low cost compared to other alternatives(UNHCR 2006), leaves it to be a preferred choice also in this project. See table 6 below for an overview of the chosen concepts.

Alternative 1

Groundwater exploitation with flywheel handpump, elevated storage tank and gravity based distribution to community tap stand

Alternative 2

Rainwater harvesting with swale-trench filtration and flywheel handpump, elevated storage tank and gravity based distribution to community tap stand

Alternative 3

Combination of groundwater exploitation and rainwater harvesting, similar to alternative 1, with the addition of RWH at the village school.

Table 6 - Alternative technical concepts for qualitative comparison

	Alternative 1	Alternative 2	Alternative 3
Water source	Groundwater	Rainwater	Rainwater and groundwater
Initial access gained through	Existing wells	Manually excavated trench	Rainwater and existing wells
Top-side solution	Manually driven flywheel pump and an elevated storage tank for gravity-based distribution	Manually driven flywheel pump and an elevated storage tank for gravity-based distribution	Manually driven flywheel pump and an elevated storage tank for gravity-based distribution. Corrugated iron roof-tops as catchment area, galvanized steel sheets as gutters, and a ferro-cement tank for storage.
Equipment and material required for initial installation	Flywheel pump with pump rod, rising main and pump cylinder, ferro-cement, reinforcement and chicken wire for construction of storage tank, distribution pipes and tap stands, and necessary tools	Excavation equipment for trench digging, impermeable wall lining material, pea gravel, stones and sand for natural trench filtration, drainage pipe, flywheel pump, with pump rod, riser main and pump cylinder, ferro-cement, reinforcement and chicken wire for construction of storage tank, distribution pipes and tap stands, and necessary tools	Flywheel pump with pump rod, rising main and pump cylinder, a storage tank, distribution pipes and tap stands, and necessary tools. Steel sheets for gutters, ferro-cement, reinforcement and chicken wire for construction of storage tank. Distribution pipes.
Additional purification	Assumed not necessary	If necessary: PET-bottles for solar disinfection of	If necessary: PET-bottles for solar disinfection of

		drinking water at household level.	drinking water at household level, or a sand filter collection box which the water is filtrated through before it is led to the storage tank.
Distribution from storage tank	Gravity-based piping to community tap stands	Gravity-based piping to community tap stands	Gravity-based piping to community tap stands
Expected yield rate [litres/day]	≥ 12 000	≥ 12 000	≥ 12 000
Maintenance activities	Inspection of well, pump, pipes and storage tank - only simple tools required. General maintenance on a day-to-day basis. Repairs when necessary.	Inspection of pipes, pump and storage tank, ensure that the area around the swale-trench is tidy and avoid animal and human activity in/close to the catchment area. General maintenance on a day-to-day basis. Repairs when necessary. Only simple tools required.	Inspection of wells, pipes, pump and storage tanks. Keep RWH catchment area clean. General maintenance on a day-to-day basis. Repairs when necessary. Only simple tools required.
Expected capital cost[1] [$]	6600	40000	9100
Expected O&M cost[1] [$/year]	2250	1800	3000
Expected lifetime[1] [years ±10 years]	15	15	15

[1] The Capital and O&M cost, as well as the expected system lifetime are based on information from OECD. See next chapter for more information.

In assessing the sustainability of the three concepts presented in the previous chapter, an evaluation of the triple bottom line (TBL) – the social, economic and environmental dimensions, is a natural approach. However, sustainability should be evaluated in relation to a particular context, and the TBL approach is not always sufficient to measure the sustainability of a project. Several studies suggest that infrastructure and governance should be included as dimensions of sustainability (Brattebø 2012). In the context of a rural water supply project of this kind, the issue of natural resource depletion is not a key factor, and functional sustainability is therefore more relevant than environmental sustainability. The assessment of infrastructural reliability as well as the importance of considering institutional aspects has therefore led to the conclusion that in the following, the sustainability of the possible solutions will be evaluated based on these dimensions:

- Institutional/organizational
- Social
- Technical
- Economic
- Environmental

(Perry-Jones, Reed et al. 2001)

7.1 SWOT-analysis of technical concepts

Three potential technical concepts were identified in the previous chapter, and in the process of narrowing down to one concept it is important to evaluate each of them in terms of:

- Benefits
- Limitations
- Costs
- Maintenance needs
- Management needs

(Harvey and Reed 2004)

The following section will therefore present a SWOT-analysis of the suggested concepts.

Table 7 - SWOT-analysis alternative 1, Groundwater

	Helpful in achieving the project objectives	*Harmful in achieving the project objectives*
Internal origin (Attributes of the concept)	Strengths • Low capital cost • Low O&M cost • High-quality water with no need for further purification • Easy management and maintenance • Storage tank serves as a security with regards to demand fluctuations • Manual pumping of water to storage tank creates income-generating jobs • The concept is in compliance with the community's desires • The concept is similar to the existing technical solutions, i.e. the community is already familiar with it	Weaknesses • Aquifer might not be reliable • Does not make use of other available water resources (rainwater) • Structure weaknesses if installation is not carried out correctly • Fast deterioration of technical components if maintenance is not carried out properly
External origin (Attributes of the environment)	Opportunities • Implies an introduction to effective management, financial and technical competence, which is beneficial for further development • Donor's/NGO's interest in supporting the rural water supply sector • Concept can be operated and maintained by a community assigned management team which does not interfere with the existing social structure • Can contribute to an empowerment of women if they are to be assigned to the management committee • The Cameroonian government recently initiated a rural water supply programme – including local and national admin. changes (Kane 2009)	Threats • Lack of technical skills • Water demand is expected to increase in the future • Lack of cost recovery system in village • Lack of proper understanding of WATSAN related issues • Dependence on external aid support • Lack of reliable spare part supply network • Lack of regional support institutions • Possible corruption between water committee and consumers, or government agencies and the village

Table 8 - SWOT-analysis alternative 2, Rainwater

	Helpful in achieving the project objectives	*Harmful in achieving the project objectives*
Internal origin (Attributes of the concept)	Strengths • Low O&M cost • Easy maintenance • Natural filtration of rainwater • Storage tank serves as a security towards short-term demand and climatic fluctuations • Manual pumping of water to storage tank creates income-generating jobs	Weaknesses • High capital cost • Not readily suited for further expansion to meet an increased need in the future • Fast deterioration of technical components if maintenance is not carried out properly • Difficult to measure water level in swale-trench – increases the risk of over-extraction • Silt-clogging of drainage pipe in swale-trench if installation is not carried out properly • Concept is not entirely in compliance with the community's desires as it implies that large areas of arable land have to be removed at the expense of swale-trenches and catchment areas • Does not make use of other available water resources (groundwater)
External origin (Attributes of the environment)	Opportunities • Implies an introduction to effective management, financial and technical competence, which is beneficial for further development • Donor's/NGO's interest in supporting the rural water supply sector • Concept can be operated and maintained by a community assigned management team which does not interfere with the existing social structure • Can contribute to an empowerment of women if they are to be assigned to the management committee • The Cameroonian government recently initiated a rural water supply programme – including local and national admin. changes (Kane 2009)	Threats • Lack of technical skills • Human and animal activity close to catchment area and swale-trench can cause contamination of water. Open defecation is a particular risk. • Decrease in food production as large areas have to be used at the expense of arable land • Vulnerable to long-term climatic fluctuations • Water demand is expected to increase in the future • Lack of cost recovery system in village • Lack of proper understanding of WATSAN related issues • Dependence on external aid support • Lack of spare part supply network • Lack of regional support institutions • Possible corruption between water committee and consumers, or government agencies and the village

Table 9 - SWOT-analysis alternative 3, Groundwater and Rainwater combined

	Helpful in achieving the project objectives	*Harmful in achieving the project objectives*
Internal origin *(Attributes of the concept*	Strengths • Low capital cost • Acceptable O&M cost • Easy management and maintenance • Storage tank serves as a security with regards to demand fluctuations • Manual pumping of water to storage tank creates income-generating jobs • The concept is in compliance with the community's desires • The concept is similar to the existing technical solutions, i.e. the community is already familiar with it • Efficient exploitation of available water resources • Especially increases awareness of WATSAN related issues amongst the village school children	Weaknesses • Has the highest O&M cost • Structure weaknesses if installation is not carried out correctly • Fast deterioration of technical components if maintenance is not carried out properly
External origin *(Attributes of the environment)*	Opportunities • Implies an introduction to effective management, financial and technical competence, which is beneficial for further development • Donor's/NGO's interest in supporting the rural water supply sector • Concept can be operated and maintained by a community assigned management team which does not interfere with the existing social structure • Can contribute to an empowerment of women if they are to be assigned to the management committee • The Cameroonian government recently initiated a rural water supply programme – including local and national admin. changes (Kane 2009)	Threats • Lack of technical skills • Water demand is expected to increase in the future • Lack of cost recovery system in village • Lack of proper understanding of WATSAN related issues • Dependence on external aid support • Lack of reliable spare part supply network • Lack of regional support institutions • Possible corruption might occur between water committee and consumers, or government agencies and the village

7.2 Qualitative indicator comparison of technical concepts

The decision making support tool developed in the previous project work will serve as a base for deciding upon a suitable technological concept also in this report. The results will, however, be more reliable as the indicators are based on information obtained directly from members of the community of interest.

The scenarios to be qualitatively compared are:

- Scenario 0 – Situation remains unchanged
- Scenario 1 – Groundwater extraction with manual flywheel pumping and storage tank
- Scenario 2 – RWH with swale-trench filtration, manual flywheel pumping, storage tank and solar disinfection
- Scenario 3 – Groundwater extraction with manual flywheel pumping and storage tank, and RWH by village school

As in the project work, the indicators have been chosen based on their ability to show a move towards or away from sustainability, as well as their ability to provide an early warning for potential system inadequacies.

1. The *capital cost* of a technical solution is of outmost interest and is therefore chosen as one of seven indicators to determine the sustainability of the alternative solutions. In many cases, the capital cost of a project like this is split between the community and an external agency or financial institution. However, the marginal economy in Mpagne implies that it is desirable with a low-cost solution.
2. The *O&M cost* on a yearly basis and the degree to which this complies with the villager's financial capacity is another factor affecting the long-term sustainability of a technical facility. Currently, there are few incentives for external agencies and private sector to invest time and money on this matter(RWSN 2010). On the contrary, it is in the communities' own interest that the water supply facility is well-functioning, and their ability to handle the required costs is therefore an essential element. A low long-term operation and maintenance cost of a technical system is to prefer over a low capital cost. This increases the beneficiaries' opportunities for independent management, as it is easier to find funding for the initial one-time capital investment.

3. The importance of community's *ability to pay* for operation and maintenance has long been downgraded. The result is that these communities are dependent upon long-term external funding from NGOs or donor agencies for the well-functioning of their water supply systems. This is not in compliance with the agencies' short-term perspectives and idea of initiating self-help projects. Ensuring that the project beneficiaries are able to pay for the O&M cost is therefore an indicator to be prioritized.
4. Even more important is the community's *willingness* to contribute to capital cost and pay for operation and maintenance once a water supply facility has been implemented. This reflects their perception of the importance of the implemented technology. It also serves as an incentive for sustaining the water supply system as it gives them a sense of ownership and responsibility as opposed to a situation in which all costs are externally funded.
5. The *compliance with the community's desires* is a reflection of the information gathered during the field trip with regards to what the informants' ideas of what an appropriate solution would be based on their needs and knowledge.
6. The *yield capacity* of the technical solution is also an important indicator as it reflects the solution's ability to satisfy the community's need.
7. The last indicator, *estimated design lifetime*, gives an indication on how many years the community will be served before further investment is required to upgrade or improve the initially installed system.

Table 10 - Indicators developed for qualitative comparison of technical concepts

Category	Quantified indicator
1. Capital cost	[$]
2. O&M cost	[$/year]
3. Affordability	[Capital cost per capita as a percentage of household budget]
4. Willingness to pay	[$/month]
5. Compliance with community desires	[scale 1-10]
6. Yield capacity	[litre/day]
7. Estimated design lifetime	[years]

The quantification of these indicators has been carried out based on data available from published literature, information gathered in the village, as well as reasonable assumptions.

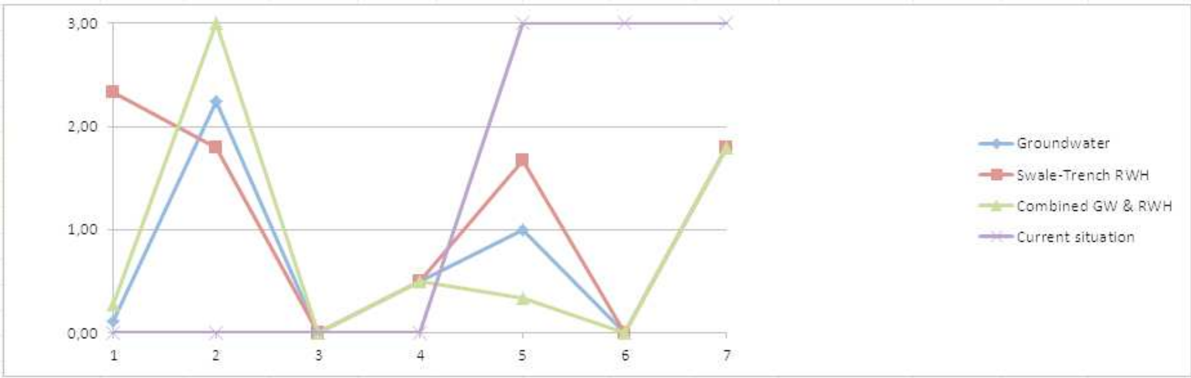
1. Capital cost – includes estimates of the costs of the equipment and material required for the initial installation of the water supply facility and is based on costs from previous similar projects given by (OECD 2005). The cost is set to 10% of the actual capital cost to reflect a somewhat reasonable community contribution to the capital cost.
2. O&M cost – include the cost of necessary spare parts and salaries to staff responsible for operation and maintenance of the system. Also this from (OECD 2005).
3. Affordability – has not been possible to quantify, due to lack of information regarding household budget in the village.
4. Willingness to pay – data on the specific income for the households in the village is not available. However, the informants stated that they are willing to pay a certain percentage of their income as a monthly fee to sustain the water supply facility. It is therefore assumed that the average sum the villagers are willing to pay is at a level which is sufficient to offset the yearly cost of operation and maintenance.
5. Compliance with community's desires – as the community has previously participated in a water supply project they have a basic understanding of different aspects which are important in the generation of technical solutions, as well as they have an idea of what they think might be a proper solution in terms of appropriate technology and reliable water sources. This was made clear through the interviews carried out during the field trip. The degree of compliance with the community's desires, scaled from one to ten, is therefor based on this information.
6. Yield capacity – a minimum of 12 000 litres per day is required to satisfy the daily need of the community, and all three alternatives are assumed to have a yield capacity larger than or equal to this.
7. Estimated design lifetime – alternative 2 will not be in operation until after the first significant rainfall following the implementation, as this is when the trench is filled with water. This will, however, not be taken into consideration in the

calculations. The system design lifetime, based on data from the WHO(Hutton 2004), is assumed to be 15 years for all the alternatives.

Table 11 - Estimated quantification of indicators, see appendix III for cost calculations

	Alternative 1	Alternative 2	Alternative 3
Capital cost [$]	660	4 000	910
O&M cost [$/year]	2 250	1 800	3 000
Affordability [Capital cost per capita as a percentage of household budget]	NA	NA	NA
Willingness to pay [$/month]	0,5	0,2	0,6
Compliance with community's desires [Scale 1-10]	7	5	9
Yield capacity [litre/day]	≥12,000	≥12,000	≥12,000
Design lifetime [years]	15	15	15

Figure 6 - Results from the qualitative indicator comparison decision making support tool



Criteria and indicator	1 Capital cost (community) [$]	2 Operation and Maintenance cost [$/year]	3 Affordability [percentage of budget]	4 Willingness to pay [$/month]	5 Compliance w/community's desires [1-10]	6 Water yield capacity [litre/day]	7 Durability [years]
Reject criteria	☐ Yes?	☐ Yes?	☑ Yes?	☐ Yes?	☐ Yes?	☐ Yes?	☐ Yes?
Weighting	6	6	1	8	10	10	5

Alternatives	*Result*	*User valuation*	*Corrected result*	*Order*
Groundwater	0,59		0,59	1
Swale-Trench RWH	0,82		0,82	3
Combined GW & RWH	0,71		0,71	2
Current Situation	0,98		0,98	4

7.3 Chosen technical concept

The results from the indicator comparison demonstrate that there is not a big difference in the final score of the three technical concepts. This was a predicted result as they share many of the same features. The score of alternative 1 is slightly better than the two other alternatives and is therefore, according to this decision making support tool, the best suited solution. However, this support tool should not be the sole element of the base generated for the selection of an appropriate technical solution. The SWOT-analysis presented a variety of benefits and limitations related to the technical concepts. These are of a nature different from those included in the indicators, and are therefore important to consider when evaluating and comparing the technical concepts. The SWOT-analysis presents strengths and weaknesses of internal origin i.e. directly related to the technical concept at a village level, which contribute to or impede the process of achieving the project objectives. The opportunities and threats of external origin are mostly related to organizational regional and national factors, which will be discussed in chapter 9.

The construction of the swale-trench rainwater harvesting, which came in 3rd in the indicator comparison, is not considered an appropriate solution. The topographic characteristics in the area indicate that the only areas suitable for construction of large, levelled swale-trenches is either at the expense of arable land where fruit and vegetable are cultivated, or in the residential areas. The latter is not desirable with regards to human and animal activity possibly causing contamination of the catchment and filtration area. Further, the removal of arable land is a decisive disadvantage for not choosing this alternative, as it will negatively affect the already marginal food production in the village. There are also some decisive factors with regards to alternative 1 which are not clear through the indicator comparison. As stated by the villagers, the pumps which were installed ten years ago did not quantitatively satisfy the village needs at all times, at the same time as it does not make good use of the available water resources, as rainwater is not being collected during the rainy season. The storage tank is meant to serve as a security with regards to demand and climatic fluctuations, but this concept is, as alternative 2, not readily suitable for meeting the expected increase in demand. Alternative 3 scores somewhat worse than alternative 1, this is largely due to its higher maintenance cost. This cost is, however, considered to be within the community's affordability range, and the concept is therefore chosen as the most appropriate due to its many benefits, such as:

- Enhancing the school children's awareness of WATSAN related issues
- Providing water for the children throughout their school day
- The concept is in compliance with the community's desires
- Efficient exploitation of available water resources in a social, economic and environmentally sound context
- It serves as an initial introduction to two sustainable manners of water supply, where increased demand easily can be met through expanding the rainwater collection at a later stage by increasing the total area suitable for roof-catchment and constructing several storage tanks

7.4 Discussion of validity of the results

A SWOT-analysis is a means of structuring opportunities and limitations, and identifying internal and external factors which are beneficial or unfavourable in relation to the achievement of a project's objectives. In this project it is used as a tool to support the qualitative indicator comparison methodology; however it has its weaknesses. The most important is that it does not include any prioritizing or weighting of the resulting lists of strengths, weaknesses, opportunities and threats. It might therefore appear as if a weak benefit can balance out a strong weakness.

The results from the indicator comparison are, as discussed in the previous project work, influenced by a range of factors affecting the final validity of the indicator scores. Some of them being:

- The normalization was done based on the assumption of a linear relationship between the indicators
- The indicators were normalized relative to each other, not relative to a market value
- The beneficiaries' actual valuation of the different technical concepts has not obtainable and has therefore been determined based on related information from interviews

Improvements have, however been made from the fall project. This especially in relation to the validity of the methodology input. The information gathered in the village contributed in developing indicators with a lesser degree of estimates than what was possible in the fall project. Further, the quantification of the cost indicators was carried out based on a report from the (OECD 2005), which is considered to be more reliable than the information background used for the quantification in the previous project work. These are factors which contribute to increase the validity of the results, and the concept chosen is seen as an appropriate draft which can be presented to the villagers and discussed as a possible future solution.

The following chapter will present a description of the technology required for the new water supply facility in Mpagne, to the level it is possible with the information available at this stage. The first section will present the groundwater exploitation part of the chosen concept, followed by a section presenting the rainwater harvesting at the village school.

8.1 Groundwater exploitation

The basic groundwater pumping design is shown in figure 7. One of the advantages with this system is that the design is very simple, as it only consists of the VOLANTA handpump, a storage tank and piping between the two. The VOLANTA pump produced by the Dutch company Jansen Venneboer (Venneboer 2008) is a reciprocating pump driven by a flywheel. This is a protected product which implies that it is not intended for local production; however, locally based assembly and installation is possible. This is considered to be one of the most reliable pumps in the developing world today, and has an already established dealer network in Cameroon (Venneboer m.y.). The design of the pump is such that only the surface components require regular maintenance. Spare parts, such as seals and connection rods, are standardized items which can be found locally, and as opposed to the pumps already installed in the village, the PVC rising mains has a glued connection (Venneboer m.y.). This pump was observed in many of the villages in the region surrounding Mpagne.

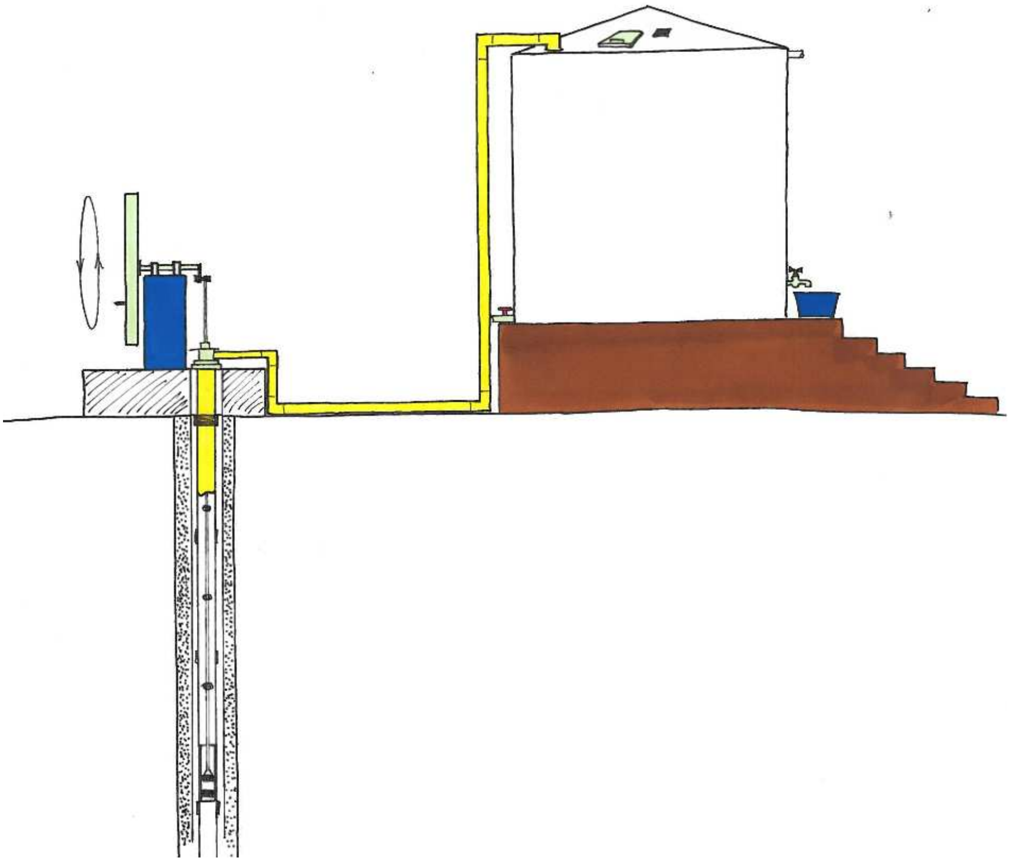


Figure 7 – Sketch of groundwater pumping system

The handpump can be fitted on the existing wells in the village, which are assumed to still be in proper condition. As of today there are three wells, spread between the four neighbourhoods. The structure of the village and the number of inhabitants indicate that this is a reasonable number, as one pump is suited for serving up to 250 people. A storage tank is to be constructed by each pump, as the four residential areas are too far apart for there to one common storage tank for the entire village. The water is lifted from the well through the rising mains by the reciprocation pump driven by the manually driven flywheel, which is designed with a counterweight to ease the continuity of the pumping. Figure 8 shows an example of the pump cylinder which consists of a cylinder house in which a non-return footvalve is fitted near the bottom and another non-return valve is fitted on the piston. The cylinder is attached to the pump rod, signifying that it can be lifted from the well without removing the rising mains, which again facilitates control and maintenance (Baumann and Erpf 2005). The functioning of this type of reciprocating pump is caused by the principle that water flows from areas with high pressure to areas with lower pressure (Baumann and Erpf 2005). When operated, the piston pump creates an area of sufficiently low pressure above the water body, causing the water to rise toward the surface.

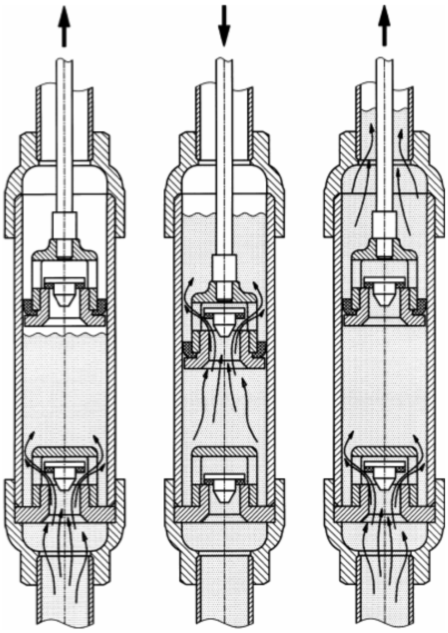


Figure 8 – Piston pump principle (Baumann and Erpf 2005)

The stainless-steel pump rod and PVC-U rising mains, as well as painted mild steel flywheel and a concrete pump stand leaves this to be a corrosion resistant system(Baumann and Erpf 2005). Once above ground level, the pressure from the reciprocating pump action is high enough to lift the water to the elevated storage tank. As there are three storage tanks, each can be dimensioned for serving one third of the village, i.e. 200 people. If it is to serve as a buffer against demand fluctuations it is desirable with tanks that can carry 2-3 days water need. If the daily consumption is set to 20 litres per person, in line with the WHO poverty threshold, this renders three 10 m^3 tanks.

The ferro-cement storage tanks are designed bade on directions from the (UNHCR 2006), and consists of:

- A cylindrical foundation of masonry packed with sand and covered with a lean concrete cover slab
- Ferro-cement walls reinforced with vertical stiffeners and steel channels for enhanced stiffness, wrapped in chicken mesh before the cement is plastered on
- A ferro-cement roof reinforced with trusses and bars, wrapped in chicken mesh before cement is plastered

See figure 9 for a sketch of the tank. A manhole is implemented in the roof of the tank, for access to the tank's interior to carry out inspections, maintenance and possible larger repairs. The manhole can also be used to keep track of the water level in the tank. The height of the foundation depends on the water head desired. To minimize the capital cost, a minimum need for additional piping is desirable. In the initial installation, a tap will therefore be implemented in the storage tank, where the villagers can collect water. For future improvements in terms of for example piped distribution to several tap stands closer to the houses, the storage tank is to be elevated to a height which yields the required pressure. However, due to lack of data, the specific height will not be quantified at this stage. Further, an overflow pipe and a drainage pipe will be implemented at the upper and lower most section of the tank wall. See table 13 at the end of the chapter for an overview of the complete water supply system.

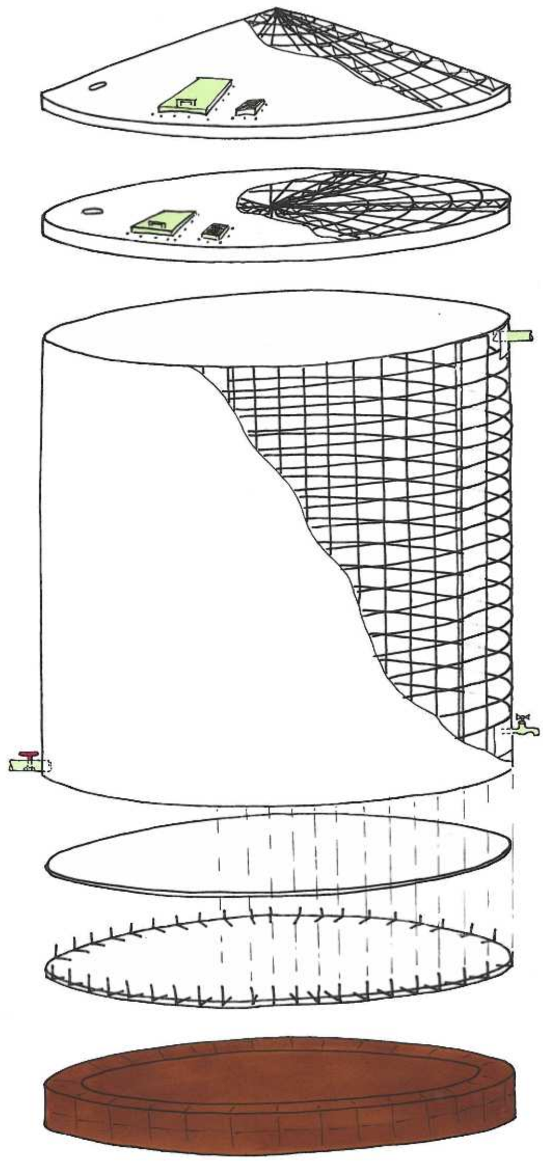


Figure 9 – Sketch of water storage tank

8.2 Rainwater harvesting

The rainwater harvesting at the village school requires the addition of gutters, down pipes, a filtration box and a storage tank, as the roof is already suited for RWH. The school consists of two buildings, with a total roof area of about 180 m^2. The buildings are constructed perpendicular to each other, with an open corner space, suitable for a storage tank, between them, see figure 10 below. In this way, the length of the down pipes from the gutters to the filtration box on top of the storage tank is minimized, at the same time as the tank is easily accessible for the children and teachers to get water

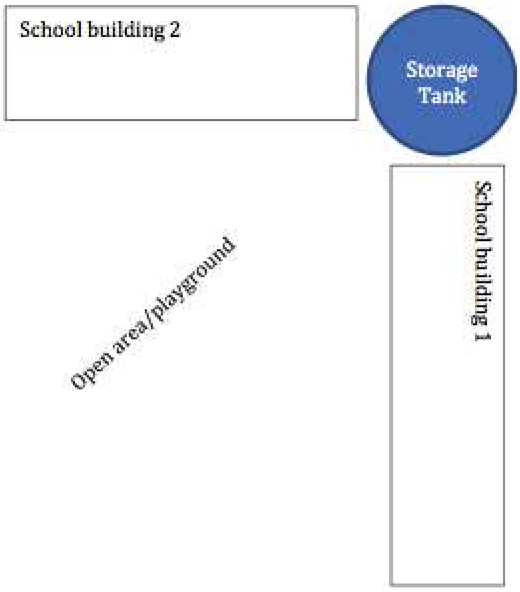


Figure 10 - Plan sketch of school area

throughout the day. The gutters can be made of galvanized steel sheets, wood or PVC. The HI-PVC rising mains from the old pumping system could possibly be suitible gutters, but with a diameter of only 1.5 inches (3.05 cm)(VRM m.y.) they are assumed to be too small for collection of the massive rainfall during the months of September and Octoober. An alternative low-cost solution is galvanized steel sheets which are bent in a V-shape and, attachet to the corrugated iron roof eves with simple galvanized wire (WaterAid m.y.). A filtration box is to be implemented on top of the storage tank this to safeguard the quality of the water, by ensuring that potential pollutants do not enter the storage tank. A light-weight, low-cost solution is to construct a ferro-cement box and fill it with gravel, pea gravel and sand arranged in layers in line with the sand filter principle (WaterAid m.y.). A diffuser made of galvanized flat sheet is to be mounted in the upper section of the filtration box. This prevents disturbing the filtration sand layer, and protects the bio-layer when water pours into the box from the down pipes(CAWST 2009). The filtration box is sealed with a removable cover slab to avoid mosquitos and ingress of other sources of contamination. The storage tank is a ferro-cement construction similar to that constructed for the storage of groundwater. The decision is based on the same arguments as presented in chapter 7. The capacity of the storage tank depends on the pattern and volume of yearly rainfall, and should be dimensioned to carry the maximum amount of water possible to collect during the heaviest rainfall in September and October. Table 12 shows an overview of the average monthly rainfall in the region, as given by the World Weather and Climate Information(WWCI 2011), and the proportional run-off. The volume of run-off is based on the following equation, given by the (OECD 2005):

$$V\left[\frac{m^3}{month}\right] = \frac{1}{1000} \times monthlyRa\inf all_{av}\left[\frac{mm}{month}\right] \times RunoffCoefficient \times RoofArea\left[m^2\right]$$

A runoff coefficient of 0.8, also given by the OECD, can be used to obtain a rough estimate.

Table 12 - Pattern and volume of rainfall in Mpagne

Month	**Average rainfall***[mm]*	**Volume of runoff** *[m³]*
January	10	1.44
February	12	2.88
March	80	11.52
April	110	15.84
May	220	31.68
June	170	24.48
July	190	27.36
August	215	30.96
September	310	44.64
October	295	42.48
November	60	8.64
December	10	1.44
Total pr. year	1682	243,36

There are about 120 students attending school in the village. If they are to use this as their main source of drinking water, this renders 600 litres outflow per day given that the ration is set to 5 litres per person per day. In September this corresponds to four day's average rainfall, whereas in January and December it corresponds to 125 day's average rainfall. The monthly quantity of water required to satisfy the daily 5 litres per student is 18 m^3. As shown in the table, the average monthly runoff volume is well above this level six months of the year. However, during the remaining six months the average runoff is well below the level of satisfaction. The pattern of the rainfall indicates that the storage tank must be dimensioned to have a carrying capacity large enough to collect the amount of water required for the driest months during the rainy season. The total deficit during the months with little rainfall is 66.2 m^3, if one includes spillage, evaporation and fluctuations in rainfall the storage tank volume is set to 100 m^3. This is a fairly large construction. The inlet pipe of the filtration box on top of the storage tank must be lower that the gutters along the eaves of the buildings. It might therefore be more convenient with two smaller storage tanks at each end of the two buildings. These are, however, initial suggestions. The required tank volume is set to 100 m^3, further information related to, for example the villagers' desires and the exact measurements of buildings and area, is required to set the final dimensions of the rainwater storage tank. As for the groundwater storage tanks, this will also be fitted with a manhole for inspection, maintenance and repairs, an overflow pipe at the uppermost section of the tank, a drainage pipe at the lowermost section of the tank, and a faucet for tapping water. See figure 11 for a sketch of the complete rainwater harvesting system.

For both systems, PVC-pipes have been chosen due to the material's corrosion resistance and low-cost compared to stainless steel, however threaded screw-fixation will be avoided as this most likely was the technical cause of the previous system failure.

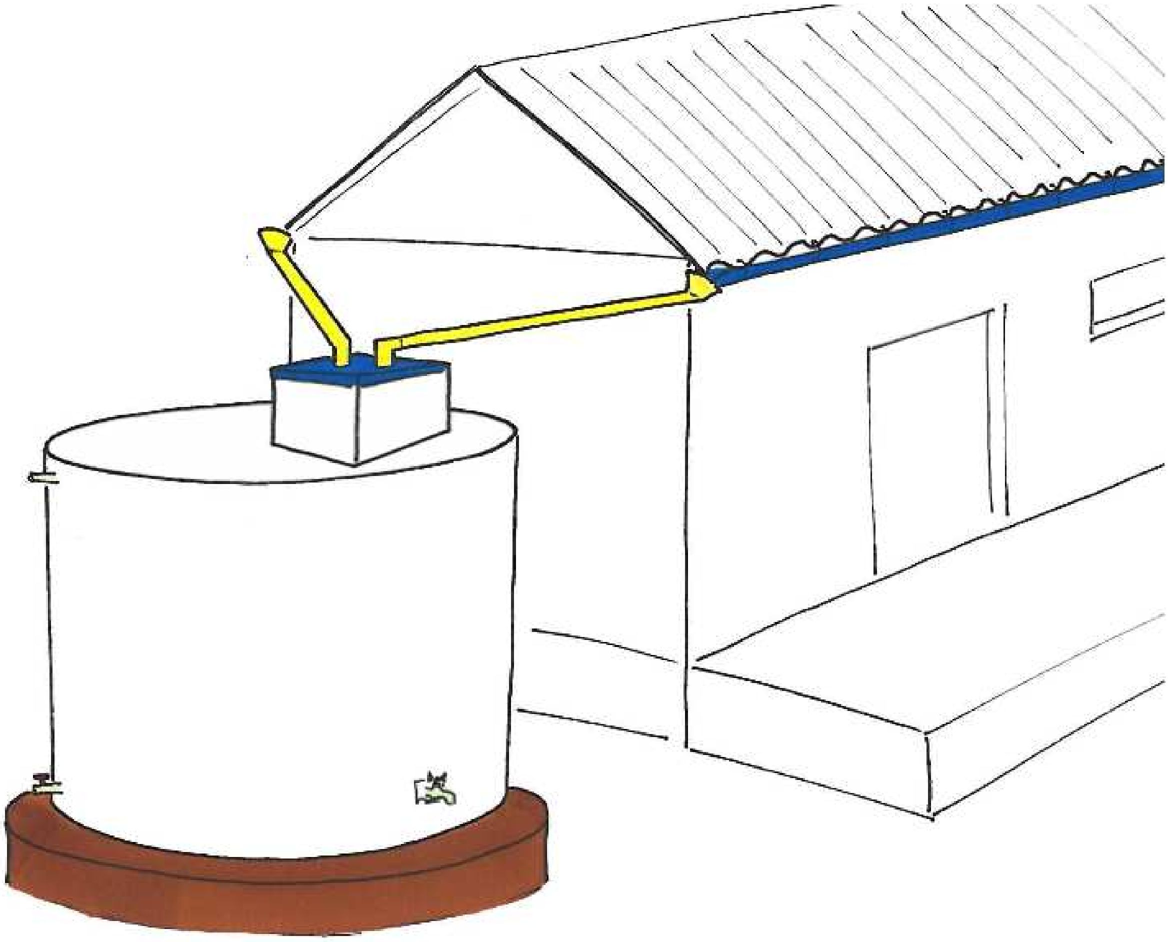


Figure 11 – Sketch of rainwater harvesting system at the village school

Table 13 - Overview of components required for the water supply facility

Components		
Volanta handpump	Flywheel	
	Pedestal	
	Ball bearing	
	Crank shaft	
	Pump rod	
	Spout	
	PVC pipes form ground level to storage tank	
	Casing pipe	
	Rising main	
	Cylinder w/plunger and footvalve	
	Suction pipe	
Rainwater catchment	Gutters	
	Galvanized wire for attaching gutters to eaves of roof	
	Down-pipes to filtration box	
	Filtration box	Gravel
		Sand
		Pea gravel
		Discharge pipe
Storage tank (groundwater and rainwater storage)	Basement	Masonry
		Sand
	Base slab	Concrete cover slab to level and water-tighten the base
		Base slab reinforcement, with L-bars along the base of the wall to strengthen the construction
		Final casting of basement
	Walls	Reinforcement bars and steel stiffeners
		Inner and outer layer of chicken wire, leaving openings for pipes
		Ferro-cement for plastering
	Roof	Roof trusses/stiffeners
		Reinforcement bars
		Inner and outer layer of chicken wire, leaving openings for manhole and ventilation pipes

As proven through the discussions in the preceding chapters the implementation phase is crucial to the success of a water supply project. Even though a technical concept has been suggested in this report, the following implementation strategy will start with the initial planning required prior to the technical decision making. The implementation will be divided into the following four phases:

1. Planning
2. Construction
3. Operation and Maintenance
4. Follow-up and evaluation

In addition, some national and regional administrative and business changes are needed for the long-term sustainability of the project. This is an out of scope subject; however, they will be presented to give an understanding of the complexity of a water supply project, as it cannot be treated as a problem at an isolated village level only.

9.1 Planning

Despite the fact that a technical concept has been presented in the preceding chapter, the brief field trip to Mpagne is not sufficient to state that this is the most suitable technical solution. Further and more detailed information is required in order to specify the community's needs and requirements.

In general the essential information required for a thorough planning process can be presented in two groups(Davis, Garvey et al. 1993):

1. Socio-economic information
2. Technical information

However, this is just a means of structuring the information collected. In reality data is collected for both categories in combination. Considering the past failed project in Mpagne, the villager's motivation is low. The villagers have to be re-convinced to trust authorities, and getting the sustainability aspects right amongst skeptical users becomes many times harder. In this case it is therefore necessary to initiate the planning process with a discussion of the project with a long term perspective, including the effects and importance of the community's commitment. The frame for the future commitment of the agency should also be set. A clear understanding of the goals of the planning process and the community's acceptance of it is vital. Further, it is important to set the frame for the relationship and decide the roles of the community and agency throughout the project. Subjects to be discussed are what the agency can offer the community in terms of support, as well as what the community's likely input should be. Thereafter, a community development committee must be assigned. For the success of the project this should be anchored in the existing social structure, and preferably be based on an existing institution or social organization. In Mpagne an elected board serves as the decision making body in the village. Other than this, organizations and institutions which exist are a board of elders, the Chief and the village school. For the committee to be linked to the existing social structure; it is natural to suggest that the elected committee functions as the development committee, or that they are given the task of assigning a committee. Assigning a system management team, consisting of technicians, accountant(s) and health and sanitation promoters should also be done at this stage, and training ought to be initiated as soon as possible. Ideally a group of women should be assigned this task; however, with the current traditional role they have in the Mpagne community, it might create more conflicts than it is beneficial. More information is required to decide upon who are best suited to be assigned positions in the technical tem. With regards to the training, this should be conducted as a continuous process of meaningful and proper training to provide the technicians and system managers with the proper tools. Once the committees have been chosen, the process of information gathering can begin. As given by (Davis, Garvey et al. 1993), this includes:

- mapping of the villager's own perception of the situation, their requirements, desires and needs
- generating an overview of the health state, sanitary conditions and hygiene habits
- map practical opportunities and limitations with regard to a technical solution

These are activities the community itself can contribute to, and to a large extent preform themselves, with support from the agency. Oxfam has developed a set of methods for gathering information in their "Developing and Managing Community Water Supplies"(Davis, Garvey et al. 1993). These methods cover techniques which can be used to collect essential information for water projects, and which also results in the initiation of an in-depth involvement of the community at an early stage of the project planning. The latter has been proven to largely affect the long-term sustainability of the projects as it creates a sense of responsibility from the very start of the project (Davis, Garvey et al. 1993).

Planning also includes preparing a technical proposal. This is what has been done in the preceding chapters. The identification of an appropriate water supply system has been developed based on the preliminary assessment carried out during the field trip. The next step in the process is to specify and finalise the design in cooperation with the villagers. Taking into account the beneficiaries' preferences is an important step in the process of finalising the system design, and should therefore be a priority before developing a final technical proposal.

As part of the technical planning the existing wells are to be inspected and evaluated with regards to their suitability for rehabilitation. Abandoned boreholes of the kind seen in Mpagne are possible pathways for contaminating the groundwater aquifers (Soulsby 2012). However, the boreholes were fitted with cement cover slabs, and the pumps are still mounted on top. This leaves reason to believe that the groundwater has not been readily exposed to contamination, but water sampling and analysis should be carried out in order to ensure that the quality of the water is at a satisfactory level. If the boreholes are beyond repair, they should be backfilled with clean sand and gravel. In that case the construction of new boreholes is necessary. International Committee of the Red Cross has recently published a review on borehole development and rehabilitation(Soulsby 2012), which should be used as a guideline for inspection, evaluation and rehabilitation of the boreholes in Mpagne.

The transportation of equipment required for construction must also be considered at this stage. It is not known how equipment and pumps were transported to the village in the previous attempt of improving the water supply, but it is assumed that sturdy four-by-four pick-up trucks were used. In order to ease the difficulty of transportation to the village, the construction work should be carried out in the long dry season. In this period the soil is dry, making the roads more stable. The rough nature of the roads imposes a risk of damaging the equipment during transportation if it is not properly protected. As discussed earlier, a little surface scratch is enough to critically reduce the robustness of a PVC-pipe. This is an unwanted situation, and it is therefore desirable to use for example wooden transportation cases, where the equipment is wrapped in or covered with protecting materials such as expanded polyester. This will reduce the impact forces induced by the rough ride and thereby minimize the risk of damaging the technical equipment.

To round off the planning phase, a final project proposal should be generated by the development committee in cooperation with the external agency. As stated by(Davis, Garvey et al. 1993) this should contain specification of subjects such as:

- Goals and timeframes
- A gender impact statement, to indicate the women's involvement in the project
- Detailed description of final technical solution chosen
- Staffing and training, specifying the number and type of staff required for the conduction of the project, such as the training staff, and an outline of the type and duration of training
- Budget, with an estimate of total funding required as well as the percentage the community will contribute with
- Monitoring and evaluation strategy, indication who is to be responsible for the project monitoring, the entity responsible for carrying out assessments of project outcome

9.2 Construction

The construction phase of a water supply project involves several integral components, where a 'water supply – sanitation – health' awareness campaign, water supply development, and sanitation improvements are the most important. The scope of this project is focussed around the supply of clean drinking water. Despite the fact that health and sanitation are factors of vital importance to achieve ideal effects of this type of project, they will not be thoroughly discussed in this section.

It can be argued whether community participation in construction has a positive effect on the long-term community management. The matter of fact is that it is a good opportunity for the community to acquire an understanding of how the system works and how it best can be operated and maintained in the future. The community in Mpagne have already been introduced to a technical system, however, there did not appear to exist a thorough understanding as to how the system worked, which components were what, and how the pump was acting during operation. It is therefore essential that the technical team assigned in the planning stage of the project have a well-integrated role in the construction phase.

Construction activities:

- Preparatory work, meetings with villagers, under the direction of the development committee, to inform them about the planned construction. Cleaning of areas where storage tanks are to be built, cleaning of rooftops and areas around wells. Preparation of technical equipment.
- Rehabilitation of boreholes if possible. If they are beyond repair, existing wells are to backfilled and new ones are to be constructed.
- Construction of storage tanks, three for groundwater storage, one or two for rainwater harvesting.
- Construction of filtration box on top of RWH storage tank.
- Assembly and installation of handpumps, including piping to storage tank.
- Installation of gutters along the eaves of the school building.
- Assembly and installation of piping from rooftop to storage tank, via filtration box.

In addition this phase also includes on-the-job training of technical personal, as well as hygiene and sanitation education for the entire village. Ideally, the agency functions as a facilitator and supervisor in the construction phase, supporting the development committee and technical team in their work. It is also the role of the agency to ensure the quality of the construction work, and the safety of the workers.

9.3 Operation and Maintenance

Once the construction work is completed, it is time to initiate the operation and maintenance, and general management of the implemented facility. There exists a variety of management options, ranging from agency management to community management(Davis, Garvey et al. 1993). Due to the isolated nature of Mpagne, it is desirable that the project is a self-help initiative and that the community aims at and is motivated for an independent community management strategy. This does not imply that the agency has completed its work once the system is up and running. The community is dependent upon long-term commitment and support in order to reach the desired independence, and since there does not exist any reliable governmental or private technical support entity in the region as of today, the agency should provide this support for as long as it is needed. The lack of such long-term commitment is, as previously discussed, one of the most common inadequacies in today's approach, and will be further discussed in section 9.5 National and Regional Administrative Changes.

In detail, this is where the local O&M and management team commence their day-to-day care-take of the installed system. The technicians are responsible for operation and maintenance, purchase of spare parts, and conduct of larger repairs when necessary. One or two other members of the team should be assigned the responsibility of establishing a financial system, which includes collecting payment from community members and keeping financial account. Further, someone should also be assigned the task of promoting hygienic water use and good sanitary practice. In Mpagne, with no improved sanitary facilities this would especially imply to encourage defecation in restricted areas to avoid contamination of water sources, until such facilities have been constructed. The Water, Engineering and Development Centre, Loughborough University presents typical maintenance routines in their report on Rural Water Supply in Africa, Building Blocks for Handpump Sustainability. These include:

Table 14 - Typical maintenance routines as given by the WEDC (Harvey and Reed 2004)

Daily: Pump operation Pump and base cleanliness Wastewater drainage Comments of users	Weekly : Lubricate moving parts Check and tighten nuts and bolts Check security of pump on base
Monthly: Check output (flow) rate Check condition of concrete base and apron	Yearly: Remove downhole assembly Inspect, tighten and replace parts where necessary

Additional maintenance activities include inspection, cleaning and repair of storage tanks, and water pipes, and regular control and maintenance of sand filter in filtration box on top of the RWH tank. Similarities with the bio-sand filter principles indicates that maintenance can be done in line with guidelines for maintenance of bio-sand filters given by the Canadian Centre for Affordable Water and Sanitation Technology (CAWST 2009). Cleaning of outlet pipes is also an integral part of the daily maintenance, as these frequently are contaminated by dirty hands, animals and insects. The agency’s responsibility in this phase is to monitor the community management and provide support and advice when necessary.

9.4 Evaluation and Follow-up

This phase is included in today's theoretical approach, and stressed as an aspect of importance. Nonetheless, the degree to which this is carried out in real life is not satisfactory. The situation in Mpagne is a perfect example. The external agency has not been back in the village after the implementation was finalised, the community is in no power to hold them accountable for their failed project, and there does not exist a reliable governmental water supply support entity. This is evidence that a continuing commitment by the agency, with a clear evaluation and follow-up strategy is essential for the long-term success of the project, until governmental or private support agencies are well established and ready to take over the responsibility. The nature and frequency of the evaluation and follow-up must be on the community's terms. In line with (Harvey and Reed 2004)'s "Rural Water Supply in Africa", performance evaluation should include assessment of the following:

- Management performance
- Operational performance
- Maintenance performance
- Environmental performance

The above are to be assessed through for example focus group discussions, user satisfaction surveys, inspection of technical facilities, as well as a sustainability snapshot which identifies the status of issues related to finance, technology and spares/equipment(Harvey and Reed 2004). The agency's responsibility in this phase is to be flexible and available to provide the support and follow-up needed, when it is needed.

The importance of project evaluation and follow-up is undisputable, as it is the only way in which one can determine whether or not strategies and approaches have been successful in achieving the desired goals. For the sake of the end-user, proper monitoring and evaluation may result in early identification of problems and timely solutions, and thereby pre-empt failure(Harvey and Reed 2004). As for the external agency, it is a means of assessing own processes and improving them to better meet the challenges in the water supply sector on a general level.

Evaluation and follow-up is also of essence to the further development in the village. As previously mentioned a step by step introduction to technology is seen as a good solution on a long-term perspective. The initial installation of simple technical systems of the kind suggested in the preceding chapters is a starting point for the generation of a solid technical and social platform on which the community can support its future development. As of today, the community is in need of adequate water supply to cover their most basic need, and has no particular outlook for future development. However, if the community for example is to expand their agricultural activities in the future, it is the responsibility of experienced and technically competent agency representatives to make a solution adaptable for this kind of development. As the technical competence and organizational water management structure in the village develops and becomes well established, they will be better suited for substituting the handpumps with for example PV-driven submersible pumps, which are more efficient. However, no improvement will be successful in the long-term if there does not exist a supportive environment on a national and regional administrative level which renders them possible.

9.5 National and Regional administrative changes

As stated in the needs assessment, lack of governmental or private regional technical support entities and reliable supply networks are issues affecting the long-term sustainability of water supply programmes. These are governing issues on a general regional, national and international aid level, and action is required in order for the success rate in the water supply sector to come to a satisfactory level. Some countries, amongst others Norway, have shifted their aid strategies to focus more on institutional and capacity building at the national level to better prepare local governments for the challenges in the sector and for them to be capable of taking responsibility for the water supply sector. Results from the evaluation of NORAD's involvement in Tanzania and Kenya, shows that while external agencies and international government support entities are preoccupied with national context thinking and development principles, the local agencies and governmental entities focus more on benefits in a local context (Tranor 2007). As these are results from one evaluation report one cannot draw a conclusion on a general level. However, it is evidence that more focus should be set on coordinating sector operators at all levels. This is also supported by the previously discussed subject of external agencies not adhering to existing local policies and that most project beneficiaries are left to be independent once the technical facility is up and running. As the existence of decentralised support systems is far from reliable in many cases, initially simple issues such as the need for spare parts have fatal consequences.

Although these are prevalent problems in many countries in the developing world today, they have been on the agenda for years. During the 80's one realised that the local governments do not have the financial capacity or physical resources to adequately accomplish their role in the rural water supply sector (Perry-Jones, Reed et al. 2001). This was the initiation of the community management principles, where communities are responsible for operation and maintenance. However, it should be evident that when there does not exist a reliable governmental or private support system, this is not a feasible approach. As discussed in this report, the community management approach is still widespread today, however, there is much more awareness on the importance of institution and capacity building at all levels in order to create an institutional framework which enables reliable support for a well-functioning water supply sector. In order for the water supply sector to be well-functioning at all levels, the following is recommended:

- Decentralisation of water supply support entities, with long term financial mechanisms, reliable spare part supply networks and standardization of technical solutions i.e. handpumps.
- Development of mechanisms for holding agencies accountable for failed projects.
- Strategic support to enable private sector to develop and become active in manufacturing and supply of handpumps and spare parts for rural water supply. This is an aspect of importance in particular for Cameroon as the private business environment is the country is highly unfavourable (see project work for further information on the current private business climate).
- Raise awareness among agencies of the damage they can actually do with misdirect approaches and actions.

These recommendations are largely based on information from the following reports:

(Harvey and Reed 2004), (Perry-Jones, Reed et al. 2001) and (RWSN 2010)

With regards to Cameroon in particular, development is in progress based on the government's initiation of the Rural Drinking Water and Supply Project as of 2010. Findings resulting from the development of a Country Strategy Paper by the African Ministers' Council on Water show that the rural water supply is less well-structured and is currently being overlooked by external funders (AMCOW 2009/2010). In addition there has been a growing realisation of the urban-rural coverage rate disparity, as well as the need for institutional building and decentralisation of support entities(Traore 2010). The resulting programme objectives as given in the project appraisal report(Traore 2010) include the following:

1. Rehabilitation and construction of 88 drinking water supply networks
2. Construction of 285 six-compartment pit latrines in schools and health centres, 1332 single-compartment ventilated pit latrines on private plots and 2 gender-sensitive toilet complexes in the South and North-West Regions
3. Rehabilitation of Ministry of Energy and Water Resources (MINEE) and its regional delegations (DREEs) in the South-West and North-West Regions, construction of MINEE regional delegation (DREEs) offices in the South and West Regions
4. Training and awareness-raising for the beneficiaries on drinking water use, sanitation and hygiene
5. Capacity-building for sector management structures

The programme schedule is set to 2010 – 2014, and although informants in Cameroon are sceptical to the actual results which will be seen on the ground, there exists an understanding of the fact that action is needed. Even though Mpagne is not included in the on-going governmentally initiated WATSAN programme, change is in progress and with the years to come a well-established enabling environment can hopefully take over the supporting role. As the sector develops one should focus on a gradual shift from external agency administration to national province and district staff based administration. Until this is possible, the agencies involved in the water supply sector play a vital role for the development and progress towards universal coverage.

Chapter 10 – Conclusion

To conclude the report I will in the following present an options review where a brief summary of the current theoretical approach will be given in combination with the previously presented technical concepts, as well as the most important aspects of the implementation strategy.

The background study shows that despite the fact that external agencies have been operating in the water supply sector for over 50 years, there is still a lack of adequate coordination between sector operators. Policies are not being adhered, programmes are being conducted on a quantitative rather than a qualitative basis, and only the recent years have agencies started to evaluate their past projects. After an initial output oriented approach, where the installation of technical solutions was prioritized, the sector operators have come far in the realization of the importance of software aspects, which today are well-integrated in water supply projects, at least in theory. The actual application of the theoretical approaches is disputable, as was demonstrated by the current situation in Mpagne. The results from the evaluation of the previous project show that a technical system was implemented, despite the fact that it has been proven to have a high failure rate. Furthermore, it was implemented without taking the surrounding factors such as the level of technical and financial capacity in the village, as well as external factors such as the existence of governmental or private sector support entities and the existence of and reliability of spare part supply networks.

For an infrastructural project to be successful it is, as discussed, of vital importance to evaluate the context in which the project will be implemented. What are the needs? What is the local capacity in terms of economy and competence? Where are the gaps, and which are the critical issues? If this is not thoroughly into account the resulting situation will be a disparity between the actual needs and solution provided, as seen in Mpagne – which is far from a unique story. An assessment of the external factors is an aspect which should be given more attention, as this is the only means of evaluating whether or not the proper contextual preconditions are in place for communities to be self-sustained. Especially as it is shown that the NGOs and donor agencies generally pull out of projects after a short time period, and leave the communities to be more independent than they are suited for.

As for the technical aspect of a water supply project, several concepts were developed based on the exploitation of the two most suitable water sources in the village – groundwater and rainwater. In compliance with the needs assessment and requirement specification, three technical concepts were chosen to be qualitatively compared:

Alternative 1	**Alternative 2**	**Alternative 3**
Groundwater extraction with flywheel handpump, elevated storage tank and gravity based distribution to community tap stand	Rainwater harvesting with swale-trench filtration and flywheel handpump, elevated storage tank and gravity based distribution to community tap stand	Combination of groundwater exploitation and rainwater harvesting, similar to alternative 1, with the addition of RWH at the village school.

The results from the decision making support tool did not show any significant difference between the three options. Alternative 1 did, however, score somewhat better than the two other alternatives. A SWOT-analysis was carried out for each of the alternative concepts, which presented a variety of benefits and limitations related to the technical concepts. These were of a nature different from those included in the indicators, and are therefore important to consider when evaluating and comparing the technical concepts. The combination of these support tools led to the selection of alternative three as the most suitable. This should be considered as an initial suggestion which is to be presented to the villagers for further development of a final design.

A technical solution is but one of several factors affecting the sustainability of water supply projects. An effective and thoroughly planned implementation process contributes in the development of essential knowledge with regards to both social and technical aspect. In Mpagne the implementation process will be especially important considering the past failed project. The discussion of the implementation strategy led to the following:
Planning should be initiated with assigning a development team and a system management team. Further the roles of the agency and the community are set in terms for physical and financial contribution throughout the project. The villagers are to be included in the process from an early stage and are to carry out the information gathering as well as contribute to the development of a final technical proposal.

Construction is to be based on community participation with supervision and guidance from the agency. This phase also includes on-the-job training of technical personal, as well as hygiene and sanitation education for the entire village. This is done to enhance the understanding of the technical facility and health related issues being addressed, and thereby increase the sustainability of the project on a village level. Operation and maintenance will be community based, due to the isolated nature of the village. However, the agency is responsible for providing the necessary support when needed until local governmental or private operators are ready to take over the responsibility. Finally, follow-up and evaluation should be a priority as it is the only way in which one can determine whether or not strategies and approaches have been successful in achieving the desired goals. Thorough monitoring will also result in early identification of problems and timely solutions, and thereby pre-empt failure.

In order to avoid making the same mistake again, the following is recommended on a national and international aid level:

1. Intensify the evaluation of past projects to learn from past mistakes
2. Provide proper and meaningful long-term training of local technical teams
3. Focus on establishing decentralized governmental financial and technical support entities
4. Support standardization of technical solutions and establishment of a reliable spare part supply network also covering the rural areas
5. Focus on coordinating sector operators at all levels, and encourage NGOs and donor agencies to adhere to existing policies and to initiate project with commitment on a long-term perspective
6. Strategic support to enable private sector to develop and become active in manufacturing and supply of handpumps and spare parts for rural water supply. This is an aspect of importance in particular for Cameroon as the private business environment is the country is highly unfavourable (see project work for further information on the current private business climate).
7. Develop mechanisms for holding agencies and governments accountable for failed projects
8. Continued focus on capacity building on an institutional level, in order for the local governments to eventually take over the full responsibility of the water supply sector

Until these aspects are adequately satisfied, a priority should be to focus more on ensuring that projects are carried out in adherence to existing policies, where engaged agencies are better coordinated to jointly create an enabling environment, until the immature institutional framework in many developing countries has advanced to a level which indicates that local authorities are in possession of the proper tool to support the water supply sector.

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Appendix

Appendix I - Focus group questions

How does the daily life evolve? What do you normally do throughout the day?

How is the general labour division organized? Who are in charge of the daily life chores – water collection, agricultural activities, food preparation, and education?

When important decisions are to be made - who do you have confidence in? Who do you consult? Who are the resource persons in the village? Why are these people considered to be resource persons (in terms of what, based on what – education, religious leadership, experience, age)?

Who is the chief in relation to this kind of project? (Spiritual leader/active deciding body/passive deciding body).

Do you want to change anything about the current village life? (Water, sanitation, roads/infrastructure, education) What do you want to change with the current situation? Why?

Can you tell me a little bit about the water situation in the village? Where do you get water today/throughout the year? How has the water situation evolved over the years? Where did you get water many years ago? Where do you get it today? Are there sources in the area where water can be found all year around?

Why should an improved water system be implemented?

What do you want to use the water for? (Drinking water only, all-purpose household and/or livestock).

Have you done anything to try to improve the situation yourself? Are there any wells in the area, in other villages close by? If so, is there water all year around? How deep are they? Who built them and how?

If someone were to have responsibility for the water-post and its well-functioning, who would that be? Trustworthy, technically skilled/practically inclined men? Will the work required be taken care of, will break-down be followed up? (Women – if doubtful to men having operation and maintenance responsibility – why? Give specific examples if possible).

Could a group of women be responsible for the care-take? Could the creation of a development, operation and management committee of women be a solution, or would this interfere with the existing social structure and possible cause conflicts between social groups? Will it function well in the existing social structure?

Are there aspects related to the water collecting activity that the women/children don't want to miss? (A social thing, is it a loss not to take part in the daily activity).

What will the women do if the water point is close by and supply is stable? (More time at their hands).

How can an improved water source be implemented in the existing social structure/with a minimal change of social structure? Who is best set to take care of a technical system? Is the community/men/chief/board of elders/women open/motivated for structural changes?

What is the school's position in the village? Is it a gathering point for general activities, or just a place for education? Where is it situated?

Could the school function as a base for the responsibility (elder students together with the teacher)? What do the children think of the situation as it is today? What would they like to change and how?

How do you want to ensure the financing of the system maintenance?
What are you willing to pay for an improved water system? (Implementation, operation and maintenance, Willingness to pay/ability to pay).

How is your relationship with the other villages in the area? Will they take advantage of an improved water system, or will the villagers in Mpagne be the only ones to benefit from it?

Appendix II – Table 15, Technical note, alternative solutions based on previous project work

Groundwater				
Main components				
Borehole	*Solar Panel*	*DC pump*	*Storage tank*	*Plumbing*
Lining - Casing (PVC) - Rubber seal - Well screen (PVC/stainless steel) - Gravel pack - Cement lining	PV-arrays (local/national supplier)	Submersible pump	Tank, V = 3-4 days req. = 18-24 m^3 (Polyethylene/Ferro-cement)	Rising main in well
Rising main (PVC)	Racks/mounting (stainless steel/non-corrosive material)	Linear current booster (?)	Insulation/cooling mechanism	Supply main – from well to storage tank
Outlet pipe (supply main) (PVC)	Electric wiring	Pump controller	Foundation (concrete), rack/poles/base (stainless steel/non-corrosive material/concrete)	Distribution main – from storage tank to tap stand(s)
Borehole cap (stainless steel) completed above ground		Electric wiring	Inlet pipe from well to tank (supply main) (PVC)	Tap stand(s) - Faucet - Security valve (?) - Concrete apron - Waste-water collection and drainage
Concrete apron around borehole cap			Outlet pipe from tank to tap stand (distribution main) (PVC)	Pipe racks/mounting

Security valve
Air vent
Float switch/pump controller or overflow outlet to extra storage tank
Drain/clean-out pipe w/valve
Water level monitoring mechanism (ex. dipstick in air vent)

Rainwater Harvesting						
Main components						
Swale trench	*Catchment area*	*Solar panel*	*DC pump*	*Disinfection*	*Storage tank*	*Plumbing*
Lining - Impermeable fabric/material	Large-surface area covered with tiles, plastic sheet or corrugated iron sheets	PV-arrays (local/national supplier)	Surface pump	SODIS PET bottles	Tank, V = 3-4 days req. = 18-24 m^3 (Polyethylene/PVC/Ferro-cement)	Supply main – from trench to storage tank
Porous matter - Sand - Stones - Gravel	Racks and foundation (stainless steel/non-corrosive material)	Racks/mounting (stainless steel/non-corrosive material)	Linear current booster	UV-disinfection chamber - germicidal lamp - curved reflector - metal tray - electrical interlock	Insulation/cooling mechanism	Distribution main – from storage tank to tap stand(s)

Check dams (stones/logs)	Electric wiring	Pump controller	Foundation (concrete), rack/poles/base (stainless steel/non-corrosive material/concrete)	Tap stand(s) - Faucet - Security valve (?) - Concrete apron - Waste-water collection and drainage
Drainage pipe (PVC)		Electric wiring	Supply main – inlet pipe from trench to tank (PVC)	Pipe racks/mounting
			Distribution main – outlet pipe from tank to tap stand (PVC)	
			Air vent	
			Float switch/pump controller or overflow outlet to extra storage tank	
			Drain/clean-out pipe w/valve	
			Water level monitoring mechanism (ex. dipstick in air vent)	

Appendix III – Calculations

A – Quantification of indicators, based on information from (OECD 2005) and (Venneboer m.y.)

Capital cost

Groundwater extraction with flywheel pumping and storage tank:

C_{pump} = 3 x \$1875 = \$5625
C_{tank} = 8 m^3 x \$37,5/m^3 = \$300/tank x 3 = \$900
C_{tot} = approx. \$ 6600

RWH in swale-trench with flywheel pumping and storage tank:

C_{pump} = 3 x \$1875 = \$5625
$C_{SwaleTrench}$ = \$6000/100 pers x 6 = \$36 000
C_{tot} = approx. \$ 40 000

Combined groundwater extraction and rainwater harvesting:

$C_{tot, GW}$ = approx. \$ 6600
C_{RWH} = 100 m^3 x \$37.5/m^3 = \$3750
C_{tot} = approx.. \$9900

O&M cost

Groundwater extraction with flywheel pumping and storage tank:

$C_{O\&M}$ = \$3.75/pers./year = \$0.3/pers./month, fee is set to \$ 0.5 to create a buffer for larger repairs

RWH in swale-trench with flywheel pumping and storage tank:

$C_{O\&M}$ = \$132.5/100 pers./year x 6 = \$795/year : 600 = \$1.32/pers./year : 12 = \$0.11/pers./month, fee is set to \$ 0.2 to create a buffer for larger repairs

Combined groundwater extraction and rainwater harvesting:

$C_{O\&M}$ = \$7.5/6 pers./year x 100 = \$ 750/year : 600 = \$1.25/pers./year : 12 = \$0.1 + \$0.5 (O&M for groundwater extraction), fee is set to \$ 0.5 to create a buffer for larger repairs

Appendix IV – Decision making support tool as developed in Excel

Reference values:

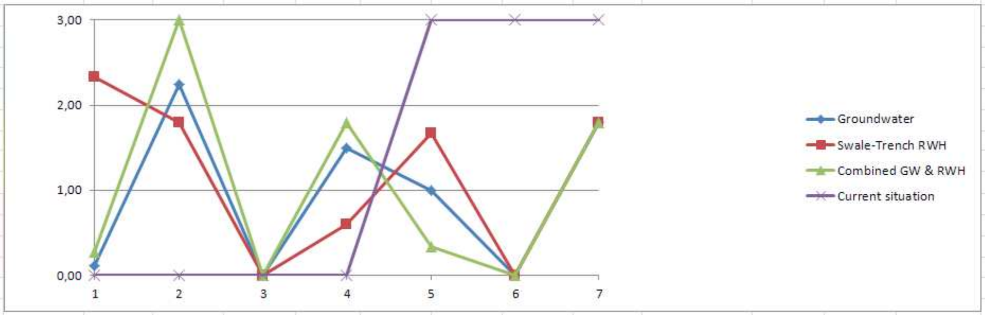
		Good				Acceptable				Not acceptable			
		X_max											X_min
1 Capital cost (community) [$]	decrease	from	1	to	2000	from	2000	to	4000	from	4000	to	6000
2 Operation and Maintenance cost [$/year]	decrease	from	1	to	1000	from	1000	to	2000	from	2000	to	3000
3 Affordability [percentage of budget]	decrease	from	0	to	20	from	20	to	40	from	40	to	100
4 Willingness to pay [$/month]	increase	from	1	to	0,7	from	0,7	to	0,4	from	0,4	to	0
5 Compilance w/community's desires [1-10]	increase	from	10	to	7	from	7	to	4	from	4	to	1
6 Water yield capacity [litre/day]	increase	from	12000	to	8000	from	8000	to	4000	from	4000	to	0
7 Durability [years]	increase	from	25	to	15	from	15	to	5	from	5	to	0

Specification of scenarios through quantification and normalization of indicator values, corrected value differs from normalized value if the specific value is rejected from the calculations:

	Capital Cost (community) *[$]*	*Normalized values*	*Corrected value w/rejection criteria*	**Operation and Maintenence Cost** *[$/year]*	*Normalized values*	*Corrected value w/rejection criteria*	**Affordability** *[percentage of budget]*	*Normalized values*	*Corrected value w/rejection criteria*	**Willingness to Pay** *[$/month]*	*Normalized values*	*Corrected value w/rejection criteria*
	USANN			*USANN*			*SANN*			*USANN*		
Borehole with handpump and storage tank	660,00	0,11	0,11	2250,00	2,25	2,25	200,00	-3,00	-0,10	0,50	0,50	0,50
RWH with swale-trench filtration, handpump and storage tank	4000,00	2,33	2,33	1800,00	1,80	1,80	200,00	-3,00	-0,10	0,20	0,50	0,50
Borehole with handpump and storage tank, RWH at village school	910,00	0,27	0,27	3000,00	3,00	3,00	2000,00	-3,00	-0,10	0,60	0,50	0,50
Existing solution	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,10	0,00	0,00	0,00

Compliance with community's desires *[1-10]*	*Normallized values*	*Corrected valus w/rejection criteria*	**Water yield Capacity** *[l/day]*	*Normalized values*	*Corrected value w/rejection criteria*	**Durability** *[years]*	*Normalized values*	*Corrected value w/rejection criteria*
USANN			*USANN*			*USANN*		
7,00	1,00	1,00	12000	0,00	0,00	15	1,80	1,80
4,00	1,67	1,67	12000	0,00	0,00	15	1,80	1,80
9,00	0,33	0,33	12000	0,00	0,00	15	1,80	1,80
0,00	3,00	3,00	0,00	3,00	3,00	0	3,00	3,00

Results based on normalized and weighted indicator values:



Criteria and indicator	1 Capital cost (community) [$]	2 Operation and Maintenance cost [$/year]	3 Affordability [percentage of budget]	4 Willingness to pay [$/month]	5 Compilance w/community's desires [1-10]	6 Water yield capacity [litre/day]	7 Durability [years]
Reject criteria	☐ Yes?	☐ Yes?	☑ Yes?	☐ Yes?	☐ Yes?	☐ Yes?	☐ Yes?
Weighting	6	6	1	8	10	10	5

Alternatives	*Result*	*User valuation*	*Corrected result*	*Order*
Groundwater	0,76		0,76	1
Swale-Trench RWH	0,84		0,84	2
Combined GW & RWH	0,94		0,94	3
Current Situation	0,98		0,98	4