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SUSTAINABLE WATER MANAGEMENT AT VALLEY VIEW UNIVERSITY, GHANA – Evaluation and Further Development

Master's thesis
Natural Resources Management and Ecological Engineering

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Foreword

This Master's thesis and the related research was written and conducted between March and December 2009 in the frame of the International Joint Master Program "Natural Resources Management and Ecological Engineering". The Master is based on a collaboration of the University of Natural Resources and Applied Life Sciences (BOKU), Vienna, and the Lincoln University, Christchurch. Students obtain a Master certificate from BOKU and an MSc from Lincoln University.

The thesis was written at the Institute of Sanitary Engineering and Water Pollution Control (SIG), BOKU, within a Climate project conducted at Valley View University, Ghana, that was financed by the German Ministry of Environment.

I would like to thank following people who made this thesis possible and supported me during my research:

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Additionally, I want to thank all other staff members of VVU and persons from different institutions in Ghana who assisted me during my two field studies and provided useful information.

Table of contents

Abstract

This Master's thesis was written in the context of a project called "Large-scale rainwater collection, power production from biogas and solar cells, construction of a climate-neutral environmental building at Valley View University, Accra, Ghana". It was conducted at Valley View University (VVU), a private Seventh Day Adventist university in Ghana. This study investigates water management practices and suggests further development steps.

The university is facing challenges such as economical constraints, increasing number of students, water quantity and water quality problems. Little money is available for proper operation and maintenance (O&M) of water supply and sanitation (WS&S). The actual water demand of people living on campus cannot be met. A future increase in student numbers and possible sachet water production (selling of drinking water in 450ml plastic bags) will exceed the supply possibilities of existing resources even more. Water infrastructure (pumps, rainwater tanks,…) periodically breaks down. Drinking water quality cannot be guaranteed for water supplied on campus. Without treatment, iron concentrations and turbidity are often too high in groundwater. Concentrations of E.coli and Enterococcus above the drinking water requirements (WHO) have been measured in the university's supply network, especially where rainwater collection systems are in use.

Until this study the university had little knowledge about their resources; thus, decision making about water management issues was not easy. This study summarizes necessary knowledge about water resources (groundwater, rainwater, grey water) available on campus including quantitative and qualitative evaluations. Water supply is compared with actual consumption and demand. Water losses, unmetered consumption and unfulfilled demands are problems VVU has to face. Management proposals to improve the water system are presented. Management plans for rainwater and groundwater resources, as well as general water management plans aiming for sustainable development, are suggested. Furthermore, this master's thesis includes an evaluation of filtration units, whose implementation are currently being discussed. They should guarantee sustainable supply of high quality water. Moreover, impacts of groundwater extraction, rainwater supply, communication with stakeholders and demonstration of activities are discussed in the context of the projects implemented at VVU.

Keywords: Ghana, groundwater management, rainwater utilization, sustainable water management, water balance, water quality analyses, Valley View University

Zusammenfassung

Diese Diplomarbeit wurde im Zuge eines Klimaprojektes mit dem Namen "Großflächige Regenwasserspeicher, Energieerzeugung aus Biogas und Solarzellen, klimaneutrales Umweltgebäude an der Valley View University, Accra Ghana" an der Valley View University (VVU), einer privaten Siebenten Tags Adventisten Universität in Ghana, verfasst. Diese Studie untersucht die Wassermanagementpraktiken and schlägt Schritte für eine weitere nachhaltige Entwicklung vor.

VVU steht einigen Problem wie ökonomische Einschränkungen, steigende Studentenzahl, zu geringer Wasserquantität und –qualität gegenüber. Es fehlt Geld für geeigneten Betrieb und Erhaltung der Wasserver- und Entsorgung. Die Wassernachfrage, der am Universitätsgelände lebenden Menschen, kann nicht zufrieden stellend befriedigt werden. Eine, für die Zukunft zu erwartende, steigende Studentenzahl und die Möglichkeit einer Trinkwasserproduktion (Verkauf von Wasser in 450ml Plastikbeutel) an der Universität, übersteigen das Versorgungspotential der existierenden Ressourcen. Wasserinstallationen (Pumpen, Regenwassertanks,…) sind regelmäßig nicht in Ordnung und können deshalb nicht ordnungsgemäß verwendet werden. Außerdem hat das verwendete Wasser keine Trinkwasserqualität. Grundwasser ohne Aufbereitung weist gelegentlich zu hohe Eisenkonzentrationen und Trübung auf. Wasser, das über das Versorgungsnetz der Universität verteilt wird, sowie gesammeltes Regenwasser ist mit E.coli und Enterococcus verschmutzt.

Vor dieser Studie hatte VVU wenige Informationen über ihre Wasserressourcen. Daher war es bisher nicht möglich, Wassermanagement relevante Entscheidungen zu treffen, die auf gut recherchiertem Wissen basieren. Diese Studie fasst wichtiges Wissen über die vorhandenen Wasserressourcen (Grundwasser, Regenwasser und Grauwasser) zusammen. Spezieller Wert wird dabei auf eine quantitative und qualitative Beurteilung gelegt. Die Wasserversorgung wird mit der aktuellen Konsumation und Nachfrage verglichen. Dabei wird aufgezeigt, dass Wasserverluste oder ungemessene Konsumation und unbefriedigte Wassernachfrage vorkommen. Managementvorschläge zur Verbesserung des Wassersystems werden gegeben. Pläne für Regenwasser- und Grundwassermanagement sowie generelle Wassermanagementpläne werden vorgeschlagen. Aufbereitungsanlagen, die zum Einsatz kommen könnten, werden evaluiert. Die Anlagen sollen eine nachhaltige Versorgung von qualitativ gutem Wasser gewährleisten. Außerdem werden für VVU relevante Auswirkungen der laufenden Projekte wie Grundwasserentnahme, Verwendung von Regenwasser, Kommunikation mit Stakeholdern und Demonstration von diversen Aktivitäten diskutiert.

Stichwörter: Ghana, Grundwassermangagement, nachhaltiges Wassermanagement, Regenwassernutzung, Wasserbilanz, Wasserqualitätsanalysen, Valley View University

List of figures

List of tables

Acronyms

BMU – Ministry of Environment, Germany

BOD – Biological Oxygen Demand

BOKU – University of Natural resources and Applied Life Sciences

COD – Chemical Oxygen Demand

CWSA – Community Water and Sanitation Agency

e.g. – for example

EDL – Estimated Detection Limit

GSB – Ghana Standards Board

GWCL – Ghana Water Company Limited

IHP – International Hydrological Programme

IWRM – Integrated Water Resources Management

NCWSP – National Community Water and Sanitation Programme

O&M – Operation and Maintenance

SIG – Institute of Sanitary Engineering and Water Pollution Control

VVU – Valley View University

WATSAN – Water and Sanitation Agency

Watsan committee – Water and Sanitation committee

WHO – World Health Organisation

WRC – Water Resource Commission

WRI – Water Resource Institute

WS&S – Water Supply and Sanitation

1. Introduction

Sustainable water management is an important issue all over the world because water resources are getting increasingly scarce. As a result, especially people from developing countries suffer from the lack of adequate water supply and sanitation (WS&S) systems. This is internationally agreed. For example the UN Millennium Development Goal number 7, target 3, emphasises the need to “halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation” (UN, 2008).

Developing countries often face severe problems concerning water issues. Reasons for this include: lack of clean water due to polluted resources, little general availability, lack of financial resources, lack of knowledge and weak policies. Implementing sustainable water management strategies for poor countries should be a priority, otherwise problems will increase. It is necessary to find methods that are socially acceptable, financially affordable and environmentally friendly to provide long term access to qualitatively and quantitatively safe drinking water. The challenge is that developing countries are lacking the capacities and means to implement such methods. Development aid can help to get projects started. However, the aid has to be used wisely so that the receiving partner profits also in the future.

This Master’s thesis was incorporated in a development project, which was financed by the German Ministry of Environment (BMU). The water issues were headed by the University of Natural Resources and Applied Life Sciences (BOKU), the Institute of Sanitary Engineering and Water Pollution Control (SIG) respectively. The main objective was to enable the development of an ecologically friendly system adapted to the climate conditions for Valley View University (VVU), a private Seventh Day Adventist university in Ghana. Several instruments and financial means were available to establish and conduct research for climate friendly solutions. The participation of SIG in the project began in March 2009 and ended in March 2010. Research was conducted from March 2009 until December 2009. Water quality and quantity assessments, investigation of management structures and sustainability evaluations of the whole water system were conducted during two field studies in the period of May 14th to June 6th and October 11th to December 11th in 2009. These investigations were used to give recommendations for implementing sustainable water management at VVU.

A major problem that occurred during the research was difficulty in accessing information and data. In Ghana, general information about water, especially on regional level, is hard to find. If data are available, they can be found at various institutions. Thus, visiting those institutions, discussing with experts or conducting research in their libraries was an important prerequisite.

This thesis gives best practice examples how to implement and conduct sustainable water management. In addition, it provides general information about relevant water issues in Ghana and the Greater-Accra Region.

2. Objectives

2.1 Overall objectives

The main objectives of the master thesis are:

1. the investigation of current WS&S at VVU
2. the evaluation of planned solutions for sustainable water supply within the project "Large-scale rainwater collection, power production from biogas and solar cells, construction of a climate-neutral environmental building at Valley View University, Accra, Ghana" (from here on referred as "climate project")

2.1.1 Investigation of current water supply and sanitation at VVU

The first overall objective "**investigation of current water supply and sanitation at VVU**" aims at understanding WS&S at VVU and identifying its strengths and weaknesses. It should enable to draw lessons from past projects at VVU and to make recommendations for improvement and for the development of solutions planned in the context of the climate project.

Special emphasises are put on:

- **water demand**: update of mid-term demand forecast
- **local water resources**: collection of data related to quality and quantity of resources
- **water management**: evaluation of resources allocations, water balances and development scenarios
- **water facilities**: compilation and update of existing information/data

Knowledge of water demand, water resources, current management practices and status of water facilities are a base of WS&S. During the last years, an extensive knowledge has been gained throughout diverse research works on that issue at VVU. Especially, a lot of information has been collected on water demand, water management, roof rainwater harvesting systems and water facilities up to 2007 (e.g. KRÄMER, 2007 and others). It is a goal of this thesis to update this information.

Considering water resources, most of the research works have been focused on water re-use (e.g. as a resource for agriculture) so far. However, the question of fresh water has not yet been really investigated. Groundwater wells on campus and the public water supply was not investigated intensively. Except two analyses of ground water carried out in 2008 by external laboratories (Water Research Institute and Aqua Vitens Rand LTD.), no data on groundwater quality are available. Also rainwater quality has not been analysed, although it is frequently used at VVU. Knowledge, on the amount of local fresh water available at VVU, should be improved, too. Daily rainfalls have been measured between 2004 and 2007. But since 2007, the measurements have been stopped. No information at all was available on groundwater prior to the project. This gap needs to be filled, especially because the use of ground and rain water has recently increased and is very likely to increase further in the coming years.

In 2008, two new boreholes have been drilled and the extracted water is now used to partially meet the water demand on campus. Rain water use at VVU will be developed within the climate project. Thus, the use of rainwater should be investigated not only for toilet flushing but eventually also as drinking water.

2.1.2 Evaluation of planned solutions for sustainable water supply

The second overall objective of the thesis is the "**evaluation of planned solutions for sustainable water supply within the BMU climate project (emphasizes on rainwater and groundwater use)**".

The planned solutions consist in increasing VVU's rainwater storage capacity at two sites (Women Centre and Baobab Centre), where harvested rainwater will be stored in underground storage tanks. If necessary, harvested rain water will be treated before being supplied. The treatment is foreseen with low energy filtration technologies.

It is in evidence that these solutions should be sustainable and the following questions arise: Is it possible to achieve a sustainable development of rainwater use at VVU? How could sustainability be achieved?

Following a discussion on sustainability as a whole and in particular at VVU, theses two questions are discussed. The impacts of WS&S projects at VVU are also considered.

For the second overall objective, focuses are on:

- **WS&S sustainability as a whole**: definition and status in WS&S projects in developing countries
- **WS&S sustainability at VVU**: consideration of sustainability of WS&S at VVU, proposal for management plans
- **Implementation of sustainable filtration technologies for harvested rain water**: identification of relevant criteria and comparison of technologies; proposal for the education and training of involved staff
- **Impacts of WS&S projects at VVU**: discussion with regard to issues such as water resources (e.g. ground water extraction), communication with other relevant WS&S stakeholders and demonstration of activities to contribute to the improvement of WS&S outside VVU

2.2 Outline

This thesis has seven major parts.

1. Introduction
2. Objectives
3. General basis
4. Materials and methods
5. Results
6. Interpretation and discussion of results
7. Summary

The introduction briefly describes the global water challenge before it introduces the main topic and content of this thesis. The period of the involved working process is outlined as well as major challenges that were faced during the writing and research process.

In the second chapter, the two overall objectives are stated as well as eight detailed objectives.

The general basis gives an introduction into the problems that were investigated during the research. Thus, at the beginning sustainable water management is introduced as it is internationally understood.

Then a brief description of the Republic of Ghana is provided.

The third part of this chapter gives background information of the climate project at VVU. It introduces the cooperation with Germany and VVU, the project goals and the university's water system, urban planning and agricultural practices.

This part is followed by an interdisciplinary approach to VVU stating relevant circumstances like regional information about geology, hydrology and soils, groundwater quality, rainwater harvesting and special challenges.

The fifth part of this chapter gives a short introduction into Ghana's water sector with general information about Ghana's water sources, relevant institutions (plus directory) and laws and guidelines. Beside that, it notes some challenges of the water sector.

Finally, an introduction into water quality issues is given. Water quality requirements or guidelines of Ghana, the World Health Organisation (WHO) and Austria are compared. Then parameters that were used for water quality analyses on site are briefly discussed.

The fourth chapter summarizes the used materials and methods.

At the beginning general preparation is stated, which was mainly secondary data review and the set up of a work plan for the conducted field study.

This is followed by a chapter about historical data like water meter data, rainfall data and information gathering due to expert queries.

The third part introduces the materials and methods that were used during the field study, including water quality analyses, data logging, public participation and on site surveys.

The fourth method describes the multi-criteria decision making technique used for choosing an appropriate filtration technology for VVU's purposes.

Chapter five gives the results obtained during this research project.

Firstly, VVU's five water sources are quantitatively and qualitatively introduced, namely: the public water supply, groundwater, rainwater, re-used water and water bought with a lorry. At the end of this part, a short summary of the findings is given and verifications of the applied water analyses.

Secondly, VVU's water balance and the respective facilities are discussed. Therefore, VVU's water fluxes are outlined, and then VVU's water consumption is discussed for each building. A summary for all buildings is presented at the end. Then, the water availability, as assessed in the previous part, is compared with the water consumption and water demand, as assessed in this part. Additionally, a general figure of VVU's water fluxes is given with major outflow and inflow amounts.

Thirdly, VVU's water management is investigated more closely. Therefore, the university's current water responsibility structure is introduced and then recommendations for further improvements are given. These recommendations are concluded with management plans for groundwater, rainwater and general water issues. At the end of this part, a short summary is given with a plan for sustainable development of VVU's water management.

Fourthly, four filtration technologies are introduced. They were chosen by BOKU for a bench mark test for sustainable filtration technologies at VVU. In this thesis, relevant sustainability criteria for VVU are defined. Then the technologies are compared with a simple multi-criteria decision making method. At the end, education and training proposals are given for the chosen filtration units.

Fifthly, the impacts of water supply and sanitation projects at VVU are investigated. Therefore, four points are discussed. Possible impacts on groundwater, impacts of rainwater supply, communication with relevant stakeholders and the demonstration of project activities.

The sixth chapter is a discussion and interpretation of obtained results. Moreover, results are compared to previous data if they were available.

The seventh chapter briefly summarizes the thesis.

3. General basis

3.1 Sustainable water management with special emphasis on developing countries

Speaking of sustainability, the most famous quotation is from the WCED (1987): “Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future”. The three main pillars that have to be equally considered in this development process are: economy, environment and society. Although this book is already over 20 years old, this quotation gives a first introduction into the topic of sustainability.

However, over the years, sustainability has become a term that is widely used by several professions for all different kinds of topics. This is also true for water management. Terms like economy, environment, society, participation, appropriate and equity are among the most common to describe sustainability or sustainable water management. They are used in guidelines and laws or for goals and visions. Thus, they contribute to sustainable development.

Of course, sustainability is also a goal in most development projects and so it is the case for VVU. The establishment of sustainable water management is of high priority. This chapter gives a first idea what this management should look like as it is internationally agreed. Beside that, it upgrades the term sustainability to “appropriate” and introduces a definition of Integrated Water Resources Management (IWRM). In chapter 5.3 actual recommendations are presented for VVU.

3.1.1 Sustainable water management an international consensus

According to the EC (1998), sustainable water management needs international collaboration on water issues and a general consensus. This consensus is based on the Dublin Principles and Agenda 21.

The Dublin Principles were announced in the Dublin Statement on Water and Sustainable Development at the UN (1992a). The objectives were to reverse overconsumption, pollution and rising threats from droughts and floods. Therefore, the report recommends actions at local, national and international levels based on the following four guiding principles.

1. Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment
2. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels
3. Women play a central part in the provision, management and safeguarding of water
4. Water has an economic value in all its competing uses and should be recognized as an economic good

Agenda 21 was announced at the United Nations Conference on Environment and Development in 1992. It is an expression of a global consensus and a political commitment to cooperate in the areas of environment and development. In the Agenda 21, issues are stated with bases of actions, goals, actions and implementation modalities (UN, 1992b).

One basis of action (out of 39) is for example, the protection of freshwater quality and freshwater sources and the application of integrated approaches for developing, managing and using water resources. Proposed actions are for example: national action plans and investment programmes, raising public awareness or support of international research and collaborations (UN, 1992b).

3.1.2 Appropriate technologies

Speaking of sustainable technologies, especially for developing countries, an extension of the concept to appropriate technologies is necessary. Many technologies in developing countries are imposed by developed nations through development aid. Although the incentive may be well-intentioned, the implementation or choice of technology is often neither adequate nor sustainable.

To find appropriate technologies, three interrelating and dynamic system components should be considered, namely:

- Technical-economical system with technical facilities
- Socio-political system with organisational structures
- Socio-cultural system with standards, values and visions

(JUNG, 2008)

If deficits in one of these dimensions occur, technological development is necessary. At VVU this is true for all three components. The technical-economical system is weak (broken facilities, lacking finances). The socio-political (governmental institutions, university administration) system demands sustainable technologies and the socio-cultural system (students, staff) demands sufficient and consistent water. These circumstances require the implementation of appropriate technologies for water management.

The linked principles of appropriate technologies are sustainability, equity, replicability, effectiveness and efficiency (JUNG, 2008). Thus, in this concept, sustainability is just one of the principles but not the main issue.

JUNG (2008) suggests different measures, converting those rather abstract principles, into more practical advises according to the three levels: sector policy level, program and project level and technology level. For this thesis the technology level is relevant. The advice for this level is rather simple. The technical infrastructure has to be affordable, manageable, adaptable and expandable. Moreover, JUNG (2008) highlights the importance of low running costs to guarantee users to pay for the maintenance and operation.

3.1.3 The Global Water Partnership (GWP) ToolBox for Integrated Water Resources Management (IWRM)

The GWP (GWP, 2008) defines IWRM as "a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems". Moreover, three key strategic objectives are stated:

- "efficiency to make water resources go as far as possible;
- Equity, in the allocation of water across different social and economic groups;
- Environmental sustainability, to protect the water resources base and associated ecosystems".

IWRM has to be seen as process. Thus, improvement and change is always necessary to guarantee good management practices.

The GWP (2008) sets out recommendations for IWRM based on the four Dublin Principles (see chapter 3.1.1) and an additional principle, namely "integrating three E's" (Economic efficiency in water use, Equity and Environmental and Ecological sustainability).

3.2 Republic of Ghana

The Republic of Ghana is a country in West Africa (see Figure 3.1). The capital city is Accra. It is situated in the south of Ghana. VVU is about 30 km north of the capital city Accra (see Figure 3.2 – red point).

Ghana has an area of about 240 000 km² and a population of approximately 23 400 000 (2007). 68% of the population are Christians, 15,9% are Muslims, 8,5% have traditional believes and approximately 6,1% are without any confession (SASI, 2009).

Ghana became a presidential republic in 1979. It is represented in the Commonwealth. However, Ghana became independent from Great Britain as the first African state in 1957. Nevertheless, English is still the official language (SASI, 2009).

Figure 3.1: Ghana's location in West Africa (SASI, 2009)

Figure 3.2: Map of Ghana (SASI, 2009 adapted by Lauterböck, 2009)

3.3 Project background

The project to establish an ecological master plan (see Figure 3.3) for VVU began in 2003. The German Ministry of Research and Education funded this project until 2008. VVU's goal became to develop to the first ecological university in Africa. Furthermore, the university has been preparing for an increasing number of students and staff from about 2000 to 5000 persons. The idea of the master plan has been to achieve these goals with sustainable development in the fields of urban planning, building, sanitation, agriculture and water and nutrient cycle management (see Figure 3.4). In 2008, a second project started at VVU that has been financed by the BMU. This project is divided into two parts, one is called "Klimaangepasster Ausbau der Valley View University" (climate adapted development of Valley View University, Accra, Ghana) and the other one "Großflächige Regenwasserspeicher, Energieerzeugung aus Biogas und Solarzellen, klimaneutrales Umweltgebäude an der Valley View University, Accra Ghana" (large-scale rainwater collection, power production from biogas and solar cells, construction of a climate-neutral environmental building at Valley View University, Accra, Ghana) (FRIES, 2006 and GELLER and LARYEA, 2008). In 2009, BOKU University joined as project partner for water relevant issues. This thesis deals with those water issues.

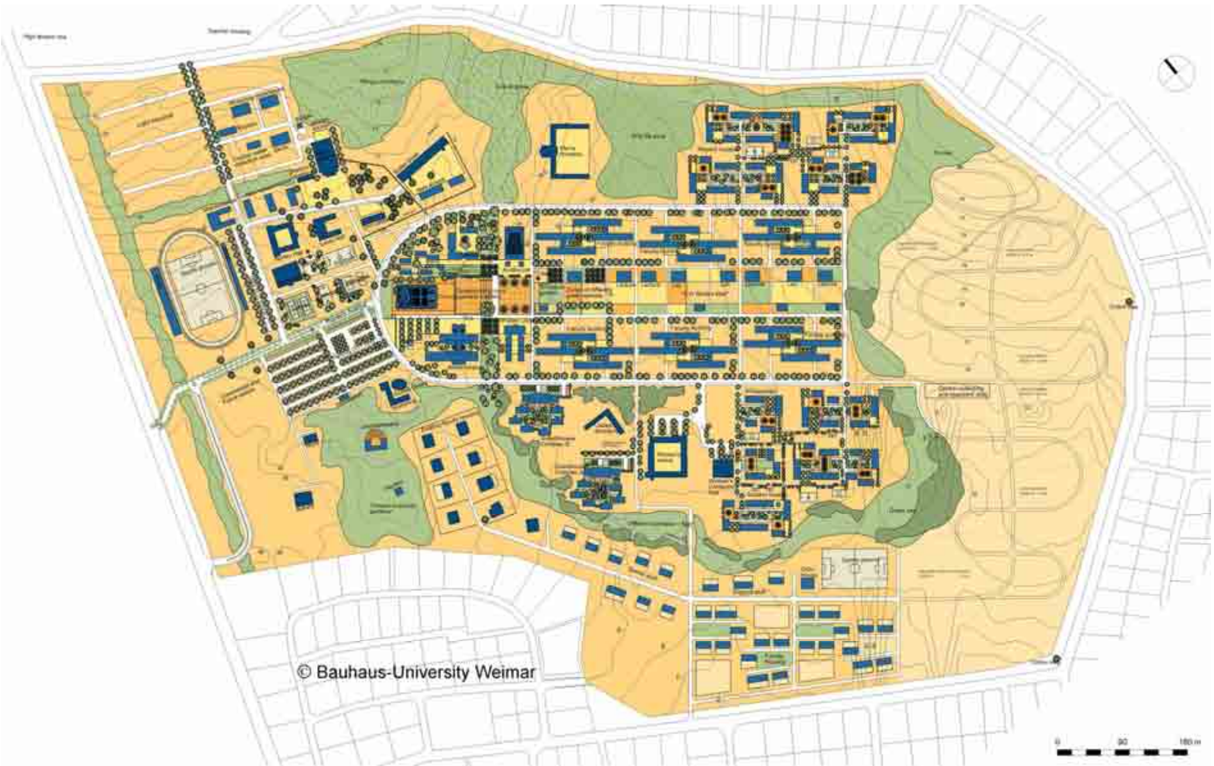

Figure 3.3: Ecological master plan of VVU (FRIES, 2006)

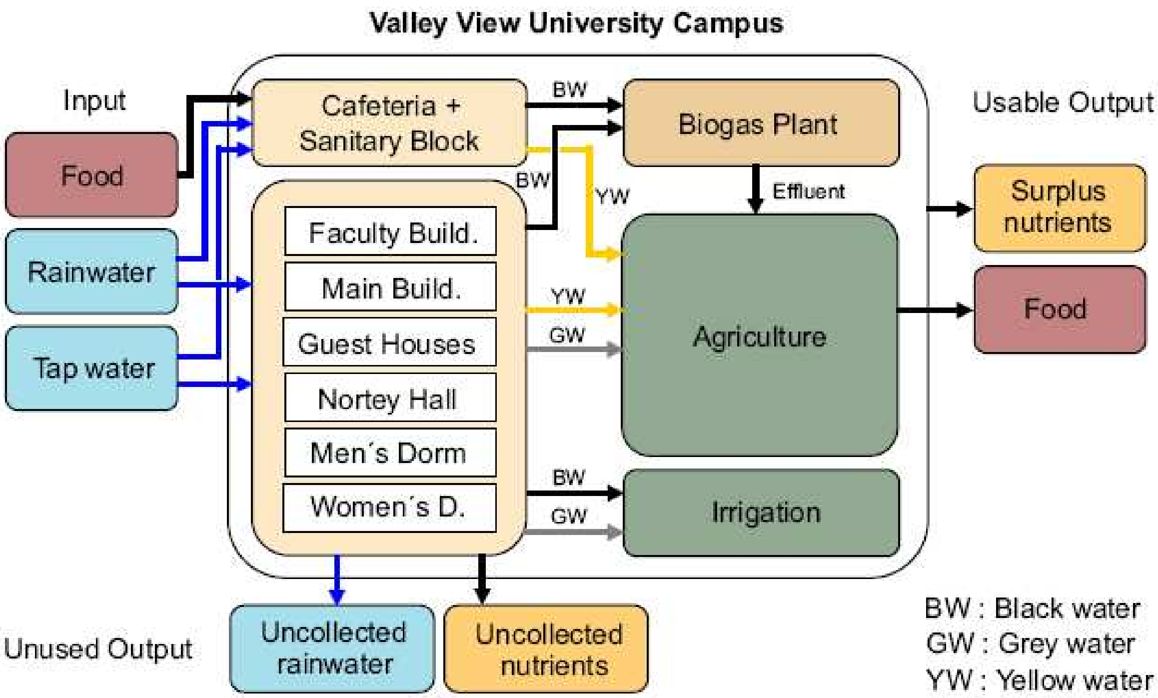

Figure 3.4: Diagram of water and nutrient cycle management at VVU campus (FRIES, 2006)

3.3.1 Water cycle management

Given targets for water cycle management were:

- Protection and conservation of water resources
- Reduction of waste water
- Closed loop recycling management for water and nutrients
- Rainwater utilization
- Retention of rainwater to improve bioactivity
- Groundwater replenishment through percolation

(FRIES, 2006)

This research project fulfils the targets to protect and conserve water resources and to use rainwater. It builds up on the previous project. In addition to the mentioned objectives, a special consideration has to be that the future demand of the growing student population is quantitatively and qualitatively met in a sustainable manner. Therefore, supply side (e.g.: rainwater harvesting, grey water use) and demand side (e.g.: low volume flushing toilets, dry toilets) measures were implemented

Water cycle management deals with the university's four water sources: groundwater, rainwater, grey water (water re-use) and surface water (FRIES, 2006). Groundwater is used from the Oyibi Water Supply Scheme and from 3 boreholes on site. The Oyibi Water Supply Scheme irregularly delivers about 318 m^3 per week via a pipeline. Additionally, about 25 m^3 per day are pumped up, mainly from one of three groundwater wells, but one is not functioning adequately. Groundwater is stored in an underground tank with a size of 225 m^3. From there, it is pumped to an elevated tank with 45 m^3. Subsequently, it is distributed into the university's water supply network (see Figure 3.5). Rainwater is separately stored in tanks next to buildings where rainwater collection systems are in use. In most cases, the rainwater is used as "process" water (e.g.: for toilet flushing). Nevertheless, improvements of the rainwater system are necessary (not all gutters are fixed; pollution is possible because of poorly protected tanks). Grey water use is restricted to few applications. In some buildings, depending on the quality and amount of grey water, it is used for irrigating nearby trees, gardens or the farm on campus. Surface water can be obtained from the Ghana Water Company Limited. The water has to be picked up with the university's tank lorry and is just used in times of water shortage. Water saving applications for toilets and hand washbasins are in use as complementary water saving activities. Moreover, re-use of human excreta is conducted. Yellow water is used as fertilizer on the university's farmland. Black water is led to a biogas plant, which supplies the Cafeteria with gas for a stove (FRIES, 2006; KRÄMER, 2007; PALUTEC, 2008 and GELLER and LARYEA, 2008).

Compared to other ecological issues at VVU, integrated and sustainable water management was not covered by extensive research previous to this project. Few data and information are available about water sources, their availability and proper management. This thesis covers these issues more thoroughly.

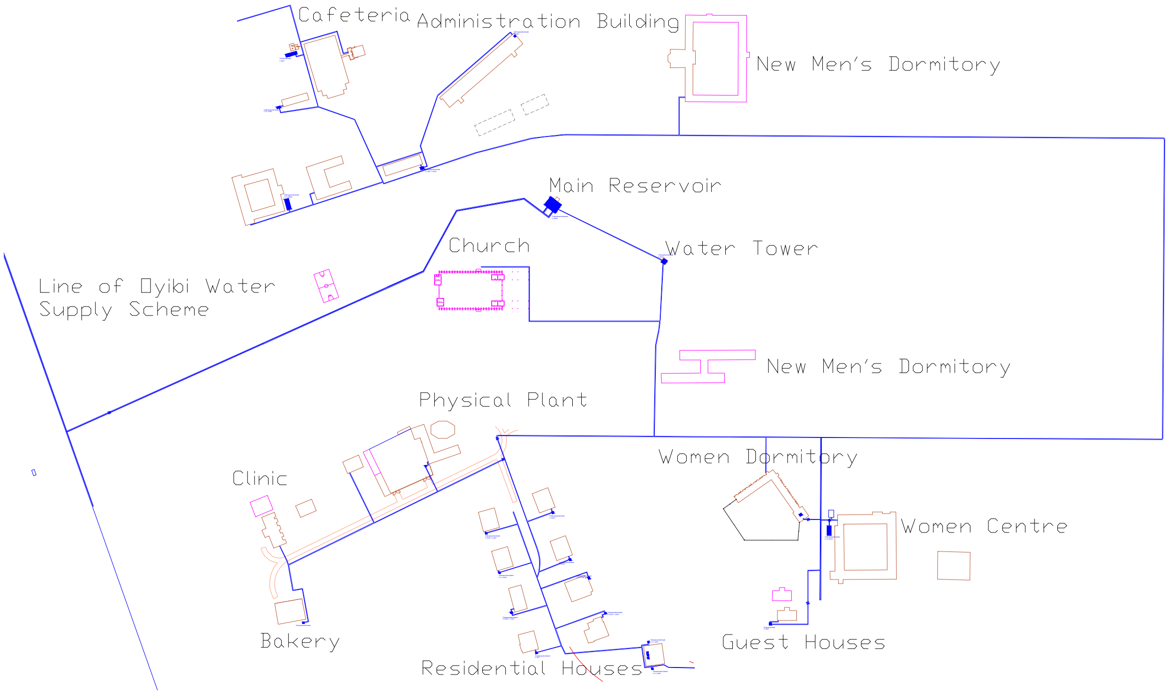

Figure 3.5: VVU's water supply network (GLÜCKLICH and MEYER, 2006, adapted by LAUTERBÖCK, 2009)

3.3.2 Urban planning and building

As already mentioned, an ecological master plan was developed at the beginning (see Figure 3.5). This plan allows holistic development and cycle management of ecological concepts for traffic, water and nutrients, open space, energy and waste (FRIES, 2006).

Buildings will be ecologically developed and decentralized sanitation concepts adapted, including water saving installations and collection of yellow, grey and rainwater for re-use and agricultural purposes (FRIES, 2006).

3.3.3 Agriculture

Environmental conditions are not the best for agriculture in the area of VVU. Specifically, water availability and poor soils are the major constraints. Rainfall and major water bodies are missing and fertilizers are mostly unaffordable (FRIES, 2006).

To overcome these shortcomings, separation toilets are used. Collected urine is utilized as fertilizer. Black water is sent to a biogas plant on campus to produce gas for one stove in the cafeteria, or to septic tanks from where it is used as soil conditioner. Also grey water is re-used for irrigating farmland after treatment processes. Water and nutrients are recycled in circular flow system (FRIES, 2006).

3.4 Interdisciplinary approach to VVU's environment

This thesis deals with IWRM. Therefore, a brief insight into relevant issues is given in this chapter. The information obtained, helps to draw conclusions for the project.

3.4.1 Hydrogeology

VVU is situated on the crest of a foothill that stretches south-eastwards, from the Akwapim-Togo ranges along Oyibi to Obeye into the Accra plains. This stretch is the boarder between two bedrock formations in the Precambrian Guinea Shield of West Africa, namely the metamorphosed and folded Dahomean system and the Togo series (FRIES, 2006). Figure 3.6 illustrates hydrogeological conditions in the VVU region.

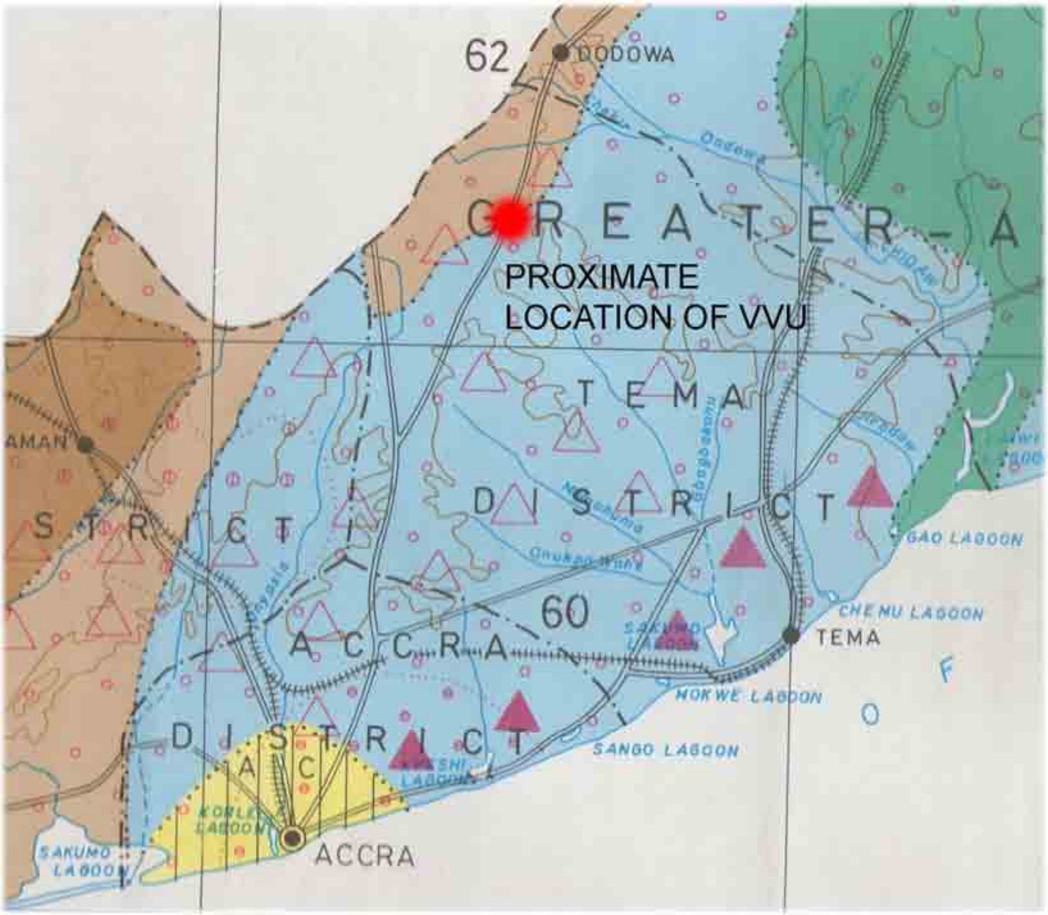

Figure 3.6: Hydrogeological map of Tema District, Greater Accra Region (WRI, 1996, adapted by LAUTERBÖCK, 2009)

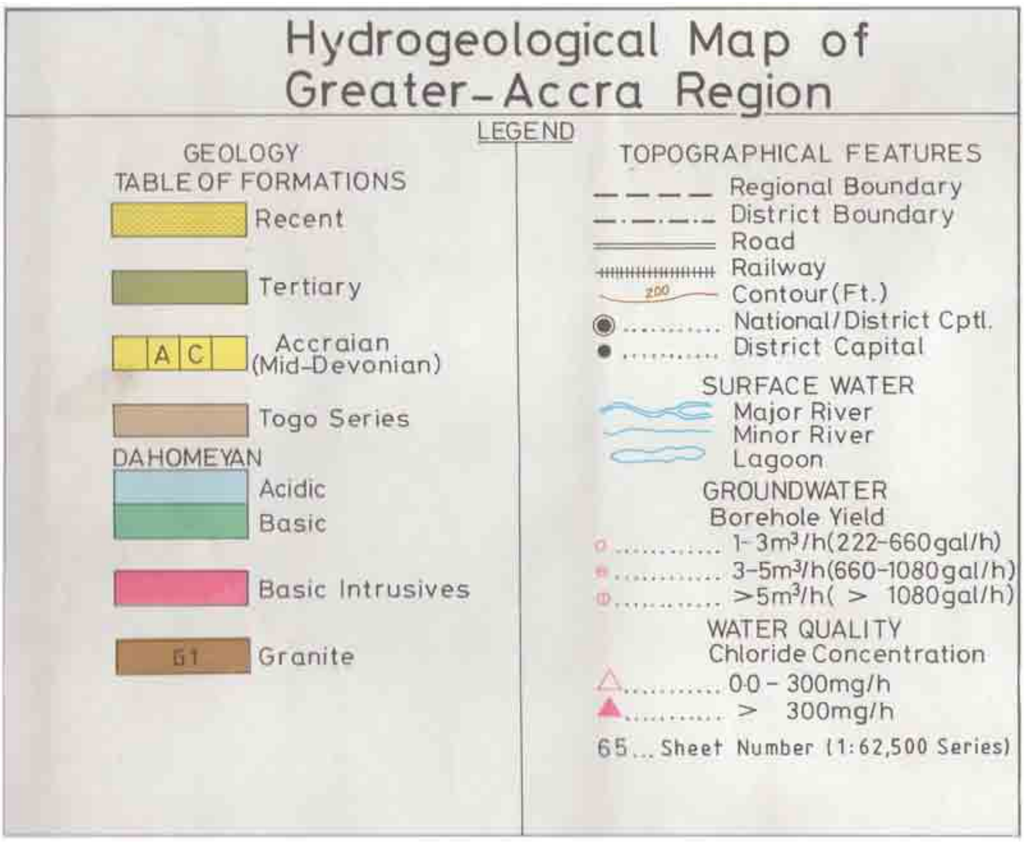

Figure 3.7: Legend for hydrogeological map of Greater Accra Region (WRI, 1996)

The red dot in Figure 3.6 shows that VVU is located within the boundary zone of the Togo Series (brown) and the acidic Dahomeyan geological zone (light blue) (see Figure 3.7). The surrounding borehole yield prospects are rather low with 1-3 m^3 /h. The Chloride concentration is considered to be between 0 and 300 mg/l.

The Togo Formation consists of Precambrian crystalline igneous and metamorphic rock formations (KESSE, 1985, as cited in KORTATSI et al., 2008). It is a highly folded, fractured and jointed compound of sandstones, quartzite, quartz schist, shale, phyllites, and some talc mica schist (FIANKO et al., 2009 and DARKO et al., 1995).

The Dahomeyan system consists of alternating belts of acid and basic gneisses. VVU is located in the immediate east of the Togo-Akwapim ranges thus, in an acidic belt with disconnected Togo quartzite outliers. The acid Dahomeyan consist mainly of muscovite-biotitic gneiss, quartz-feldspar gneiss, augen gneiss and minor amphibolites, rocks that decompose to slightly permeable calcareous clay (DARKO et al., 1995).

Looking at the Togo series, borehole prospects are considered to be good. However, the location has to be carefully chosen because of complicated petrography and tectonics (ERDELYI, 1965). According to DAPAAH-SIAKWAN (2009), the Head of the Groundwater Division of the WRI, one out of three drilled groundwater wells will be dry in the area of VVU. The groundwater occurrence is mainly influenced by secondary porosities like fractures, faults, joints and the associated weathered zones. Rocks in the Greater Accra region (granitic gneiss and schistose lithologies) are usually impermeable (NII CONSULT, 1998, as cited in KORTATSI et al., 2008) and have limited storage capacities within their matrix (DARKO et al., 1995). Furthermore, the transmissivities are rather low with a range of 0,5 – 70,0m^2/h (WRRI, 1996, as cited in KORTATSI et al., 2008). The pattern of fractures controls the groundwater occurrence. From isolated water filled cracks with limited water resources to dense fracture networks everything is possible (DARKO et al., 1995).

3.4.2 Groundwater conditions

3.4.2.1 Occurrence

The groundwater table around VVU lies at least 30 meters deep (SEBALD, 2004, as cited in FRIES, 2006). KORTATSI and JORGENSEN (2001, as cited in FRIES, 2006) "assume a short groundwater residence time and conclude that the area around the Akwapim-Togo range is probably the recharge area for the groundwater of the Accra Plains". Low annual precipitation, high evapotranspiration and the absence of surface waters make groundwater replenishment from local percolation unlikely (FRIES, 2006).

The flanks and foothills of the Akwapim-Togo range are considered to have several groundwater discharge zones and spring sources. Additionally, infiltration of rainwater is possible in zones with fractures and intergranular pore spaces. Static water level tests provided evidence that the groundwater level is correlated to rainfall. This was observed seasonally as well as for long periods over ten years (DARKO et al., 1995).

Concerning flow pattern, it is assumed that "the overall groundwater flow direction was from the foothills of the mountains south-southeastwards into the [Greater-Accra] Plains proper towards the coast" (DARKO et al., 1995). This assumption is based on the fact that the groundwater at the foothills is generally less mineralized and younger (isotopic dating) (AKITI, 1984 as cited in DARKO et al., 1995).

3.4.2.2 Quality

As one important part of the study was to estimate the water quality of the three groundwater wells on campus, this section introduces quality data of groundwater wells from villages nearby and the only two water quality analysis conducted at VVU. The results indicate expected water quality and can be compared with the results obtained at VVU (see chapter 5.1.2).

Previous to this study, only two water quality analyses were conducted (Table 3.1) at VVU: one for Borehole 1 and one for the Main Reservoir (mixture of groundwater from boreholes at VVU and groundwater from the public water supplier).

Table 3.1: Water quality of Borehole 1 [2] and of the Main Reservoir [3]

Parameters	Borehole 1 [1, 2]	Main Reservoir [1, 3]
pH	5,7+	6,7
Turbidity (NTU)	37,5+	0,8
Conductivity (µS/cm)	503	662
Ammonium (mg/l)	<0,001	0,2
Nitrate (mg/l)	1,19	2
Nitrite (mg/l)	0,018	0,01
Chloride (mg/l)	114	146
Phosphate (mg/l)	0,379	1,0
Total Iron (mg/l)	0,397+	0
Manganese (mg/l)	0,095	0
Total Coliform/ 1ml	-	3+

[1] Values marked with + are not conform with the GSB requirements for drinking water
[2] Water analysis conducted by WRI in February, 2008
[3] Water analysis conducted by Aqua Vitens Rand LTD in November, 2008

The water did not meet GSB's drinking water quality standards for iron, pH, turbidity and total coliform. High iron concentrations are common throughout Ghana. Usually, they are associated with acidic or anaerobic groundwater (BRITISH GEOLOGICAL SURVEY, 2001). Groundwater quality in the Greater-Accra Region is generally poor. High salinity and high hardness in the water additional to clay in the soil lead to high electrical conductivity values of up to 4000 µS/cm at sites in Accra or Tema (DAPAAH-SIAKWAN, 2009). These sites are close to the ocean. Thus, seawater intrusion might also influence conductivity.

The water quality data in Table 3.2 were obtained during a study conducted by DARKO et al. (1995). They chose 29 groundwater wells in the Greater Accra region for chemical analyses. Results of selected wells located around VVU are presented in Table 3.2.

Table 3.2: Chemical water quality of selected groundwater wells close to VVU (DARKO et al., 1995)

Location	Amrahia AP 31	Amrahia AP 34	Amrahia	Malejor	Oyibi [1]	Danfa [1]
pH	7	6,4	6,9	6,1	6,2	6,1
Temperature [°C]	25,5	26,2	28	27	26,3	30
Conductivity [µS/cm]	975	679	820	550	2400	2740
Calcium [mg/l]	104,2	30	43	5,2	56	65
Magnesium [mg/l]	12	27,7	69,5	50,3	41	55
Sodium [mg/l]	55	50	65,3	75	97	61
Potassium [mg/l]	1,4	0,6	6,3	4	0,2	2,2
Bicarbonate [mg/l]	68,3	70	320	85	244	153,7
Chloride [mg/l]	174	143	162	56	362+	560+
Sulphate [mg/l]	34,3	28,6	39,8	100	57	229
Nitrate [mg/l]	2,6	1,7	3,8	1,9	1,1	2,1

[1] *Values marked with + are not conform with the GSB requirements for drinking water*

SARPONG (2009b) handed over water quality data from the two groundwater wells used at Oyibi Pubic Supply Scheme. These data are from chemical analyses conducted in June 2009 (Table 3.3).

Table 3.3: Chemical water quality of the Oyibi Public Supply Scheme's groundwater wells

Parameters	**KPONE SEDUASE (Oyibi)**	**OLD SAASABI (Oyibi) [1]**
pH	6,7	7,1
Colour (HU)	< 5	< 5
Turbidity (NTU)	0,39	3,92
Total Alkalinity (mg/l)	60	124
Total Hardness (mg/l)	140	300
Calcium Hardness (mg/l)	30	50
Magnesium Hardness (mg/l)	110	250
Total Iron (mg/l)	0,1	0,51+
Manganese (mg/l)	0	0,2+

[1] *Values marked with + are not conform with the GSB requirements for drinking water*

Results (Table 3.1, Table 3.2 and Table 3.3) obtained from groundwater wells at and around VVU verify the general conditions of Ghana and the Greater Accra region. Most likely problems are high salinity (high chloride concentrations and electrical conductivity values) as well as high concentrations of iron and manganese. Moreover, DARKO et al. (1995) detected coliform bacteria at some sites.

3.4.3 Soils

Predominant soils are deeply weathered reddish soils with a thin A horizon (approximately 10 cm) without a clearly defined E horizon. However, transitional AE and BE horizons occur with a thickness of 15 to 40 cm. The following horizon is a dark red-brown argic B horizon. This horizon consists of iron mottles and shows a rather high clay content. The C horizon is highly weathered and compact. It is mainly composed of sand, quartzite gravel and stones. Thus, the soil is in the group of Acrisols (FRIES, 2006). High pH values, cation exchange capacities and base saturations measured in soil samples from VVU are more characteristic for connatural Lixisols. This implies that these soils derivate from the more alkaline Togo Series (KPORMEGBE, 2006). Consequently, the soils are classified as Ferric Acrisols/ Ferric Lixisols (FAO, 1998 as quoted in KPORMEGBE, 2006).

Acrisols and Lixisols are low in organic matter content, water holding capacity and prone to water and wind erosion (SAUERBORN and GERMER, 2005b as quoted in KPORMEGBE, 2006).

Reddish soils at the top are laterite (originating from the Togo Series) containing iron and they usually have high clay contents. This leads to low permeability and high elasticity (DAPAAH-SIAKWAN, 2009).

3.4.4 Rainwater harvesting

LUNDGREN and AKERBERG (2006) claim that rainwater harvesting is one solution for the most vulnerable people in terms of water supply and it is “an innovative approach for the integrated and sustainable development of the poorer areas” (ibidem). Therefore, it appears to be suitable for integrated and sustainable water management. However, appropriate protection measures against contamination of water and mosquito breeding are necessary (LUNDGREN and AKERBERG, 2006). Thus, rainwater harvesting could be also suitable for VVU.

LUNDGREN and AKERBERG (2006) conducted their study in four areas of Accra’s peri-urban agglomeration with scarce drinking water resources. There, 71% of households harvest rainwater and apply purification or filtration methods. Most of the people questioned the use of water for drinking and cooking as well as washing and bathing. The people expressed likes of rainwater, including:

- it is very tasty (32%)
- it has several advantages (20%)
- it is a good source of water (19%)
- it is good for washing (11%)
- it is free of charge (8%)

LUNDGREN and AKERBERG (2006) collected rainwater samples at four sites. The results were only indicative. The measurements included conductivity, alkalinity, some cations and anions.

Table 3.4 presents the results of the analysis.

Table 3.4: Water analyses results of rainwater samples [1] (LUNDGREN and AKERBERG, 2006)

Conductivity [µS/cm]	**Alkalinity [mekv/l]**	**HCO_3 [mg/]**	**Cl^- [mg/l]**	**NO_3^- [mg/l]**
16 - 141	0,054 – 1,058	3,29 – 64,54	0,83 – 37,23	1,16 – 2,37
SO_4^{2-} [mg/l]	**Na^+ [mg/l]**	**K^+ [mg/l]**	**Ca^{2+} [mg/l]**	**Mg^{2+} [mg/l]**
1,19 – 9,70	0,76 – 12,34	0,20 – 1,49	1,62 – 11,36	0,41 – 1,1

[1] *Values are expressed as range from measured minimum to maximum*

The values for conductivity, Cl^- and NO^{3-} can be compared with the water analysis conducted during this study (chapter 5.1.3). However, it should be considered that results of LUNDGREN and AKERBERG (2006) are only indicative.

3.4.5 Challenges

3.4.5.1 Land cultivation

Land cultivation can influence the water balance of regions. Especially irrigation and little overall availability of water can lead to problems like water shortage for households, desertification, degradation, salinisation of soils and depletion of groundwater.

In the Greater Accra Region, agriculture does not play a significant role. Its small size, poor soils and missing major water bodies leave agriculture little opportunities. Crops usually grow under rain-fed conditions. Major animal husbandry includes poultry and cattle. Fishing is from great importance in the country's fishing industry, with a share of 25% in the total production (GREATER ACCRA COUNCIL, 2007).

According to Dr. MENSAH-BONSU (2009), the major crops are annual vegetables and corn. Usually, crops are irrigated with buckets. Water is mostly taken from surface water bodies. Fertilization is not conducted on a big scale. Some farmers have animal husbandry, mainly with cattle, sheep and goats.

As the agricultural sector seems to be of small scale in this area, no major impact on water management issues is expected. Particularly the depletion of groundwater sources is unlikely due to little use of fertilizers, extensive animal husbandry and irrigation with surface water.

3.4.5.2 Environmental considerations

VVU lies within the wider area of Accra. YANKSON and GOUGH (1999) published a study about environmental impacts of rapid urbanization in the peri-urban area of Accra. This study gives an idea of the development that is likely to happen sooner or later around VVU, as the university is located about 10 kilometres north of Adenta, which is one of the outlying peri-urban areas north of Accra. A road connecting Accra, Medina and Adenta is currently under construction. This development will most likely intensify the urbanisation of this area.

Among other problems the study reveals:

- rapid land-use changes: especially clearing of forest initially for agricultural purposes and firewood harvesting and residential purposes
- vegetal degradation: bush fires artificially set by hunters or farmers
- shortage of land for farming and residential purposes: especially for indigenous people of the old villages
- reduction in soil fertility: resulting in low yields of traditional farming

- soil erosions: due to lacking drainage facilities

(YANKSON and GOUGH, 1999)

Concerning water supply, the major problems are:

- polluted or dried up streams and ponds traditionally used for water supply (public supply network not sufficient to meet the demand)
- illnesses resulting from natural resources (e.g.: diarrhoea, cholera or malnutrition)
- many people rely on private water companies

(YANKSON and GOUGH, 1999)

As stated in the article, the Ghana Water Company Limited (GWCL) is facing a lack of appropriate treatment plants and poor conditions of pipe networks. It is most likely that the periphery of Accra will not get reliable water supply in the long term (YANKSON and GOUGH, 1999).

In addition to unreliable water supply, several communities face sanitation problems. Main sewerage systems and public facilities are rare. Therefore, most of the houses use septic tanks in the garden for their waste water (YANKSON and GOUGH, 1999).

Similar to YANKSON and GOUGH (1999), the EPA (2009) states the following key environmental issues for the Greater Accra Region:

- Poor sanitation and waste management
- Unplanned human settlement and poor development control
- Land degradation from sand winning and quarrying
- Water pollution of Densu River, Odaw and Lagoons
- Land use conflicts
- Coastal erosion and pollution

There are several environmental problems in the Greater Accra Region. VVU can act as a role model for communities or institutions. Sustainable concepts for water, waste and land management would help to combat the environmental challenges mentioned in this chapter.

3.4.5.3 Climate change

According to KUUZEGH (2009), deputy director in Ghana's ministry of environment and science, Ghana will be affected by climate change in various sectors, namely human health (increasing diseases), agriculture (reduced yields), land management (decreasing soil fertility, increasing desertification and biodiversity loss), coastal zone (erosion) and water resources (decreasing availability).

KUUZEGH (2009) expects a rising temperature and decreasing rainfall in Ghana for the long term. It is estimated that the temperature will rise on average by 0,6℃ (2020), 2℃ (2050) and 3,9℃ (2080). Precipitation will decrease on average by 2,8% (2020), 10,9% (2050) and 18,6% (2080). Additionally, the sea level will rise up to 34,5cm until 2080 (KUUZEGH, 2009).

3.4.5.4 Population

Another issue is the rapidly growing population, which will also intensify current challenges. More people imply an increasing stress on natural resources like water and land as well as more waste (solid and waste water). The growing population is a major problem in developing countries and Ghana is no exception. Especially the area where VVU is located is likely to face a high population growth.

Ghana is among the most populous countries in Sub-Saharan Africa with about 23,4 million inhabitants (SASI, 2009). Forecast for 2020 expect the population to increase to 27 million.

By then, about 18 million people will be between 15 and 64 years. 8 Million people will be under 15 and about 1 million above 64 (ADLAKHA, 1996).

Ghana urban population is increasing by approximately 4 percent a year. The rural population in comparison is growing by under 2 percent a year (ADLAKHA, 1996).

Table 3.5 highlights the most important population census data.

Table 3.5: Ghana's population from 1960 to 2000 (UN, 1960-2000)

	Inhabitants	**Annual rate of increase**	**People/ km²**	**Accra urban agglomeration**	**Urban population**
2000	18 912 079	2,2	81	1 155 414	
1984	12 205 574	3,1	56	738 498	31,3%
1970	8 545 561	3	38	758 300	23,1%
1960	6 690 730	1,6	21	-	-

It is obvious that Ghana's population is increasing steadily. The share of urban population is expanding, so is Accra's urban agglomeration. These facts can influence VVU's water situation because this area is part of an extended urban agglomeration of Accra. The population growth will put more pressure on scarce water resources and on VVU's public supplier.

As VVU lies within the Greater Accra Region and in the 2007 newly created Adenta Municipal (formerly part of Tema Metropolitan). Greater Accra is the most densely populated region (895,5 persons per km² in 2000) in the country since 1960. The growth rate of 4,4 per cent between 1984 and 2000 is higher than the national average. In 2000, almost 3 million people lived in the Greater Accra Region. The region's share of the total population has increased from 7,3% in 1960 to 15,4% in 2000 (MINISTRY OF LOCAL GOVERNMENT AND RURAL DEVELOPMENT, 2006).

70,8% of the region's population are economically active, with an unemployment rate of 13,4%. 42% were engaged in sales and services. Professionals, technicians, transport operators and related workers have a share of 10,8%. In the occupational structure agriculture, animal husbandry, forestry, fishermen and hunters only share 9,1%. The major industrial activities are wholesale, retail trade and manufacturing (MINISTRY OF LOCAL GOVERNMENT AND RURAL DEVELOPMENT, 2006).

3.5 Water sector in Ghana

This chapter gives a short introduction into Ghana's water sector. The major water resources are discussed and the most important institutions, laws, guidelines and challenges are introduced. Analysing the objectives and goals of the different institutions and policy instruments, one soon realizes that Ghana has a good basis for improvements and tackling the challenges. However, Ghana is lacking financial means. Therefore, proper implementation of policies and guidelines is hard to achieve. WS&S is by far not sufficient in the country. Moreover, health issues and public awareness rising, concerning WS&S, are important factors throughout the sector because there is a large lack of knowledge.

Incorporation of sustainability, health issues, awareness rising and operation and maintenance (O&M) aspects in targets, guidelines or responsibilities are necessary and good ways to improve the water sector and overcome the challenges. Institutions, laws and guidelines and especially their measures and activities are the bases to success. They have to give incentives of how to manage Ghana's water resources properly.

3.5.1 Water resources

Ghana's water resources distribution is seasonal and regional varying (WRC, 2008b). The region around VVU lies in the costal savannah zone. Therefore, a tropical monsoon climate leads to two rain periods, from April to July and from September to November (FRIES, 2006). The rainfall in the Accra area ranges from 600 to 1,500 mm per year (VOLLMERT et al., 2003; quote by BRAUHAUS-UNIVERSITY WEIMAR, 2006).

Groundwater yields are rather low. In limestone aquifers yields up to 180 m³ per hour are possible. However, these aquifers are seldom. Whereas groundwater is the most important water source in rural areas, domestic and industrial urban water supply is mainly based on surface water from river systems (e.g.: Lake Volta and Densu River for Accra). Moreover, it is expected, that future water demands can be met by surface water, but proper management of these resources additional to increasing rainwater harvesting are necessary (WRC, 2008b).

Nevertheless, the overall availability of water is decreasing because of climate change, population growth, pollution of rivers and draining of wetlands (WRC, 2008b). Therefore, sustainable water management gets increasingly important. Good institutional settings and appropriate policy instruments are the major requirements to meet future demands.

3.5.2 Stakeholders

Figure 3.8 shows an organization chart of the most important institutions. The Ministry is on the top with its three major water departments. The District Assemblies are on the local level the highest policy institution. The Ghana Standards Board (GSB) and the Water Research Institute have mandates to fulfil certain functions.

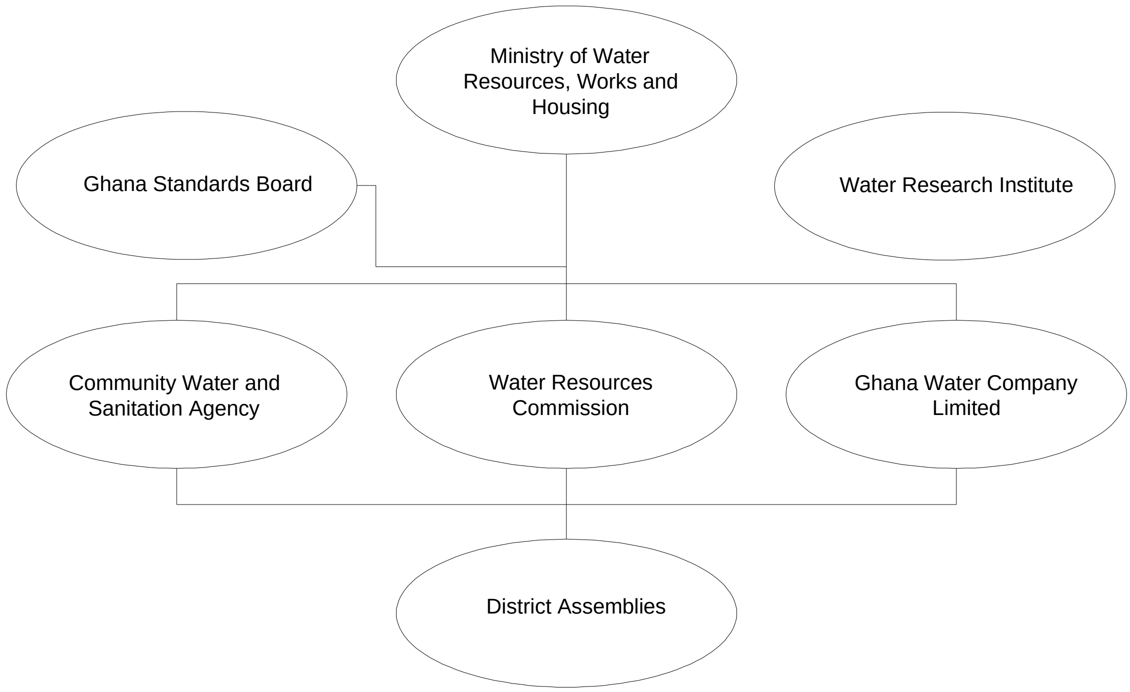

Figure 3.8: Organization chart of major institutions in the water sector

3.5.2.1 Ministry of Water Resources, Works and Housing

The Ministry of Water Resources, Works and Housing has a department called Water Directorate. It is responsible for governance, intersectoral coordination of projects and monitoring the achievement of national goals in the water sector. Moreover, there are three important central institutions with different competencies in the water directorate of the Ministry:

- Water Resources Commission (WRC)
- Community Water and Sanitation Agency (CWSA)
- Ghana Water Company Limited (GWCL)

(ZEF, 2005)

A revision of the Ghana Water and Sewerage Corporation became necessary due to insufficient water supply in Ghana’s rural areas from 1965 to 1985, and the United Nations’ proclaimed ”International Drinking Water Supply and Sanitation Decade” from 1981 until 1990 (CWSA, 2008). The outcome was the creation of the above mentioned institutions that are subsequently described.

3.5.2.2 Water Resources Commission (WRC)

The WRC was established by the Act 522 in 1996. Its responsibilities are to regulate and manage Ghana’s water resources and the coordination of related policies. Moreover, the Act appoints the president as full owner of all water resources (WRC, 2008a).

The responsibilities of the WRC as stated on their homepage (2008a) are:

- Processing of water rights and permits (abstraction level > 5 litres per second)
- Water resources development and management with catchments as planning units
- Collection and spreading of data and information of water resources
- Monitoring and assessing activities and programmes

These responsibilities should be achieved by implementing IWRM, establishing a cost effective organization, establishing collaboration with all stakeholders and accelerate participation of institutions and private partners (WRC, 2008a).

3.5.2.3 Community Water and Sanitation Agency (CWSA)

The Act 564 established the CWSA in 1998. It is the successor of the Community Water and Sanitation Division, which was a sub-unit of the previous Ghana Water and Sewerage Corporation. It operates under the Ministry of Water Resources, Works and Housing (CWSA, 2008). The CWSA is responsible for “facilitating the provision of safe water and related sanitation services to small communities and towns” (CWSA, 2005) and the implementation of the National Community Water and Sanitation Programme (NCWSP – see chapter 3.5.4.2) (CWSA, 2008).

“The Community and Sanitation Agency (CWSA), is committed to effective facilitation of the provision of sustainable potable water and related sanitation services as well as hygiene promotion to rural communities and small towns through resources mobilization, capacity building and standards setting with the active participation of major stakeholders” (CWSA, 2008). Therefore, the agency acts as facilitator, promoter and coordinator in private and public sector participation in WS&S services. Furthermore, the provision of equal distribution of facilities and their sustainable use are related tasks to this mission (CWSA, 2008).

The goals are rather ambitious. The agency aims for the provision of sustainable community water and household sanitation in 72% of rural communities and small towns by 2012, and 85% coverage by 2015 (CWSA, 2008). Proposed ways to achieve these goals are good community governance (lead roles for women, good communication and negotiation skills for responsible people), training of elected members of the community and speeding up rural development (decreasing the time lost because of long water fetching ways and water related illnesses). Figure 3.9 illustrates the water coverage status for different years. It shows a good progress (see linear trend in red); however, faster progress is still necessary if Ghana wants to achieve CWSA’s goal (yellow point) in time.

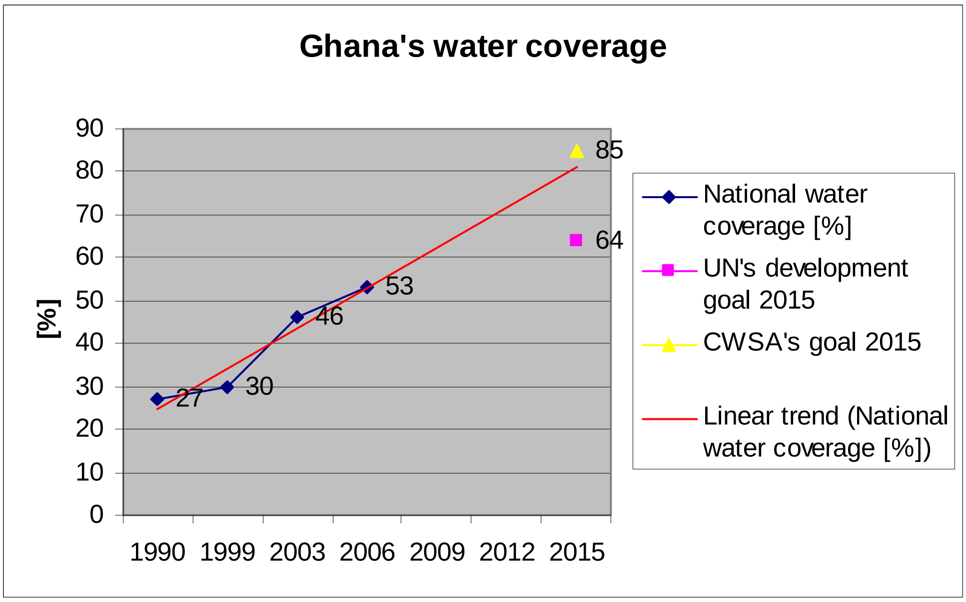

Figure 3.9: National water coverage in Ghana and respective goals (CWSA, 2007)

According to the Act 564 as described at CWSA, 2008, the major functions of the agency are among others:

- Technical support
- Formulation of strategies
- Encouragement of private sector participation
- Planning and execution of water development
- Assistance and coordination of NGOs and international agencies
- Increase public awareness
- Establish relevant standards and guidelines for WS&S
- Charge fees for provided services

3.5.2.4 Ghana Water Company Limited (GWCL)

The GWCL has similar responsibilities like the CWSA but it is in charge of large towns and cities or medium towns. It was established in 1999 by the Act 461.

The main objectives of the GWCL are:

- Planning and development of water supply systems in all urban communities
- Provision and maintenance of acceptable levels of services to consumers in respect of quantity and quality of the supplied water
- Preparation of long term plans
- Conduction of research
- Conduction of surveys and making of plans
- Construction and operation of works in urban areas
- Tariff proposals to the Public Utility Regulatory Commission
- Conduction of other related or incidental activities

(DOE, 2007)

The GWCL provides VVU indirectly with water because the university's lorry picks up water from this company (see chapter 5.1.5). Furthermore, the Oyibi Water Supply Scheme is planning a connection to a GWCL pipeline, to supplement its water yield from the boreholes. The latest development is that also VVU considers a reconnection (before the Oyibi Water Supply Scheme was established, the GWCL delivered water to VVU) to this pipeline. Although the GWCL is responsible for large towns, these interrelationships make it to an important stakeholder for VVU's water management and vice versa.

3.5.2.5 District Assemblies

At the local level the highest political authority are the District Assemblies. They have to ensure sustainable water services. Their duties are among others:

- Provision of legal frameworks for community based water supply schemes
- Supporting Water Boards (see 5.3.2.2)
- Ensure that Water Boards run financially sound
- Examination of water tariffs
- Approve rules and regulations
- Monitoring of the quality of water supplied to the communities
- Monitoring of O&M

(UNKNOWN, s.a.)

3.5.2.6 Ghana Standards Board (GSB)

The GSB was established in 1967. It acts as national standards body on behalf of the Ministry of Trade and Industry with the mission 'to contribute towards the enhancement of the quality of life of people living in Ghana through the promotion of standardisation' (GSB, 2008).

The Board is responsible for:

- National standards development and dissemination
- Testing services
- Inspection services
- Product certification scheme
- Calibration. verification and inspection of weights, measures and weighing and measuring instruments
- Pattern approval of new weighing and measuring instruments
- Destination inspection of imported high-risk goods
- Promoting quality management systems in industry
- Advising the Ministry of Trade and Industry on standards and related issues

The Board has four divisions the Metrology Division, the Standards Division, the Testing Division and the Quality Assurance Division. Two of them are of particular importance when thinking of drinking water production. The Standards Division sets out standards, among others for water quality requirements for drinking. The Quality Assurance Division certificates locally manufactured products as long as they are conform to national or international standards. This applies also to sachet water production (GSB, 2008). VVU has to meet the Ghana Standards (see chapter 3.6.1) if sachet water production (5.2.2.15) is started.

The most important standards for drinking water and sachet water production are:

- Water Quality – Specification for Natural Mineral Water, GS 220: 2005
- Code of Hygienic Practices for the Collection, Processing and Marketing of Potable Water, GS 786: 2005
- Water Quality – Requirements for Drinking Water, GS 175 PT.1: 2005

3.5.2.7 Water Research Institute (WRI)

The WRI is an institution of the Council for Scientific and Industrial Research that was formed in 1996. It has the mandate to do research in the topics of water and related resources. Therefore, the "WRI generates and provides scientific information, strategies and services towards rational development, utilization and management of the water resources of Ghana in support of the socio-economic advancement of the country (…)" (WATER AND SANITATION MONITORING PLATFORM, 2009).

3.5.3 Directory of relevant stakeholders

Beside those stakeholders introduced above, numerous other institutions work on water or related topics. Previous to this study, their contact information was not available for the project partners.

To find information about stakeholders in the Ghanaian water sector, two good sources are available. One is the AQUASTAT Institution Database (FAO, 2009). In this database it is possible to search for water relevant institutions (government ministries/ departments/ agencies, bi-lateral development partners, multi-lateral development partners, networks/ coalitions/ consortium, international NGOs, Ghanaian NGOs, private manufacturers/ suppliers, research/ educational, private companies/ consultancies institutions, on-going WASH sector management projects) according to their type of organization or type of activity.

The other source was the Directory of Ghana's Water and Sanitation Sector (WSMP, 2009). The directory briefly describes institutions and states addresses and contact information.

For this research work the following stakeholder were helpful:

- CWSA
  - E-mail (see chapter 4.2.3) to info@cwsagh.org
  - Homepage: http://www.cwsagh.org
  - Address: CWSA, PMB, KIA – Accra
  - Telephone: 021-518401/ 518405
  - Communication with Mrs. Muhammed Andani Safuratu (Water and Sanitation Engineer) at CWSA headquarter, Accra

    Contact: safuratu2002@yahoo.co.uk

    Helpful concerning information about CWSA
- Environmental Protection Agency
  - E-mail (see chapter 4.2.3) to epaozone@Africaonline.com.gh, support@epaghana.org, epaga@epaghana.org
  - Homepage: http://www.epa.gov.gh
  - Address: P.O. Box M.326, Accra
  - Telephone: 021-231132/ 228711

- GSB
  - E-mail (see chapter 4.2.3) to gsbdir@ghanastandards.org and gsbnep@ghanastandards.org
  - Library with Ghana Standards
  - Homepage: http://ghanastandards.org/contact.php
  - Address: P.O. Box MB 245, Accra
  - 021-500231, 500065/6, 506992-6
- GWCL
  - E-mail (see chapter 4.2.3) to gwcl@africaonline.com.gh
  - Homepage: not found
  - P.O. Box M 194 – Accra
  - Telephone: 021-666781-7
  - Communication with GWCL at Dodowa about GWCL's water supply along the Adenta-Dodowa road
- International Water Management Institute
  - E-mail (see chapter 4.2.3) to iwim-ghana@cgiar.org
  - Homepage: http://www.iwmi.cgiar.org/
  - Address: IWMI, PMB CT 112, Cantonments, Accra
  - Telephone: 021-784752
- Oyibi Water Supply Scheme
  - Communication with the management at the scheme's site on June 9th, 2009, Oyibi, Ghana

    Helpful concerning information about the scheme

    Hardcopies of unpublished papers
- Programme Coordinators DANIDA (Danish International Development Assistance)
  - E-mail (see chapter 4.2.3) to verayi@um.dk, lalars@um.dk

    Referred to useful internet links about DANIDA projects.
  - Homepage: http://www.ambaccra.um.dk/en/
  - Address: Embassy of Denmark, Dr. Isert Road 67, North Ridge, P.O. Box CT 596, Accra
  - Telephone: 021-253473/ 4, 021-7011331

- WRC
  - E-mail (see chapter 4.2.3) to watrecom@wrc-gh.org

    The questions were not answered. However, when they were asked about literature that was stated at their homepage they referred to a library in their office. They probably have literature about the Densu River project.

    According to Ph.D. Dapaah-Siakwan (2009) this institution is mainly dealing with policy making. Therefore, the WRC was of no further relevance for this thesis.
  - Homepage: http://www.wrc-gh.org/
  - Address: Box CT 5630, Cantonments – Accra
  - Telephone: 021-763651/ 765860
- WRI
  - E-mail (see chapter 4.2.3) to info@csir-water.com
  - Homepage: http://www.csir-water.com/
  - Address: Box M32, Accra/ AH 38, Achimota – Accra
  - Telephone: 021-775351/ 775352/ 779514
  - Library
  - Collaboration with Dr. Issac O.A. Hodgson (Chemical Engineer) at WRI, Accra

    Contact: cgioah@yahoo.co.uk

    Helpful concerning water quality analysis
  - Communication with Ph.D. S. Dapaah-Siakwan (Head of Groundwater Division)

    Helpful concerning information about hydrogeology and groundwater assessment in Ghana

    E-mail: stephendapaah@yahoo.com

    Telephone: 021-779514/5

It has to be considered that governmental institutions (e.g.: GWCL, EPA,…) require written requests for interviews or communications in advance. Short-term visits without announcements are uncommon and often rejected. Thus, meetings should be requested far in advance.

3.5.4 Laws and guidelines

3.5.4.1 National Water Policy

The Ghana's National Water Policy aims to "achieve sustainable development, management and use of Ghana's water resources to improve health and livelihoods, reduce vulnerability while assuring good governance for present and future generations" (MINISTRY OF WATER RESOURCES, WORKS AND HOUSING, 2007). The government identified certain focus areas. Two are subsequently introduced.

Focus areas for water resources management:

- IWRM
- Access to water
- Water for food security

- Water for non-consumptive and other uses
- Financing
- Climate variability and change
- Capacity building and public awareness creation
- Good governance
- Planning and research
- International cooperation

Focus areas for community water and sanitation:

- Access to potable water
- Decentralised WS&S services
- Finance
- Hygiene education and sanitation
- Public private partnership
- Capacity building
- Gender mainstreaming and good governance
- Research and development
- Operation and maintenance
- Monitoring and evaluation

3.5.4.2 National Community Water and Sanitation Programme (NCWSP)

The government of Ghana launched the NCWSP in 1994. The CWSA was mandated to facilitate this programme in 1998 (CWSA, 2009).

The objectives of the NCWSP are:

- Provide access to water and sanitation services for rural communities and small towns in Ghana
- Ensure the sustainability of water and sanitation facilities provided
- Maximize health benefits by integrating water, sanitation and hygiene promotion

(CWSA, s.a.b)

Important principles are:

- Demand Responsive Approach
- Decentralized Planning, Implementation and Management
- Community Ownership and Management
- Community contribution to capital cost
- Private Sector provision of goods and services
- Public Sector facilitation
- Integration of hygiene promotion with provision of Water and Sanitation facilities
- Gender mainstreaming at all levels

- Collaboration and coordination with relevant stakeholders

(CWSA, s.a.b)

Beside the principles and objectives, the NCWSP gives operational suggestions, too. For O&M a Water and Sanitation Committee (WATSAN) is suggested, supported by Pump Caretakers and Area Mechanics. Beside that, a National Spare Parts Distribution Network exists (CWSA, s.a.b).

Moreover, the NCWSP suggests a project cycle including the following steps:

- Community mobilisation and sensitisation
- Health and hygiene promotion
- Participatory planning, design and construction
- Operation and maintenance
- Monitoring and evaluation

(CWSA, s.a.b)

3.5.4.3 Small Communities Water and Sanitation Policy

The overall objective of this policy is to improve pubic health and economic well being “through provision of adequate, safe and sustainable water for domestic and commercial purposes in a planned and coordinated manner, with integrated hygiene education and sanitation interventions” (CWSA, 2005). Furthermore, specific goals and principles are stated, as well as roles and responsibilities of different institutions like the Ministry of Works and Housing, the CWSA or the communities themselves. Strategic operational guidelines for standards, technology choice, promotion, sustainability, O&M and other issues are advised. Moreover, specific implementation strategies are given, for example for: community mobilization, participatory planning, design, sanitation, O&M and monitoring and evaluation. (CWSA, 2005)

This policy is not directly affecting VVU because it refers to communities with 2000 people or less. Nevertheless, it gives an idea of important considerations for establishing water technologies. Unfortunately a policy for small towns, which refers to 50000 people or less, does not exist.

3.5.5 The challenges of the water sector

Visions and goals targeting sustainability and sustainable development supplement Ghana’s water sector and its respective institutions, laws and guidelines. Therefore, the water sector incorporates internationally agreed goals concerning water management (see chapter 3.1.1). Projects, such as the climate project at VVU, aim to establish role models with best practice solutions for implementing sustainable WS&S.

However, there are still many challenges to come. Missing financial means, administrative capacity constraints, lack of experts and lack of knowledge leave little opportunities for fast progress and implementation. VVU for example, is profiting from development aid. Without it, the achievements would have been impossible. The water sector as a whole has set up a good basis for future development by implementing the mentioned policies. However, it should be seen as first step. A lot of improvement is still necessary to overcome the mentioned constraints and develop sustainable.

3.6 Water quality

This chapter briefly introduces the analysed water quality parameters. They were used (among others) during the research to determine the water quality at VVU. In chapter 3.6.1 the legal requirements of Ghana are compared with the Austrian requirements and WHO guidelines. In the later chapters, some background information is given for the parameters including:

- Occurrence
- Effects
- Guideline values

3.6.1 Water quality - requirements for drinking water

“The quality of drinking-water may be controlled through a combination of protection of water sources, control of treatment processes and management of the distribution and handling of the water. Guidelines must be appropriate for national, regional and local circumstances. This requires adaptation to environmental, social, economic and cultural circumstances and priority setting” (WHO, 2008).

The World Health Organisation (WHO) (2008) suggests a “framework for safe drinking water” containing five key points:

- Health-based targets
- System assessment
- Operational monitoring of the control measures
- Management plans
- Independent surveillance

In accordance to such considerations, parameters were chosen to assess the water quality. Table 3.6 compares physical, chemical and biological requirements for drinking water given by the GSB (2005a) (some values were obtained from GSB, 1998 as cited by OKIOGA, 2007), the WHO (2008) and the Austrian Drinking Water Ordinance (BUNDESKANZLERAMT ÖSTERREICH, 2008). The stated parameters (among others) were analysed during the research (see chapter 4.3.1).

Table 3.6: Comparison of drinking water requirements or guidelines given by the WHO, GSB and the Austrian government

	World Health Organization (WHO)	**GSB**	**Austrian Drinking Water Guideline**
Physicochemical parameters			
Ammonia [NH_3-N]	1,5 mg/l	1,5 mg/l	0,5 mg/l
Chloride [Cl]	200 – 300 mg/l	250 mg/l	200 mg/l
Iron [Fe]	0,3 mg/l	0,3 mg/l	0,2 mg/l
pH	6,5 - 8	6,5 - 8,5	6,5 – 9,5
Total hardness	Between 100 and 200 mg/l (= 11,2 – 16,8 German°)	500 mg/l (= 28 German°)	No threshold
Nitrite [NO_2]	0,2 mg/l (long-term exposure); 3 mg/l (short-term exposure)	3 mg/l	0,1 mg/l
Nitrite nitrogen [NO_2-N]	~ 0,06 mg/l (long-term exposure); ~ 0,9 mg/l (short-term exposure)	~ 0,9 mg/l	~ 0,03 mg/l
Nitrate [NO_3]	50 mg/l	50 mg/l	50 mg/l
Nitrate nitrogen [NO_3-N]	~ 11 mg/l	~ 11 mg/l	~ 11 mg/l
Manganese [Mn]	0,4 mg/l	0,4 mg/l	0,05 mg/l
Chlorine	0,6 – 1 mg/l	0,5 mg/l	(acceptable taste)
Turbidity	0,1 NTU (median) (= 0,1 FAU)	5 NTU (= 5 FAU)	1 NTU (= 1 FAU)
Microbiological parameters			
E. coli	0 in 100 ml	0 in 100 ml	0 in 100 ml
Enterococcus faecalis	No threshold	1000 in 100 ml	0 in 100 ml

3.6.2 Physicochemical parameters

3.6.2.1 Biochemical oxygen demand (BOD)

“This is the quantity of oxygen consumed at 20℃ an d in darkness during given period to produce by biological means oxidation of the biodegradable organic matter present in water” (DEGREMONT, 1991).

3.6.2.2 Chemical oxygen demand (COD)

“The COD indicates the total hot oxidation by potassium dichromate [inorganic chemical reagents] and covers the majority of organic compounds as well as oxidizable mineral salts” (DEGREMONT, 1991).

3.6.2.3 Chloride

Sources of chloride in drinking water can be natural, sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion. High chloride concentrations may increase corrosion rates in the distribution network, depending on the alkalinity of the water. This can increase the concentration of metals in the system (WHO, 2008).

Chlorides give a salty taste to water. Taste-based thresholds are in the range of 200-300 mg/l. Chloride naturally occurs in drinking-water at concentrations below those at which toxic effects may occur. However, they can affect acceptability. The WHO did not establish health-based guideline values (WHO, 2008).

3.6.2.4 Chlorine

Chlorine is industrially and domestically used as disinfectant and bleach. It is a widely used chemical disinfectant (chlorination, chloramination, use of chlorine dioxide) for drinking water and swimming pools due to its chemical reactivity. There is no established guideline value. Chlorine rapidly breaks down and the chlorite threshold guarantees no adverse health effects from chlorine, too (WHO, 2008).

The guideline value for chlorine is 5 mg/l. However, “for effective disinfection, there should be a residual free chlorine concentration of ≥0,5 mg/litre after at least 30 min contact time at ph <8,0. Chlorine residuals should be maintained throughout the distribution system. At the point of delivery, the minimum residual concentration of free chlorine should be 0,2 mg/litre” (WHO, 2008). However, the taste or smell threshold for drinking water lies already at concentrations around 0,3 mg/litre (WHO, 2008).

3.6.2.5 Dissolved oxygen

Source, temperature, treatment and chemical or biological processes within the distribution network influence dissolved oxygen. Depletion of dissolved oxygen can trigger microbial reduction of nitrate to nitrite and sulphate to sulphide, or cause increasing concentrations of ferrous iron and corrosion (WHO, 2008). Oxidation can be used as treatment before filtration, too. Then dissolved iron is oxidised to an insoluble precipitate that is filtered out (UNICEF, 2008). Anyhow, there is no health-based guideline value recommended by the WHO.

3.6.2.6 Electrical conductivity

Electrical conductivity is a parameter summing up dissolved and dissociated substances (for example salts). This value varies with the concentration of dissociated ions, the temperature and the migration of ions in the electric field. This parameter is often used for analysing and monitoring the quality of surface and groundwater (RUMP, 2000).

3.6.2.7 Hardness

Hardness naturally occurs in drinking-water at concentrations below those at which toxic effects may occur. However, it can affect acceptability. The WHO did not establish guideline values (WHO, 2008).

3.6.2.8 Iron

Iron occurs naturally in fresh waters in ranging from 0,5 to 50 mg/l. Moreover, it occurs in drinking water originating from iron coagulants or corrosion of the distribution network (WHO, 2008).

Anaerobic groundwater may show ferrous iron concentrations of several milligrams per litre. Ferrous iron oxidizes to ferric iron when exposed to the atmosphere. This supports colour changes to reddish-brown as well as growth of iron bacteria. Iron stains on laundry and plumbing fixtures occur at concentrations above 0,3 mg/l. Below that level turbidity and colour may appear (WHO, 2008).

Iron is of concern because it causes corrosion in the distribution system. Excessive corrosion leads to water quality problems (so called red water). Corrosion is usually triggered by dissolved oxygen. Metal oxidizes and forms a precipitate of iron. Other important parameters influencing this process are the pH-value and alkalinity. Moreover, calcium, chloride and sulphate have impacts on iron corrosion (WHO, 2008).

3.6.2.9 Manganese

Manganese occurs in the earth crust as well as in several products, food sources, surface water and groundwater sources (WHO, 2008).

Manganese levels of 0,1 mg/l or higher cause an undesirable taste and stains laundry and sanitary installations. Moreover, it easily accumulates in the distribution network. The acceptability threshold of 0,1 is four times lower than the suggested health based threshold (WHO, 2008).

3.6.2.10 Nitrogen compounds

Nitrite and Nitrate

Nitrate (NO_3) is a plant nutrient that often occurs naturally in the environment. Nitrite (NO_2) on the contrary is significantly present just in reduction processes, as nitrate is the most stable oxidation state (WHO, 2008). In aerobic environments, organic nitrogenous matter and ammonium salts are converted first to nitrites and then to nitrates, by bacteria consuming oxygen. This process is known as nitrification (DEGREMONT, 1991). However, nitrite can also be formed by microbial reduction of nitrate, chemically, in galvanized steel pipes of distribution networks during stagnation of nitrate containing and oxygen poor drinking water, or in case of chloramination (treatment with chlorine and a small amount of ammonia) for residual disinfection (WHO, 2008).

Nitrate often arises with excessive agricultural fertilization and leaching of wastewater or other organic compounds into water bodies. In comparison to surface water, groundwater usually shows slow concentration changes (WHO, 2008).

Nitrate and nitrite are among the chemicals that are considered to have the greatest health impacts in natural waters (beside arsenic and excess natural fluoride). Treatment is rather difficult as disinfection oxidizes the more toxic nitrite to nitrate (WHO, 2008).

Nitrate is considered to cause methaemoglobinaemia, or blue-baby syndrome, in bottle-fed infants. However, in absence of faecal contamination it is unlikely to occur. Nevertheless, water with concentrations higher than 11 mg/l should not be used for bottle-fed infants (WHO, 2008).

Ammonia

Ammonia is a common chemical used for agricultural and industrial purposes. Moreover, it occurs in metabolic processes and is used for chloramination. The term includes the non-ionized (NH_3) and the ionized (NH_4^+) species. It occurs in drinking water at concentrations below those, at which toxic effects may occur. Therefore, no guideline values have been established. However, thresholds for odour concentration (1,5 mg/l) and for taste (35 mg/l) have been suggested by WHO (2008). Ammonia is an indicator for bacterial, sewage and animal waste pollution. Furthermore, it can decrease disinfection efficiency or result in nitrite formation, and it can cause the failure of filters for removal of manganese (WHO, 2008).

3.6.2.11 Oxidation reduction potential

Water can take part in oxidation-reduction reactions. Two reactions are possible:

- $2H_2O - 4e^- \leftrightarrow 4H^+ + O_2$
- $2H_2O - 2e^- \leftrightarrow 2OH^- + H_2$

(DEGREMONT, 1991)

In the first reaction, water is a donor of electrons (= reducing agent). In the second reaction, water is an electron acceptor (= oxidant). Thus, in the presence of water an oxidant releases oxygen and a reducing agent releases hydrogen. Usually those reactions are very slow without any catalysts (DEGREMONT, 1991).

However, strong oxidants and reducing agents react more quickly. Therefore, the parameter of Oxidation Reduction Potential or Redox Potential compares oxidants and reducing agents, or the likelihood of water to gain or lose electrons. Moreover, Oxidation reduction reactions are used for water treatment processes with for example, Chlorine or Ozone. In those processes the amount of compounds like iron, manganese, ammonium, organic matter or chlorine is removed or decreased (DEGREMONT, 1991).

3.6.2.12 pH-value

The pH-value is defined as negative logarithm to the base 10 of the hydrogen ion activity. Pure water has a pH-value of 7, natural waters usually have between 6,5 and 8,5. Acids, alkalis, salts and CO_2 change the pH. Moreover, pH affects many chemical processes (RUMP, 2000).

PH-values in drinking-water are naturally below those at which toxic effects may occur. However, it is an important operational water quality parameter to assess microbial safety because more alkaline (higher pH) water requires longer disinfection or higher chlorine levels (WHO, 2008). Low pH (acidic) can damage metal piping or cause aesthetic problems due to metal ions like iron or manganese (APEC, 2009).

3.6.2.13 Phosphorous

Phosphorus can be found in nucleic acids, phospholipids and polymers of bacterial walls. In waste water it is present as orthophosphate, polyphosphate or organic phosphorus (DEGREMONT, 1991).

Natural waters usually have concentrations of less than 0,1 mg/l. Discharge of waste water and residuals from fertilisers increase phosphate concentrations, especially in still surface waters. This often leads to eutrophication, decreasing oxygen and it affects water treatment processes. Groundwater is usually not affected by phosphorus contamination because it is absorbed by soil particles before reaching the aquifer (RUMP, 2000).

3.6.2.14 Temperature

The temperature influences several processes, for example oxygen solubility, nitrification, eutrophication, sedimentation, biological reactions and for tropical countries relevant, mosquito breading. Lower water temperatures increase the acceptance of drinking water (FÜRHACKER, 2009). Higher temperature supports growth of microorganisms and may increase taste, odour, colour and corrosion problems (WHO, 2008).

3.6.2.15 Turbidity

Turbidity may originate from matter of the source water, from resuspension of sediments in the distribution system, from inorganic matter in groundwater or sloughing of biofilms within the supply network (WHO, 2008).

High turbidity adversely affects disinfection processes. Thus it protects microorganisms, stimulates growth of bacteria and increases the chlorine demand. Therefore, turbidity is an important parameter when measuring microbial safety. Moreover, it is an important operational parameter for process controlling and indicating of problems within the treatment processes (WHO, 2008).

The acceptability level is below 5 NTU; however, the median turbidity should be below 0,1 NTU to guarantee effective disinfection. No health-based threshold has been suggested (WHO, 2008).

3.6.3 Microbiological parameters

3.6.3.1 Enterococcus faecalis

Enterococcus faecalis is a species of intestinal enterococci which is a subgroup of faecal streptococci. A common characteristic of these organisms is that they are gram-positive and relatively tolerant to sodium chloride and alkaline pH levels. Therefore, they are more resistant to chlorine disinfection than for example E. coli. Intestinal enterococci are relatively specific for faecal pollution (WHO, 2008).

Intestinal enterococci or enterococcus faecalis are excreted in the faeces of humans or animals. Therefore, they show high concentrations in sewage and water polluted by sewage or wastes from humans and animals (WHO, 2008).

3.6.3.2 Escherichia coli (E. coli)

E. coli occurs in human and animal faeces, and in sewage and water that is polluted with faeces. E. coli are thermotolerant bacteria. Thus, they ferment lactose at 44-45 ℃ (WHO, 2008).

Like turbidity, E. coli (other thermotolerant coliform bacteria can be an alternative) is an important parameter for estimating microbial quality. As faecal indicator bacterium it shows recent faecal pollution. However, E. coli has limitations as enteric viruses and protozoa are more resistant to disinfection as E. coli. Therefore, an absence of E. coli does not imply an absence of these organisms (WHO, 2008).

The guideline value for E. coli is that it must not be detectable in any 100 ml sample of all water directly intended for drinking, treated water entering the distribution system and treated water in the distribution system (WHO, 2008).

4. Materials and methods

At the beginning, a short subchapter describes the general preparations for the research. Then the actual materials and methods are explained. The objectives given in chapter 2 are summed up in Table 4.1. Methods and secondary data are stated that were used to answer the objectives. However, as there were overlapping issues some methods contributed to more than one objective. Especially the methods for evaluating VVU's water management and the status of the existent water facilities were overlapping. These two issues are closely linked and they influence each other. Table 4.1 summarizes the methods used for the respective objectives. Subsequently, the method descriptions can be found in the related subchapters.

Table 4.1: Overview of used methods according to the respective objectives

Objectives	**Detailed objectives**	**Secondary data**	**Chapters & Methods**
Investigation of current WS&S at VVU	Water demand assessment (5.2 VVU's water balance)	Water meter data provided by Sarpong (2009b) IÖV (2006)	4.2.1 Water meter data 4.3.3 Public participation (Semi structured interviews) 4.3.4 On site-surveys
	Local water resources (qualitative and quantitative assessment) (5.1 VVU's water sources)	Water meter data of the consumption from the public water supplier and rainfall data provided by Sarpong (2009b) Information about pressure test for all three groundwater wells (SARPONG, 2009a) IÖV (2006)	4.1.1.1 Data as basis for research 4.2 Historical data 4.3.1 Water quality analyses 4.3.2 Data loggers 4.3.4 On site-surveys
	Evaluation of water management (5.2 VVU's water balance)	Water meter data provided by SARPONG (2009b) IÖV (2006)	4.1.1.1 Data as basis for research 4.2.1 Water meter data
	Evaluation of water facilities (5.2 VVU's water balance)	-	4.3.4 On site-surveys

Evaluation of planned solutions for sustainable water supply (development of rain water use)	Description of WS&S sustainability as a whole (3.1 Sustainable water management with special emphasize on developing countries)	EC (1998) JUNG (2008) GWP (2008) UN (1992a) UN (1992b) UNESCO (2004-2006) WCED, 1987	4.1.1.2 Recommendations for sustainable water management Literature review
	Description of WS&S sustainability at VVU (5.3. Water management)	ENHEALTH (2004) OYIBI WATER SUPPLY SCHEME (2009) GWP (2008) TUINHOF et al. (2002)	4.3.2 Data loggers 4.3.3 Public participation (Semi structured interviews) 4.3.4 On site-surveys Literature review
	Evaluation of implementing sustainable filtration technologies for water resources (5.4 Sustainable filtration technology)	EVERS (2006) GSB (2005b) SKY JUICE (2007 + 2009) UN-HABITAT (2005)	4.3.4 On site-surveys 4.4 Multi-Criteria Decision Making Literature review
	Investigation of the impact of WS&S projects at VVU (5.5 Impacts of water supply and sanitation projects at VVU)	GELLER (2009) GWP (2008)	4.3.4 On site-surveys Literature review

4.1 General preparation

For preparation, implementation and carrying out of the whole project the supervision of Dr. Dipl.-Ing. Perfler and especially M.Sc. Dipl.-Ing. Richard (both BOKU) was omnipresent. They provided necessary instruments and guidelines to conduct this research. Moreover, Richard partly attended the field studies and was the main project coordinator for water relevant issues on site.

4.1.1 Secondary data review

4.1.1.1 Data as basis for research

To achieve the objectives, the first step was to review secondary data. Data that had been available about VVU previous to this thesis were evaluated and examined. Project papers were read to gain a better understanding of the whole project and to know the state of knowledge. The most comprehensive and helpful project papers were:

- FRIES, N. (2006): Ecological Cycle Management at Valley View University in Accra, Ghana
- KRÄMER, S. (2007): Ecological Development of the Valley View University Accra, Ghana

- PALUTEC (2008): BMBF-Verbundvorhaben – Ökologische Kreislaufwirtschaft an der Valley View University Accra (Ghana)
- GELLER, G. and LARYEA, S.A. (2008): Cycles in the ecological development of Valley View University, Accra, Ghana, conference paper from the 33rd WEDC International Conference, Accra, Ghana

General Information was found at the homepage of IÖV (2009), too.

More specific information about water and sanitation at VVU was found in the diploma thesis of KRÄMER (2007), with the title "Ecological Development of the Valley View University Accra, Ghana – Optimization of water consumption and recycling of waste water", and in an Excel Sheet prepared by IÖV (2006). The IÖV (2006) did research on waste water accumulations, water consumption and possible nutrient collection (waste water) of specific buildings and the whole campus. The data were based on assumptions like frequency of toilet utilization, shower times, wash basin utilization or laundry washing of one person per day.

Whereas the previous literature was useful for understanding the project, the following literature was used to get a knowledge basis for aspects of sustainable water management, including environmental, social and economic circumstances affecting VVU. The most important facts of this literature research can be found in chapter 3.

For getting an insight into policies, stakeholders, relevant institutions and policies, the following articles give a good insight into Ghana's water management sector:

- CWSA (2005): Small Communities Water and Sanitation Policy (draft)
- CWSA (2007): Board Draft, Update of the Strategic Investment Plan, 2008 – 2015 & The Medium-Term Plan, 2008-2012
- DOE, H.W. (2007): Assessing the Challenges of Water Supply in Urban Ghana: The case of North Teshie, master thesis, Stockholm
- GSB (2008): Ghana Standards Board, Online on the internet: URL: http://ghanastandards.org/about/about.html [call 22.06.2009]
- MINISTRY OF WATER RESOURCES, WORKS AND HOUSING (2007): National Water Policy, Government of Ghana
- WRC (2008a): Water Resources Commission, Online on the internet: URL: http://www.wrc-gh.org/waterresourcescommission.php [call 21.04.2009]
- ZEF (2005): Integriertes Wasserressourcenmanagement im Densu-Einzugsgebiet (Ghana) – Wissens- und Technologietransfer, Schlussbericht, Bonn

Information about geology, hydrology and soils in the area surrounding VVU can be found in:

- FRIES, N. (2006): Ecological Cycle Management at Valley View University in Accra, Ghana
- DARKO, P.K., BARNES, E.A. and Sekpey, N.K. (1995): Groundwater assessment of the Accra Plains, WRI, Accra Ghana
- ERDELYI, M. (1965): The hydrogeology of Ghana. Bull. Int. Ass. Scient. Hydrol. 10
- FIANKO, J.R. et al. (2009): The hydrochemistry of groundwater in the Densu River Basin, Ghana, Environ Monit Assess, Springer Science + Business Media B.V.
- KORTATSI, B.K. et al. (2008): Reconnaissance Survey of Arsenic Concentration in Ground-water in South-eastern Ghana, West African Journal of Applied Ecology, Vol. 13, Ecological Laboratory University

Additionally, a communication at the WRI with DAPAAH-SIAKWAN, S., the head of the Groundwater Division on October 22nd was also very helpful. He gave information about hydrogeology and groundwater wells in the Greater-Accra Region.

More specific information about water quality from boreholes as well as hand dug wells can be found at:

- DARKO, P.K., BARNES, E.A. and Sekpey, N.K. (1995): Groundwater assessment of the Accra Plains, WRI, Accra Ghana

The extend of rainwater use in the peri-urban area of Accra, the advantages and disadvantages, indicating results of rainwater quality as well as other important considerations for rainwater harvesting can be found in the Master thesis:

- LUNDGREN, A. and AKERBERG, H. (2006): Rainwater harvesting in the peri-urban areas of Accra: status and prospects, Master Thesis, Stockholm, Sweden

A good insight into environmental considerations can be found in the articles:

- YANKSON, P.W.K. and GOUGH, K.V. (1999): The environmental impact of rapid urbanization in the peri-urban area of Accra, Ghana, Danish Journal of Geography 99:89-100, Geografisk Tidsskrift
- EPA (2009): EPA's Field Operations, Field Operations & Plans, Greater Accra Region, Ghana, Environmental Protection Agency, Accra, Ghana, Online on the internet: URL: http://www.epa.gov.gh/site/index.php?option=com_content&task=view&id=31&Itemid=38 [call 14.09.2009]

The homepage briefly describe among other topics agriculture:

- GREATER ACCRA COUNCIL (2007): The Greater Accra Region, Ghana's capital region, Agricultural Development, Accra, Ghana, Online on the Internet: URL: http://greateraccrarcc.gov.gh/index.htm [call 14.09.2009]

Information about population and growth rates is available at:

- ADLAKHA, A. (1996): Population Trends: Ghana, U.S. Department of Commerce, Economic and Statistics Administration, Bureau of the Census, Washington, USA
- UN (1960-2000): Demographic Yearbook, Department of Economic and Social Affairs, New York, USA

Regional information about the Greater Accra Region's population and economy can be found on the homepage:

- MINISTRY OF LOCAL GOVERNMENT AND RURAL DEVELOPMENT (2006): Greater Accra Region, Demographic Characteristics, Online on the internet: URL: http://www.ghanadistricts.com/home/ [call 14.09.09], Marks Publications and Media-Services, Accra Ghana

Beside that, general papers or lectures about sustainable water management have been read or attended. The most important were:

- EC (1998): Towards sustainable water resources management: a strategic approach, Office for Official Publications of the European Communities, Brussels, Belgium
- UN (1992a): Dublin Statement on Water and Sustainable Development, United Nations, International Conference on Water and the Environment, January 31st, Dublin, Ireland, Online on the internet: URL: http://www.un-documents.net/h2o-dub.htm [call 16.07.2009]

- JUNG, H. (2008): Angepasste Technologien in der Wasserversorgung und Siedlungshygiene in Entwicklungsländern, summer semester 2008, presentation, Institute of Sanitary Engineering and Water Pollution Control, University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria

4.1.1.2 Recommendations for sustainable water management

The Global Water Partnership ToolBox (GWP, 2008) was used to get ideas for the improvement of VVU's water management. It is an open database, with a collection of case studies and best practices, related to integrate water management. It can be used for projects at local, regional, national or global level. It gives ideas and recommendations for IWRM.

The ToolBox (GWP, 2008) has three major sections, namely the enabling environment, institutional roles and management instruments. Each section is divided into sub-sections with different tools, contributing to the goals of the sub-section and the respective major section.

According to the challenges (see chapter 5.3.2.1) VVU is facing, tools for improvement were looked for. The enabling environment applies to policies, the legislative framework and financing and incentive structures. Thus, it can be seen as given. However, the sections about institutional roles and management instruments give recommendations suitable for VVU. So, those recommendations were adapted to support VVU (see chapter 5.3.2).

According to the findings and observations that were made during the field study, management recommendations are given. For groundwater, management recommendations of the World Bank Group (TUINHOF et al., 2002), and for rainwater management recommendation of the Australian Government (ENHEALTH, 2004), were revised and adapted for VVU and summarized in a "Management Plan for water management at VVU" (see Table 5.41).

4.1.2 Work plan for field study

A field study was conducted in May and June (May 14th, 2009 – June 19th, 2009) and from October to December (October 11th, 2009 – December 11th, 2009). In accordance with the project partners and the SIG, BOKU, a work plan for the research at VVU was developed prior to the field study. This work plan was derived from the objectives and is subsequently introduced. The related objectives (see chapter 2) are highlighted in the work plan.

- Evaluation of VVU's existing **water management** scheme and **water demand**
    - Aspects of demand management (which resources for which purpose and who consumes)
    - An updated forecast for midterm future demand
    - Balance of water abstraction from different resources and various uses (actual and future assessment)
- Evaluation of actual status of VVU's **water facilities** (tab water supply, rain water harvesting and use, wastewater/ grey water treatment and re-use, sanitation including urine diversion and composting toilets)
    - Compilation of existing data and information
    - Set up of a simple field testing equipment
    - Sampling and analysis of performance data (quantity, quality and efficiency) at existing water facilities
    - Evaluation of all data

- Investigation of quantity and quality of water abstraction from three boreholes at VVU (**local water resource**)
    - Collection of data and documentation on borehole drilling
    - Implementation of logging systems to measure temperature, electric conductivity, water level and abstraction rate
- Investigation of **sustainability aspects** referring to the investment, operation and maintenance of existing and actually planned water facilities
    - Proposal of selection criteria for the implementation of different water technologies
    - Proposal for education and training of involved staff
    - Proposal for a management plan for the different water facilities
    - Proposal for the implementation of water related subjects into academic education and research at VVU

4.2 Historical data

Historical data were provided by VVU. Most of these data were obtained by Sarpong (2009a) and some additional information was obtained by the university's administration (student and staff numbers).

4.2.1 Water meter data

In June 2006, VVU started with weekly water meter readings that were taken by the pump attendant. At the beginning, few buildings had water meters but steadily new ones were installed. Now, almost all buildings have water meters but not all are functioning. Some water meters broke and some were removed or disconnected during the field study. Moreover, new ones were installed occasionally.

On behalf of the project, new water meters were installed at the three groundwater wells during the field study. They should measure exact extraction rates; therefore, help to estimate VVU's overall water consumption, by adding them up with the water consumption from the Oyibi Water Supply Scheme.

The readings have been saved (Annex 1) and statistically analysed in Microsoft Excel until the date May 20th, 2009. The average weekly water consumption was estimated for the buildings at VVU. The results are expressed as average weekly consumption, either during the semester, the summer school or during summer school and semester combined. Although several readings are missing, they are appropriate for estimating the water balance and giving an idea of future increase. For the period from May 20th until August 12th just few water meter readings were available. Afterwards, they were taken continuously again but in a new Microsoft Excel file (Annex 2). Sven Frenzel, a student from the University of Giessen (one of the project partners), set up the new file. Additionally, daily water meter readings were taken, starting on October 19th until November 5th, during the second field study at VVU. Daily meter readings (Annex 3) were used to present consumption patterns within a week. Readings from August and September were used to compare the results obtained by previous readings.

4.2.2 Rainfall data

Rainfall data were collected from a weather station report of September 2004 until October 2007 (see Annex 4). No other rainfall data were useful. The available data were used for estimating a monthly average; furthermore, to calculate the amount of collected rainwater on roofs or surface areas. For calculating the harvested rainfall, formula 4.1 was used:

Rainfall = roof/ area size * precipitation / 1000 * runoff coefficient (KRÄMER, 2007) (4.1)

The runoff coefficient was defined with 0,75, implying 25% losses through evaporation on the roofs and losses in the pipes and tanks (see KRÄMER, 2007).

4.2.3 Experts query

As it was rather hard to find project papers and data which gave appropriate information about VVU and its surroundings, several institutions were contacted per e-mail to gather more data. As the e-mail query did not bring good results, some institutions were visited and experts were questioned directly. The obtained information was mainly used for chapter 3. As it was an open communication, the questions used were slightly adapted to the particular person interviewed. The following questions provided the basis for the interview:

- Do you have any data (quality, quantity,...) related to groundwater/ groundwater body/ groundwater aquifer at VVU, Oyibi, Accra or Dodowa or about the Greater Accra region?
- Do you have any data related to the geology in this region?
- Do you have any data related to population growth in the Greater Accra region or any mid-term or long-term forecasts concerning water demand in the future (in connection with population growth)?
- Do you have any data, reports or papers related to rainwater harvesting (including rainwater quality/ drinking water quality)?
- Do you have any information related to impacts on the environment (especially water sources like groundwater and rainwater) in Ghana or the Greater Accra Region?

4.3 Field-study at Valley View University

A field study was conducted in May and June (May 14th, 2009 to June 19th, 2009) and from October to December (October 11th, 2009 to December 11th, 2009). The aim of this field study was to gather information and data. It was important to find affordable and practical solutions for the research conducted at VVU that would develop capacities for water analyses. Economic aspects are the most important for VVU. Necessary equipment was supplied by the project consequently low running costs relevant. This approach should guarantee good research and provide a long term and sustainable benefit for VVU.

4.3.1 Water quality analyses

The main purpose of the water analysis was to estimate water quality of VVU’s water sources.

To find a suitable method for assessing the water quality, two trial days were conducted at the beginning of the field study. The idea was to estimate the number of sample sites and parameters that could be analysed within two days or less. The outcome was a protocol (see Annex 5) for water quality analyses that should be conducted on two days.

4.3.1.1 Sample sites

After the trial, following ten sample sites were chosen:

- Cafeteria (rainwater)
- Borehole 1 (groundwater)
- Borehole 2 (groundwater)
- Borehole 3 (groundwater)
- Main Reservoir (mixture of groundwater from the wells at VVU and the wells of the public water supplier)
- Guest House (rainwater)

- Guest House - outflow of sand filter (black water)
- New Faculty Building/ Columbia Hall (rainwater)
- Women's Dormitory (mixture from Main Reservoir and rainwater)
- Women's Centre (mixture from Main Reservoir and rainwater)

These ten sample sites represent the whole spectrum of water sources, except the sole public water supply and grey water. However, public water is always mixed with groundwater in the Main Reservoir, before it is distributed into VVU's water network. Moreover, the public water supplier has its own quality measurements; thus, the water quality should be conform to GSB drinking water requirements. Hence, an overall picture of the university's water quality can be achieved.

4.3.1.2 Field measurements

Depending on the accessibility, the water was fetched directly with water bottles, or with a bucket from where it was filled into bottles. Bucket and bottles were washed twice in the respective water, before the actual sample was taken. This prevents contaminations from previous samples.

The field measurements were conducted with a HACH HQ40d portable meter. When possible, direct measurements were carried out in the tank, when not, then in the bucket. Following parameters were estimated on site:

- pH -Value
- Electrical Conductivity [µS/cm]
- Temperature [℃]
- Oxygen [mg/l] and [%]
- Oxidation Reduction Potential [mV]

Additionally, the water level in the tank (surface of water to top of tank) and the sampling time was noted.

4.3.1.3 On site laboratory measurements

A provisory one was set up in the EcoTec Centre (an administrative centre for ecological enquires and responsibilities) because the university does not have its own. The chemical waste water was collected in a container and a place for safe waste disposal was found. The Legon University (Chemical Department) takes care of the waste water in their central treatment system.

At the beginning of the research, it was planned to estimate eleven parameters with the spectral photometer HACH DR/890 Portable Colorimeter, plus 2 additional parameters with other HACH measurement equipments (5B Hardness Test Kit HACH and HACH Test Kit Model 8-P), at all ten sights. Because of the long lasting analysis, the final number of parameters was reduced to eight plus two (Table 4.2). Chlorine (free and total) was estimated for two sites only (Main Reservoir and Women's Dormitory) and no laboratory measurements were done for the sites Cafeteria and Guest House (both rainwater).

The estimation procedures are all quite similar. The HACH COMPANY (1997-2005) "Procedures Manual" states procedure names, determinable concentration ranges and method numbers. It also gives exact descriptions of the analysis steps for each parameter. The samples were analysed on the same day according to manual. Since the black water samples had concentrations a lot higher than the preset ranges, the samples had to be diluted to achieve good results for NO_2-N, NO_3-N, PO_4^{3-} and NH_4-N. The used dilutions were 1:30 for NO_2-N, 1:10 for NO_3-N, 1:50 for PO_4^{3-} and 1:200 for NH_4-N. The dilutions had to be adapted occasionally because of varying concentrations. Furthermore, special consideration was given to the unstable parameters chlorine (free and total) and iron (ferrous). These parameters were analysed as soon as possible after sampling.

Table 4.2 presents the measured parameters with their ranges, method numbers and estimated detection limits (EDLs). Furthermore, it is stated if powder pillows were used. The EDL is important because it implies the lowest detection limit. Values equal to or larger than the EDL are different from zero, values lower than the EDL can be zero. According to HACH COMPANY (1997-2005) the EDL "is the calculated lowest average concentration in a deionised water matrix that is different from zero with a 99% level of confidence." In other words it is the lowest concentration differing from zero that can be determined with a 99% level of confidence. Therefore, a value equal to or exciding the EDL implies a 99% occurrence likelihood of this parameter.

Table 4.2: Water quality parameters estimated on site (HACH COMPANY, 1997-2005)

Parameter/ Procedure Name	**Range [mg/L]**	**Method Number**	**Powder Pillow**	**Estimated Detection Limit (EDL)**
Chlorine, Free	0 to 2,00	8021	Yes	0,02 mg/l
Chlorine, Total	0 to 2,00	8167	Yes	0,02 mg/l
Iron, Ferrous	0 to 3,00	8146	Yes	0,03 mg/l
Nitrate, High Range (NO_3^--N)	0 to 30,0	8039	Yes	0,8 mg/l
Nitrite, Low Range (NO_2^-N)	0 to 0,350	8507	Yes	0,005 mg/l
Nitrogen, Ammonia (NH_3-N)	0 to 0,50	8155	Yes	0,02 mg/l
Phosphorus, Reactive (PO_4^{3-}P)	0 to 2,50	8048	Yes	0,05 mg/l
Turbidity	0 to 1000 [FAU]	8237	No	21 FAU
Hardness	-	5B Hardness Test Kit HACH	Yes	-
Chloride, Cl^-	5 to 400	HACH Test Kit Model 8-P	Yes	-

Different from previous analyses undertaken by WRI and BOKU laboratory that express their results in NH_4-N (nitrogen, ammonium), the HACH laboratory measures NH_3-N concentrations. However, the conversion factor is rather small (1 mg/l NH_3-N ~ 1,06 mg/l NH_4- N according to the sum of the atomic masses). Thus, the results are compared without conversion. Nevertheless, in chapter 5.1 all results are stated as NH_4-N.

For the qualitative evaluation of the water sources with the portable HACH laboratory, it has to be considered that the EDL was rarely exceeded for several parameters. Especially the turbidity (21 FAU) and the concentrations of ammonium nitrogen (0,02 mg/l), nitrate nitrogen (0,8 mg/l), nitrite nitrogen (0,005 mg/l), chlorine (0,02 mg/l) and iron ferrous (0,03 mg/l) were very low for the groundwater, rainwater and mixed water (groundwater and rainwater) sources. Comparing the EDLs of the parameters, with values of the drinking water requirements, it has to be considered that the threshold given for turbidity (WHO: 0,1 FAU, GSB: 5 FAU) is below its EDL. Thus, the measures cannot be taken for a proper comparison in those cases.

Problems occurred during orthophosphate phosphorus measurements. Some maximum values might be wrong because multiple analyses of the same sample differed greatly sometimes. The reason could be interfering reactions with remaining reagents of the analysis conducted before.

It has to be considered that the accuracy of chloride values measured with the HACH Test Kit is poor. The results are obtained by adding drops of a solution into the sample until a colour change occurs. One drop equals 20 mg chloride per litre (concentrations > 100 mg/l).

Additionally, to the wide range per drop, the colour change was not always properly detectable.

Another problem occurred with deionised water. First, distilled water was bought at a petrol station. After analysing the deionised water, a rather high electrical conductivity value was (approximately 500 µS/cm) observed; therefore, this water was not used. It is not as pure as the sachet water that is sold on campus as drinking water. Thus, the sachet water was used instead of deionised water for dilutions and water analyses.

Problems occurred also with finding an appropriate location for conducting the analyses because VVU does not have a laboratory. Thus, a place in the EcoTec Centre was provided without running water and poor working conditions. Beside that, the reagents could not be kept in an appropriate place. They have to be stored in a cool place between 10℃ and 25℃. The best place at VVU, was a fridge in the EcoTec Centre, facing regular electricity break downs and occasional higher temperatures.

Beside several disadvantages of portable water laboratories, they are appropriate for VVU's purposes. The advantage of portable water laboratories are their handiness. They are compact and can be carried easily. Moreover, a company distributing HACH products is located near VVU. The handbook, HACH DR/890 Datalogging Colorimeter Handbook (HACH COMPANY, 1997-2005), clearly describes all necessary steps for analysing different parameters in English. Thus, instructing other people at VVU worked well. The Ecological Sanitation Manager and a student of VVU were successfully trained in using the laboratory and they carried on the analyses. The price (0,2€ - 1€ per analyses) of reagents for HACH DR/890 is lower than the compared price (1€ - 4,5€ per analyses) of reagents for another similar portable laboratory called HACH LANGE cuvette test. However, the handling of HACH DR/890 is more difficult because powder pillows are used instead of cuvettes. In this case the economic aspect was more important than advantages in easier handling of reagents and better accuracy.

4.3.1.4 Verification of the analysis

To verify the results obtained with the portable laboratory and to estimate other chemical and microbiological parameters which could not be measured with the laboratory, cooperation with a Ghanaian institute was planned. Two institutions conducting water analysis were found in Accra, the WRI and the GWCL. After a quotation request, the decision was to cooperate with the cheaper WRI. Moreover, the WRI has had already experience in the Oyibi region. However, the previously planned eight sampling days, were reduced to two because of financial reasons.

The WRI took samples on two days (three weeks in-between) at 9 sample sites. Unfortunately, Borehole 3 was not working and no samples could be taken. At the same time, separate samples were also analysed with the usual procedures (field measurements and laboratory measurements) to compare the results directly with the Water Research Institute.

The WRI had to estimate the chemical parameters ammonia (NH_4-N), nitrate (NO_3-N), nitrite (NO_2-N), ortho-phosphate (PO_4^{3-}) and iron. Moreover, the Institute also analysed BOD, COD (for black water only) and manganese (excluding rainwater only sites) as well as the microbiological parameters e. coli and enterococcus faecalis.

Additional samples were taken to Austria (frozen samples once on June 23rd, 2009), where they were analysed by SIG, BOKU.

As the first comparison of results obtained by the WRI and the on site measurements (June 16th, 2009 and July 7th, 2009) varied largely, additional direct comparisons were made between the WRI, on site measurements and the BOKU laboratory (samples from October 16th, 2009 see chapter 5.1). Furthermore, standard solution tests were conducted with the portable HACH laboratory.

4.3.2 Data loggers

Five data loggers were purchased for the project. Then they were brought to VVU, where they were supposed to be installed on site. Unfortunately one logger, the Barologger Gold (Barometer) got lost. The others will deliver useful data and help to set adequate measures for further improvement of VVU's water management. As the data loggers were installed during the field study, just few data are used in this thesis. However, incentives how to use and interpret the data is given.

The data loggers are Leveloggers from the company Solinst. Solinst provides one software programme that can be used for all three types of loggers. Each of the loggers has a certain number of readings that can be stored, and a certain battery life that is depending on the sampling rate. The data can be downloaded on a computer and the sampling rate can be adjusted via the software. Subsequently, the data loggers are briefly described.

4.3.2.1 Rainfall

"The Rainlogger is designed for use with most standard tipping-bucket rain gauges with a reed switch output. It measures total rainfall per sampling period and a five-minute maximum rainfall (intensity)" (SOLINST, 2009).

The Rainlogger has following specifications:

- Battery life: 10 years (logging two parameters/ 10 minutes)
- Maximum number of readings: 40,000 sets of readings
- Sampling rate: 5 minutes to 99 hours

The Rainlogger and the tipping-bucket (see Figure 4.1) were set up near the EcoTec Centre. It is not affected by near trees or high buildings and is situated on a podium, in a height of about 0,5 meters, to achieve unaffected and correct results.

The Rainlogger was set to a sampling rate of 5 minutes and to a fifteen-minute maximum rainfall sampling. In the dry season, the sampling rate should be adapted to about 15 minutes. Monthly data download was advised as well as regular checks of the tipping-bucket.

Figure 4.1: Tipping-bucket and rainlogger

The Rainlogger "will provide the total rainfall within the sample interval. It does so by multiplying the number of tips within the interval by the tipping bucket's calibration factor. The calibration factor is the amount of rainfall depth [mm] per tip" (SOLINST, 2009).

The fifteen-minute maximum rainfall readings "are of maximum 5 minute peak intensity within the sampling interval. This rainfall intensity value is derived by subdividing the sample interval into 5 minute sub-intervals and temporarily recording the number of tips each 5 minute sub-interval. The Peak intensity reading is calculated by multiplying the number of tips in the 5 minute interval with the largest number of tips by 12 and presenting peak intensity/hr" (SOLINST, 2009).

4.3.2.2 Groundwater

A LTC Levelogger Junior was installed in each borehole. One Barologger was supposed to be installed for data compensation. Unfortunately this device got lost at VVU.

The LTC Levelogger Junior measures the water level, temperature and electrical conductivity (specifications can be found in Table 4.3). "Water levels are displayed as temperature compensated pressure readings, and can be barometrically compensated with the aid of a Barologger Gold" (SOLINST, 2009).

"The Barologger Gold uses algorithms base on air pressure only. It measures and logs changes in atmospheric pressure, which are then used to compensate water level readings recorded by a Levelogger (…)" (SOLINST, 2009).

Table 4.3: Specifications of LTC Levelogger Junior and Barologger Gold

	LTC Levelogger Junior	Barologger Gold
Battery life	5 years (5 minute sampling rate)	10 years (1 minute sampling rate)
Maximum number of readings	16.000	40.000
Sampling rate	5 seconds to 99 hours	0,5 seconds to 99 hours

The installation of these devices turned out to be very complicated because the pumps had to be lifted out of the wells. A specialist team for groundwater wells had to come for the installation. It was decided to connect the loggers to direct read cables to ease the data collection. When the installation problems were solved, the sampling rate was set to 5 minutes.

4.3.2.2 Software

All types of dataloggers can be connected to a computer via an optical reader cable. The provided "Solinst Software Version 3.3." is a convenient programme to transfer information. Levelogger settings and logging sessions can be operated. Moreover, data are illustrated and they can be downloaded as well as saved. For better storage of data they were exported into Microsoft Excel (see Annex 6 +7).

4.3.3 Public participation

"[Public Participation] has been broadly conceived to embrace the idea that all 'stakeholders' should take part in decision making and it has been more narrowly described as the extraction of local knowledge to design programs off site' (JENNINGS, 2000). There exist several different approaches with the common goal, to achieve sustainable development through involvement and personal responsibility.

This thesis follows the Rapid Rural Appraisal (RRA) approach. One precondition is multidisciplinary team work (JENNINGS, 2000) which was conducted during the research at VVU. This was fulfilled by Laurent Richard, employee of BOKU who is specialized in water treatment and water quality analyses, Daniel Sarpong, Ecological Sanitation Manager at VVU and Benjamin Lauterböck, student of BOKU, specialized in water management. Moreover, the team conducted regular meetings with the responsible persons Dr. Perfler (BOKU) and Mr. Kwandahor (Head of EcoTec Centre). Thus, a broad spectrum of relevant water issues and social or cultural aspects was covered by the research team. Following RRA techniques were applied during the research:

- Use of secondary data
- Quantitative data collection in a short time frame (Water quality measurements, data loggers)
- Semi-structured interviews

The first two methods were previously explained in chapter 4.1.1, 4.3.1 and 4.3.2. The remaining method is subsequently explained.

Semi-structured interviews or communications were conducted with relevant water stakeholders on and off campus (off campus see 4.2.3). Therefore, meetings with the responsible persons at CWSA, the Oyibi Water Supply Scheme and the WRI were held. Additionally, interviews or communications were conducted with following people at VVU:

- Head of the EcoTec Centre
- Ecological Sanitation Manager
- Generator and Pump Attendant
- Plumber
- Caretakers of the guest houses, the women centre and the women dormitory
- Student's Dean Assistants
- Water lorry driver

The interviewees were chosen to guarantee a broad spectrum of the stakeholders on campus. On one hand specialists, and on the other hand people presenting the interests of users were questioned. This should lead to a sustainable improvement of the water system accepted by all people.

Depending on the occupation, the interview was set up differently with general questions about consumption or management patterns. However, the main goal was to find out:

- What could be improved?
- What are the main problems?
- Do you have any recommendations, wishes?

4.3.4 On site surveys

Several findings are based on personal on site surveys. They were conducted to evaluate the status of existing water facilities. Therefore, inspections of roof gutter connections, rainwater tanks, pumps and water meters were conducted.

As the research process was closely linked to actual work at VVU, the administrative and management system of the university was investigated, too. These observations were used and considered for recommendations given in this thesis.

4.4 Multi-criteria decision making

To find the right unit for sustainable water treatment at VVU, a simple multi-criteria decision making technique was applied (adapted from EDWARDS, 1971). The method is called SMART (Simple Multi-Attribute Rating Technique) and is based on numerical ratings. The attributes of the alternatives are ranked by giving the best 100 and respectively less to worse attributes. Then they are interpolated to get a utility value. Formula 4.2 expresses the overall utility of each alternative:

$$U_i = \sum cw_a * iw_x * rating_i / (\sum_i^n rating_i) \qquad (4.2)$$

U_i… Utility of alternative i

cw_a…weight of criteria a

$iw_{x\ldots}$ weight of indicator x

Different approaches were chosen to define relevant criteria, find appropriate indicators and appropriate alternatives. The alternatives were predefined by the SIG according to its research project at VVU. The SIG (2009) was testing four different alternatives of filters, namely SkyHydrant^{TM}, Rain-PC^{TM}, Evers Easy Filtration® and a sand filtration unit. The objective of this bench test was to find the most appropriate filter unit for the purposes at VVU. Therefore, the units were fed with groundwater that was contaminated with various loads of waste water. The effluent’s quality was analysed at SIG. Moreover, O&M requirements were tested and investigated.

Surveys and investigations during the field study at VVU, the respective research project at the SIG and literature reviews were used to define different sustainability criteria and indicators.

5. Results

5.1 VVU's water resources

This chapter describes VVU´s water resources. It includes qualitative and quantitative data collected prior to and during the climate project.

At the time of writing, VVU water resources could be divided into 5 categories:

1. groundwater from the Oyibi Water Supply Scheme
2. groundwater from 3 wells/boreholes located within the campus
3. rainwater harvested within the campus
4. own wastewater (grey water, treated black water, yellow water) which is then reused
5. water provided by a lorry from the Ghana Water Company

It is worth mentioning that a future connection with a transfer pipe of the GWCL is being discussed. This pipe transfers Volta river water from Kpong. It is located along Dodowa Road, where VVU is situated.

Whereas rainwater and waste water are collected and used (or reused) directly on site, waters from the Oyibi Water Supply Scheme and the groundwater wells are mixed in the Main Reservoir. The Main Reservoir consists of a 225m³ concrete tank with two chambers of equal dimension. From the Main Reservoir, water is pumped into the 45m³ water tower located between the new Baobab Centre and the Faculty Building/ Columbia Hall (see Figure 5.1). From there, it is supplied to all buildings within the campus.

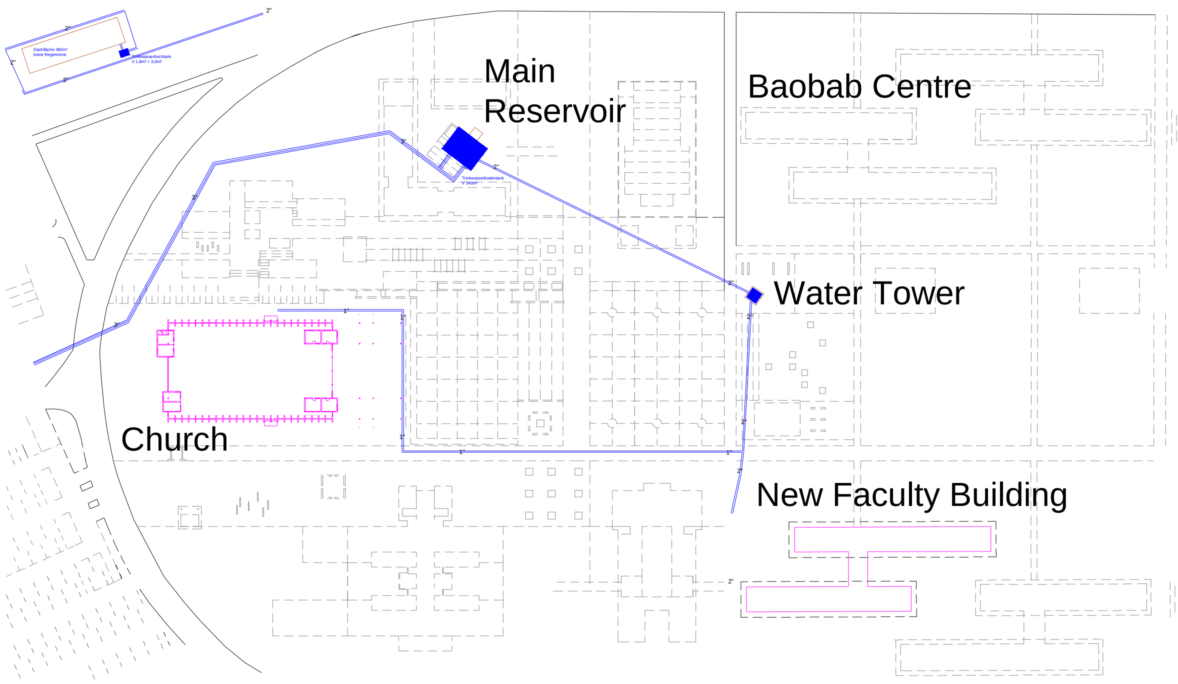

Figure 5.1: Location of Main Reservoir and Water Tower (GLÜCKLICH AND MEYER, 2006, adapted by LAUTERBÖCK, 2009)

This thesis deals with the measurements in the period from May 19th, 2009 until December 8th, 2009 and the parameters that were introduced in chapter 3.6. All measurements (including additional parameters measured by the BOKU LAB and the WRI as well as measurements before the stated period) can be found in the Annex 8.

5.1.1 Public water supply – Oyibi Water Supply Scheme

Quantitative evaluation

Between June 2006 and May 2009, VVU had an estimated average weekly consumption of 318m³ water from the public supplier. The scheme charges 1,65 GhC/m³ (1GhC ~ 2,09€). That equals monthly expenses of about 525 GhC. During semesters, the average weekly water consumption is higher (325m³) than during summer school (286m³).

Figure 5.2 shows VVU's average weekly consumption from Oyibi Water Supply Scheme starting on June 28th, 2006 and ending on May 13th, 2009. Remarkable is that the supply is highly irregular due to electrical or facility breakdowns (see also Figure 5.3), and that the overall trend is negative (it has to be considered that R^2 is very low). Especially during school year 2006/2007, consumption was still around 390m³/week, whereas in school years 2007/2008 and 2008/2009, it dropped to 305m³/week. The groundwater wells that were drilled at the beginning of 2008, do not seem to be the only reason for the decreasing water demand of VVU. A comparison of the average weekly consumption before and after 2008 (since then the groundwater wells have been used), showed a reduction of weekly water consumption from the Oyibi Supply Scheme of less than 20m³/ week. The graph shows that especially since March 2007, the consumption is mainly lower than before. It is likely that the amount of delivered water is decreasing because of supply constraints due to increasing population (see chapter 5.3.2.2). However, the most important fact is that although the student number is increasing, the water consumption from the Oyibi Water Supply Scheme is slowly decreasing.

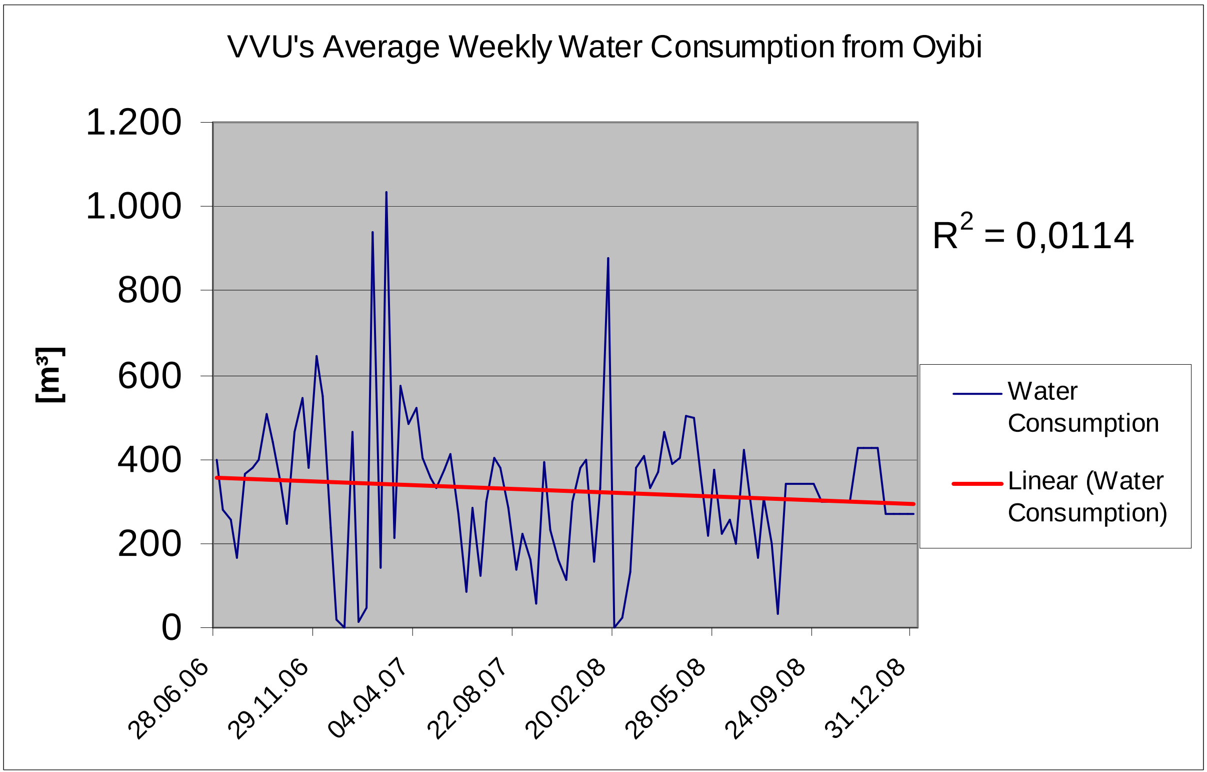

Figure 5.2: VVU's average weekly water consumption from the public water supplier (June 28th, 2006 – May 13th, 2009)

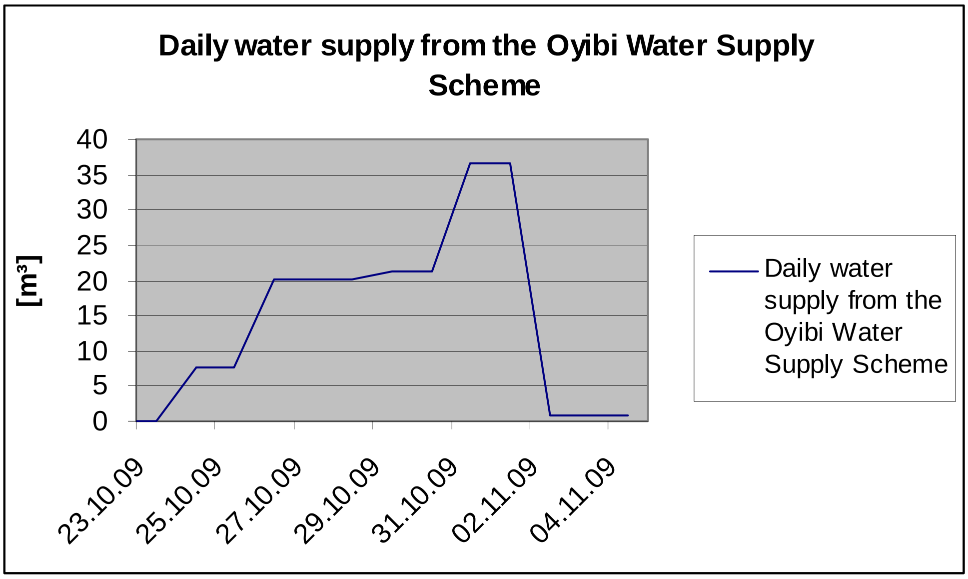

Figure 5.3: Daily public water supply to VVU

<u>Qualitative evaluation</u>

It was not possible to analyse the quality of water supplied by the Oyibi Water Supply Scheme. The water is directly led into the Main Reservoir, were it is mixed with water from the groundwater wells. However, SARPONG (2009b) handed over results of water analyses (see chapter 3.4.2.2) carried out at the two wells of Oyibi Water Supply Scheme.

According to the OYIBI WATER SUPPLY SCHEME (2009) the water quality is assured by the GWCL. They analyse the scheme's water quality three times a year. According to these measurements, the water is conform to the WHO guidelines and GSB requirements for drinking water. Moreover, chlorine is added for disinfection on a weekly basis.

Table 5.1, Table 5.2 and Table 5.3 show the results of the Main Reservoir's water analyses conducted in the course of the project.

Table 5.1: Comparison of water quality analyses of the Main Reservoir [1]

Laboratory	Comment	pH [2]	NH_4-N [mg/l] [2]	NO_3-N [mg/l] [2]	NO_2-N [mg/l] [2]	PO_4-P [mg/l] [2]	Cl [mg/l]	Tot./ Diss. Fe [mg/l] [2]	Tot./ Diss. Mn [mg/l]	Tot. Hardness [dH°]
On site	Median	6,4	<0,02	1,2	<0,005	0,5	160	<0,03	Not measured	8
On site	Standard deviation	0,2	-	0,6	0,002	0,6	17	0,03		2
On site	Maximum	6,9	<0,02	2,2	0,007	2,1	200	0,09		12
On site	Minimum	6,2+	<0,02	<0,8	<0,005	0,4	140	<0,03		6
On site	Samples	16	12	14	15	11	13	14		15
BOKU lab	13.03.09	7,7	<0,03	0,2	<0,003	-	114	0,11	0,013	13
BOKU lab	23.06.09	8	0,04	1	<0,003	1	99	0,04	0,019	5
BOKU lab	28.07.09	7,5	0,1	0,4	0,003	0,05	118	0,05	0,056	9
WRI	16.06.09	Not measured	<0,001	0,25	0,015	6,36	Not measured	$0{,}03_{Tot.}$	$0{,}04_{Tot.}$	Not measured
On site	16.06.09		<0,02	1,2	0,005	0,42		<0,03	-	
WRI	07.07.09		<0,001	0,211	0,009	4,00		$<0{,}01_{Tot.}$	$0{,}05_{Tot.}$	
On site	07.07.09		<0,02	1,1	0,005	0,36		<0,03	-	
On site	16.10.09	6,4	<0,02	-	<0,005	-	160	<0,03	-	10
BOKU lab	16.10.09	-	<0,03	0,6	<0,003	<0,02	120	0,004	0,04	8

[1] On site analyses were conducted between May 20th, 2009 and December 8th, 2009
[2] Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water

Table 5.2: Water quality of the Main Reservoir measured on site [3]

	Temperature [°C]	Dissolved Oxygen [mg/l]	Dissolved Oxygen [%]	Electrical Conductivity [µS/cm]	Oxidation Reduction Potential [mV]	Chlorine free [mg/l] [4]	Chlorine total [mg/l] [4]	Turbidity [FAU] [4]
Median	28,8	7	92	5981	148	<0,02	0,02	<21
Standard deviation	0,9	0,5	23	44	115	0,02	0,02	-
Maximum	30,3	7,5	97	679	429	0,04	0,05	<21
Minimum	26,4	5,8	77	519	61	<0,02	<0,02	<21
Samples	16	16	16	15	16	14	14	13

[3] On site analyses were conducted between May 20th, 2009 and December 8th, 2009
[4] Values marked with < are lower than the detection limit

Table 5.3: Water quality of the Main Reservoir measured by BOKU or WRI

BOKU LAB		WRI [1]	
TOC	**COD**	**E. coli [CFU/100ml]**	***Enterococcus* [CFU/1ml]**
0,5	-	2+	1
0,2	0,2	0	0
0,7	1	-	-

[1] *Values marked with + are not conform to the Ghana Standard Board requirements for drinking water*

The pH values measured by the BOKU LAB were higher than measured on site. The chloride values measured by BOKU LAB are distinct. The median value of the BOKU measurements is significantly lower than the median value of on site measurements. Though, the direct comparison from the results of October 16th showed a higher chloride concentration measured on site (160 versus 120 mg/l). Two hardness values of the BOKU LAB measurements are not within the maximum and minimum range as measured on site. The direct comparison of on site measurements (10 °dH) and the BOKU lab (8 °dH) showed similar results. Dissolved ferrous values of the BOKU LAB are slightly higher than those measured on site. Total ferrous measurements of the WRI on the other hand were comparable to those measured on site. NO_3-N values differed significantly. The direct comparisons of samples analysed by WRI and on site differ by about 4 to 5 times. However, comparing those values with other measurements conducted by the BOKU LAB, both analyses could be correct. PO_4-P values of the WRI are about 11 to 15 times higher than the values for the same sample as measured on site. Comparing these results with other results of the BOKU LAB, the analyses conducted on site are more likely to be correct. Also the NO_2-N values measured by the WRI are 2 to 3 times higher than the results obtained on site. Again, the measurements conducted on site are more likely to be accurate when compared with the BOKU analyses. The direct comparison of on site measurements and the BOKU lab also showed similar results.

Despite the differences of the results, the drinking water requirements of the GSB were not met twice in all measurements. E. coli was detected once by the WRI and one pH value was under the recommended 6,5 when measured on site. The WHO recommends a minimum residual chlorine concentration of 0,2 mg/l at the point of delivery. The water mixture at the Main Reservoir (only water from the public supply scheme is likely to have residual chlorine) and not appropriate analysis circumstances (as Chlorine is very unstable it should be measured as soon as possible but even that often took about half an hour at VVU) explain the rather low chlorine concentration of 0,02 mg/l. It is likely that the actual chlorine value of the public water is higher before it is mixed with water from the groundwater wells.

5.1.2 Groundwater wells

VVU has three groundwater wells. The wells were drilled at the beginning of 2008. Whereas Borehole 1 and Borehole 2 are well functioning, there have often been problems with Borehole 3. Borehole 3 was so far not regularly used because it has high turbidity and iron concentrations. Additionally, the pump pf Borehole 3 was broken for a long period. The main reason is that VVU does not want to use it as long as the water is not treated. Thus, no water is extracted. BOKU took two samples from Borehole 3 before the field study. On October 21st, 2009, it was possible to repair the third groundwater well and some data were collected.

<u>Quantitative evaluation</u>

Previous to this study, practically no data about the groundwater wells were available. The Ecological Sanitation Manager (SARPONG, 2009a) estimated the depth of the wells to be 66m (Borehole 1), 67m (Borehole 2) and 60m (Borehole 3). All three pumps are connected to pipes with a 3 inch diameter. After the wells were drilled, a pressure test estimated the respective yields for a running time of 24 hours, divided by the possible running time the actual yield can be approximated (see Table 5.4).

Table 5.4: Yield of the three groundwater wells as estimated with a pressure test

	Borehole 1	Borehole 2	Borehole 3
Potential yield in 24 hrs [m³]	36	27	18
Running time [hrs]	12 - 14	4	2
Actual yield per day [m³/day]	18 - 21	4,5	1,5

At VVU, these estimations (potential yield in 24 hours) were considered to be actual yields. However, water cannot be extracted continuously. Wells and pumps are not deep enough. Thus, the water level decreases steadily with the extraction, until a pump switch (lower switch) stops the pump automatically so that it does not run dry. As soon as the second pump switch (upper switch) is covered with water, the pump automatically starts again. Whereas Borehole 1 can flow for 24 hours with almost no interruptions (see Figure 5.4, 09.10.28/ 06:00:00 until 09.10.29/ 06:00:00), Borehole 2 cannot be pumped continuously as the water level drops regularly to the lower switch (see Figure 5.5).

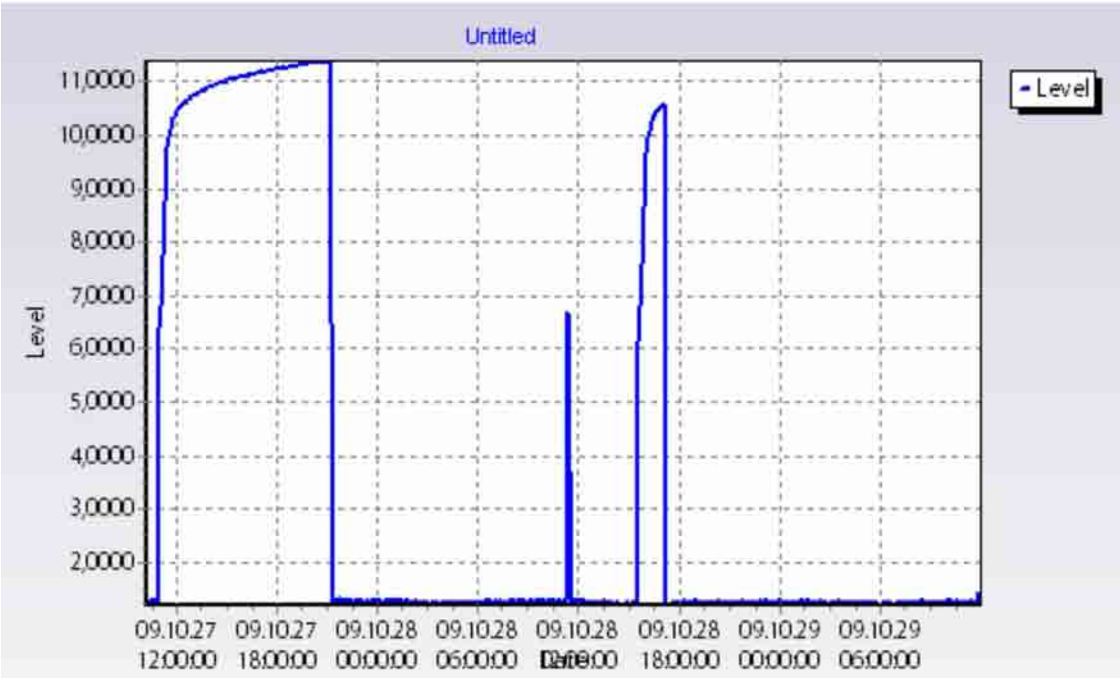

Figure 5.4: Pump operation of Borehole 1

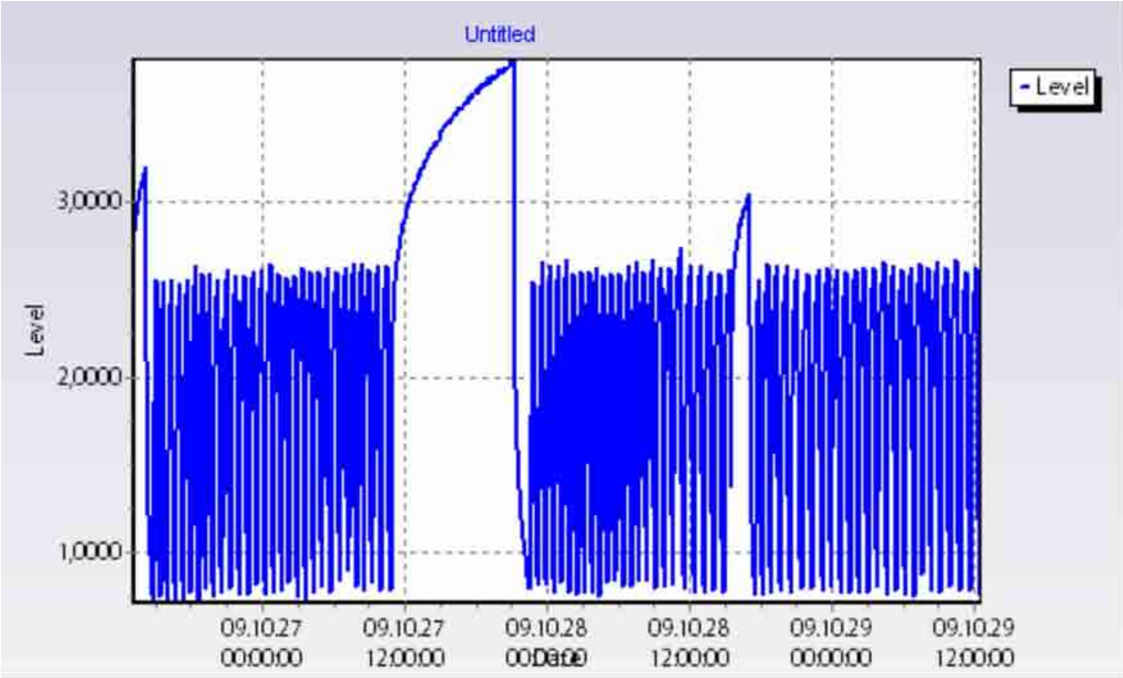

Figure 5.5: Pump operation of Borehole 2

Borehole 2 starts and stops about two to three times within one hour. The well can be pumped for about 15 to 20 minutes before the water level reaches the lowest pump switch (see Figure 5.6).

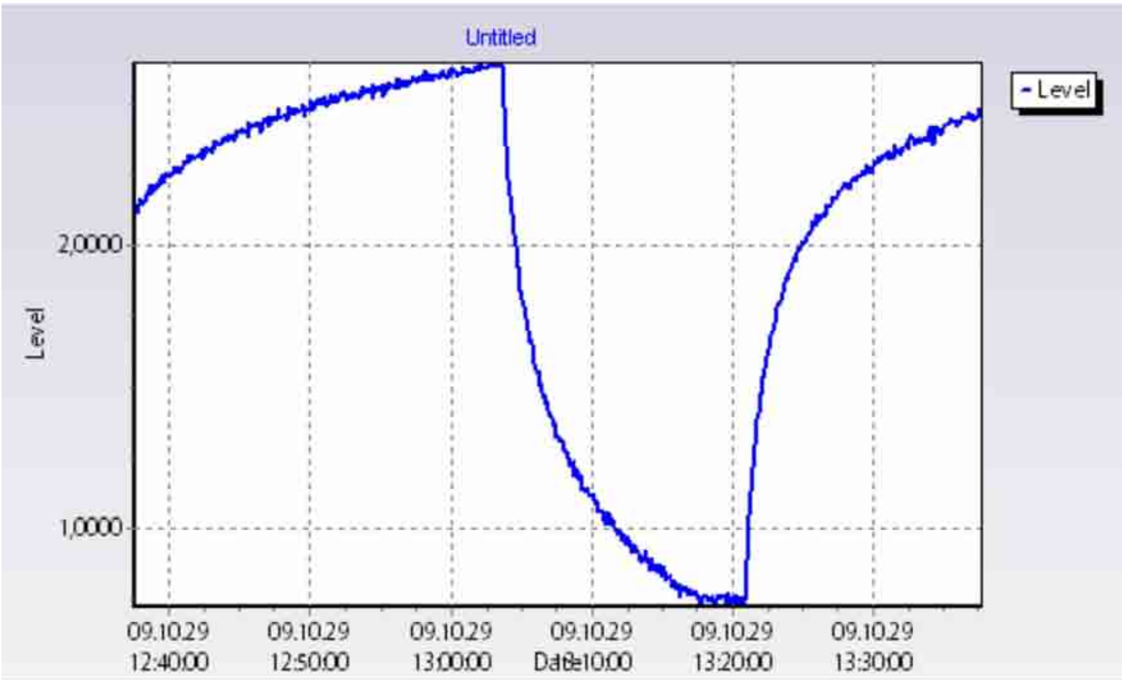

Figure 5.6: Flow period of Borehole 2

Beside water level measurements with the leveloggers, new water meters were installed to find out the actual extraction of the groundwater wells. Table 5.5 shows average weekly and daily extractions from the period of July 8th, 2009 until October 14th, 2009. All data can be found in Annex 9.

Table 5.5: Average weekly and daily water extraction from the three groundwater wells

	Weekly average [m³]	**Daily average [m³]**
Borehole 1	150,1	21,4
Borehole 2	44,0	6,3
Borehole 3	0	0
Sum	194,1	27,7

The water meter readings verify the results of the pressure test. Borehole 2 had an even better yield as estimated at the beginning. It has to be considered that the pump attendant occasionally turns off the pumps for a couple of hours during the day or during the night. Thus, a higher yield could be possible if these periods were shortened.

For Borehole 3, the yield was only observed. Water flow and pressure were very fluctuating. Sometimes the pressure was very high for a few seconds and then the flow suddenly stopped. Also the turbidity seemed very high and then rather low again. The time to get a yield of 0,01m³ was measured thrice. The time range was between 38 seconds to 205 seconds for 0,01m³. The yield per hour was estimated once with 0,6m³. Within the period from November 10th to November 23rd, Borehole 3 was operated as the other groundwater wells (Annex 9) with the exception that the water was neither collected nor used. During that time, daily water meter readings were taken. The daily yield was on average 6,8 m³ implying 47,3 m³ per week. Thus, Borehole 3 has a slightly better yield than Borehole 2. The results of the yield test are wrong.

<u>Qualitative evaluation</u>

As Borehole 3 was out of operation during the first field study, only data from two samples of earlier analysis by BOKU and some results of water analyses conducted during the second field study are available. Results of Borehole 1 and 2 are discussed more closely.

It has to be considered, that the groundwater is not used directly. It is always mixed with water from the public supplier in the Main Reservoir (see chapter 5.1.1) before it is distributed over VVU.

Table 5.6, Table 5.7 and Table 5.8 show the results of Borehole 1's water analyses conducted in the course of the project.

Table 5.6: Comparison of water quality analyses of Borehole 1

Laboratory	**Comment**	**pH** [1]	**NH_4-N [mg/l]** [1]	**NO_3-N [mg/l]** [1]	**NO_2-N [mg/l]** [1]	**PO_4-P [mg/l]**	**Cl [mg/l]**	**Tot./ Diss. Fe [mg/l]** [1]	**Tot./ Diss. Mn [mg/l]**	**Tot. Hardness [dH°]**
On site	Median	5,6+	<0,02	2	<0,005	1	160	<0,03	Not measured	4
On site	Standard deviation	0,1	-	0,7	-	1,5	18	-		1
On site	Maximum	5,7+	0,03	3,4	0,008	4,8	180	0,06		5
On site	Minimum	5,4+	<0,02	<0,8	<0,005	0,3	140	<0,03		3
On site	Samples	13	8	12	12	9	10	11		12
BOKU lab	13.02.09	5,6+	<0,03	1,6	<0,003	-	111	0,05	0,007	4
BOKU lab	13.03.09	5,5+	0,06	1,6	0,003	-	128	<0,02	0,006	4
BOKU lab	13.03.09	5,5+	0,02	1,5	<0,003	-	118	<0,02	0,006	3
BOKU lab	23.06.09	7,2	0,03	1,5	<0,003	1,5	109	0,02	0,006	4
WRI	16.06.09	Not measured	<0,001	2,60	0,002	3,75	Not measured	$0,03_{Tot.}$	$0,008_{Tot.}$	Not measured
On site	16.06.09		<0,02	3,4	<0,005	0,33		<0,03	-	
WRI	07.07.09		<0,001	0,27	0,018	4,10		$<0,01_{Tot.}$	$0,004_{Tot.}$	
On site	07.07.09		No analyse	No analyse	No analyse	No analyse		No analyse		
On site	16.10.09	5,5	<0,02	1,7	0,006		160	<0,03		5
WRI	16.10.09	5,4	<0,001	0,42	1	0,19	98,3	$0,06_{Tot.}$	$0,01_{Tot.}$	-
BOKU lab (right after pump start)	16.10.09	6,0	<0,03	1,5	<0,003	0,03	109,0	$3,24_{Tot.}$+	$0,02_{Tot.}$	4
BOKU lab	16.10.09	6,0	<0,03	1,5	<0,003	0,02	110,0	$0,48_{Tot.}$+	$0,01_{Tot.}$	4

[1] *Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water*
[2] *On site analyses were conducted between May 20th, 2009 and December 8th, 2009*

Table 5.7: Water quality parameters of Borehole 1 measured on site [1]

	Temperature [°C]	Dissolved Oxygen [mg/l]	Dissolved Oxygen [%]	Electrical Conductivity [µS/cm]	Oxidation Reduction Potential [mV]	Turbidity [FAU] [2]
Median	28,6	6,5	88	491	170	<21
Standard deviation	0,8	2,2	25	6	110	-
Maximum	30,7	7,4	100	507	442	<21
Minimum	27,6	1,2	29	485	90	<21
Samples	13	13	13	11	13	11

[1] *On site analyses were conducted between May 20th, 2009 and December 8th, 2009*
[2] *Values marked with < are lower than the detection limit*

Table 5.8: Water quality parameters of Borehole 1 measured by BOKU or WRI

BOKU LAB		WRI	
TOC	COD	E. coli [CFU/100ml]	*Enterococcus* [CFU/1ml]
0,2	-	0	0
0,6	-	0	0
0,3	-	-	-
0,2	0,2	-	-

NH_4-N values measured by BOKU LAB were slightly higher than those measured on site or at the WRI. However, all values were very low compared to drinking water standards (1,5 mg/l). NO_3-N levels measured by BOKU LAB were stable, whereas on site analyses or the WRI results showed great variations. The direct comparison from October 16th showed that on site measurements (1,7 mg/l) obtained similar results like the BOKU laboratory (1,5 mg/l), the WRI on the other hand was quiet wrong (0,42 mg/l). Similarly, the direct comparison showed rather large differences between BOKU lab (<0,003 mg/l) and the WRI (1 mg/l). On site analysis (0,006 mg/l) had a similar result as BOKU. PO_4-P measurements on site and of the WRI differed by more than 10 times. The direct comparison between BOKU (0,03 mg/l) and WRI (0,19 mg/l) showed rather high differences, too. Unfortunately, the PO_4-P reagent for on site analyses was empty. Thus, no direct comparison was possible. The chloride values measured by BOKU lab and the HACH Test Kit are quite different (see also chapter 4.3.1.3). Results of the WRI and the BOKU lab on the other hand were quite similar. Large differences were observed for ferrous concentrations. They were very low when measured by the WRI or on site, whereas the BOKU values were very high.

For the parameters measured, Borehole 1 fulfils the drinking water requirements of the GSB except for the pH values and the total ferrous concentration. The pH values were always, except once, below 6,5. However, as these pH values are not harmful for humans, this fact has to be considered mainly for technical and aesthetic purposes. Total iron exceed the drinking water standards twice (once distinctively).

Subsequently, the water quality of Borehole 2 will be stated in Table 5.9, Table 5.10 and Table 5.11.

Table 5.9: Comparison of water quality analyses of Borehole 2 [2]

Laboratory	Comment	pH [1]	NH_4-N [mg/l] [1]	NO_3-N [mg/l] [1]	NO_2-N [mg/l] [1]	PO_4-P [mg/l]	Cl [mg/l]	Tot./ Diss. Fe [mg/l] [1]	Tot./ Diss. Mn [mg/l]	Tot. Hardness [dH°]
On site	Median	5,5+	<0,02	1,3	<0,005	0,6	180	0,03	Not measured	6
On site	Standard deviation	0,1	-	0,5	-	0,4	38	0,08		1
On site	Maximum	5,7+	<0,02	1,8	<0,005	1,4	240	0,20		6
On site	Minimum	5,3+	<0,02	<0,8	<0,005	0,4	140	<0,03		5
On site	Samples	12	8	10	10	9	8	10		10
BOKU lab	13.02.09	5,6+	<0,03	0,9	<0,003	-	111	0,13	0,046	5
BOKU lab	13.03.09	5,4+	0,03	0,9	<0,003	-	128	0,02	0,04	5
BOKU lab	23.06.09	6,7	<0,03	1	<0,003	1	118	0,06	0,031	4
BOKU lab	28.07.09	5,9+	<0,03	0,8	<0,003	0,07	109	0,86+	0,037	5
WRI	16.06.09	Not measured	<0,001	0,41	0,006	5,15	Not measured	$0,08_{Tot.}$	$0,05_{Tot.}$	
On site	16.06.09		<0,02	1,1	<0,005	0,48		0,09	-	
WRI	07.07.09		<0,001	0,11	0,007	3		$<0,01_{Tot.}$	$0,01_{Tot.}$	
On site	07.07.09		<0,02	1,7	<0,005	0,5		<0,03	-	

[1] Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water
[2] On site analyses were conducted between May 20th, 2009 and December 8th, 2009

Table 5.10: Water quality parameters of Borehole 2 measured on site [3]

	Temperature [°C]	Dissolved Oxygen [mg/l]	Dissolved Oxygen [%]	Electrical Conductivity [µS/cm]	Oxidation Reduction Potential [mV]	Turbidity [FAU] [4]
Median	28,8	2,2	30	530	134	<21
Standard deviation	1,2	0,6	6	49	118	-
Maximum	32,3	3,7	42	691	437	<21
Minimum	27,7	1,1	19	525	43	<21
Samples	12	12	12	11	12	10

[3] On site analyses were conducted between May 20th, 2009 and December 8th, 2009
[4] Values marked with < are lower than the detection limit

Table 5.11: Water quality parameters of Borehole 2 measured by BOKU or WRI

BOKU LAB		WRI	
TOC	**COD**	**E. coli [CFU/100ml]**	***Enterococcus* [CFU/1ml]**
0,2	-	0	0
0,3	-	0	0
0,3	0,3	-	-
0,4	0	-	-

NO_3-N values of the WRI were remarkable lower than the measurements taken on site. Analyses conducted by BOKU LAB were also rather similar to those of on site analyses and to those of the WRI. NO_2-N values of the WRI were higher (0,006 and 0,007 mg/l) than all measurements conducted on site or the BOKU LAB (all under the detection limit <0,005 or <0,003). PO_4-P measurements of WRI exceeded those of on site analyses by 6 to more than 10 times. The results of on site measurements were similar to those of the BOKU LAB. The chloride values measured by BOKU LAB and the HACH Test Kit are also quite different (see also chapter 4.3.1.3).

Borehole 2 fulfils the drinking water requirements of the GSB, except for the pH values and one dissolved ferrous result. The pH was always, except once, below 6,5. Dissolved ferrous exceeded the required 0,3 mg/l with a concentration of 0,86 mg/l once. Moreover, the concentrations measured on site were rather high twice (0,2 and 0,19 mg/l).

As it was stated before, it was just possible to measure the water quality of Borehole 3 during the second field study (see Table 5.13). Additionally, some samples were taken during the first stay of BOKU (2009) at VVU (see Table 5.12).

Table 5.12: Water quality of borehole 3 measured by BOKU

pH	**NH_4-N [mg/l] [1]**	**NO_3-N [mg/l]**	**NO_2-N [mg/l] [1]**	**Cl [mg/l]**	**Tot. Hardness [dH°]**	**Diss. Fe [mg/l]**	**Diss. Mn [mg/l]**	**Tot. Fe [mg/l][1]**	**Tot. Mn [mg/l]**
5,6	<0,03	0,6	<0,003	113	5	-	-	15,6+	0,064
5,6	0,03	0,5	0,02	122	5	0,12	0,043	-	-

[1] *Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water*

The value of total ferrous (15,6 mg/l) is mentioned separately as it exceeds the recommended 0,3 mg/l by far.

Table 5.13: Water quality of Borehole 3 measured on site

Comment	**pH**	**Temperature [℃]**	**Dissolved Oxygen [mg/l]**	**Dissolved Oxygen [%]**	**Electrical Conductivity [µS/cm]**	**Oxidation Reduction Potential [mV]**	**Turbidity [FAU] [1]**
28.10.2009	5,5+	28,5	3,6	47,5	-	236	602+
03.11.2009	5,8+	29,8	6,7	93,0	483	110	113+
26.11.2009	5,5+	29,0	3,7	48,6	501	156	204+
01.12.2009	5,5+	28,2	2	27	486	175	275+
Median	5,5+	28,9	3,6	48	488	156	240+
Comment	**NH_4-N [mg/l]**	**NO_3-N [mg/l] [1]**	**NO_2-N [mg/l] [1]**	**PO_4-P [mg/l]**	**Chloride [mg/l]**	**Tot. Hardness [dH°]**	**Ferrous Iron [mg/l] [1]**
28.10.2009	0,5	<0,8	<0,005	-	160	5	0,37+
03.11.2009	-	1	<0,005	-	140	6	0,03
26.11.2009	-	<0,8	<0,005	0,89	-	6	0
01.12.2009	-	<0,8	<0,005	1,07	-	6	-
Median	-	-	-	1	150	6	0,2

[1] *Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water*

The problem of high turbidity and high iron concentrations is verified by these analyses.

All three groundwater wells showed iron concentrations exceeding the drinking water requirements. Borehole 3 had the highest total ferrous concentration with 15,6 mg/l, but Borehole 1 (3,24 and 0,48 mg/l) and Borehole 2 (0,86 mg/l) also exceeded the recommendations (0,3 mg/l) distinctively. A significant difference between the groundwater wells can be observed when looking at the dissolved oxygen content. Borehole 1 has an average of 88% compared to 30% of dissolved oxygen in Borehole 2 and 48% in Borehole 3. The rather low oxygen content in Borehole 2 can trigger microbial reduction of nitrate to nitrite or cause increasing concentrations of ferrous iron, thus corrosion.

5.1.3 Rainwater

As already mentioned in a previous chapter (see 3.5.1), VVU lies in a climatic, geographic zone with two distinct rainy seasons. The yearly average precipitation is 910mm. Figure 5.7 shows the average monthly precipitation measured on campus. For estimating the harvested rainwater, average precipitation of the period September 04 to October 07 was considered. For this time, the monthly rainfall data were complete. However, the yearly average is rather low with 851mm. This should avoid an overestimation. For more accurate estimations, more rainfall data would have been necessary. Nearby rainfall gauges cannot be used (Accra – at sea or Aburi – on mountain) because their rainfall differs from the rainfall around VVU.

The peaks in the rainy seasons (May – July and September – October) are obvious. However, rather high precipitation is also possible in March and April. Thus, the rainfall is considered for three periods. The dry period reflects months with rainfall under 35mm (December until February and August), the Semi-dry period are months with rainfall between 69 and 79mm (March, April, July and November) and the distinctive rainy season are months with rainfall exceeding 100mm (May, June, September and October) (see Figure 5.7).

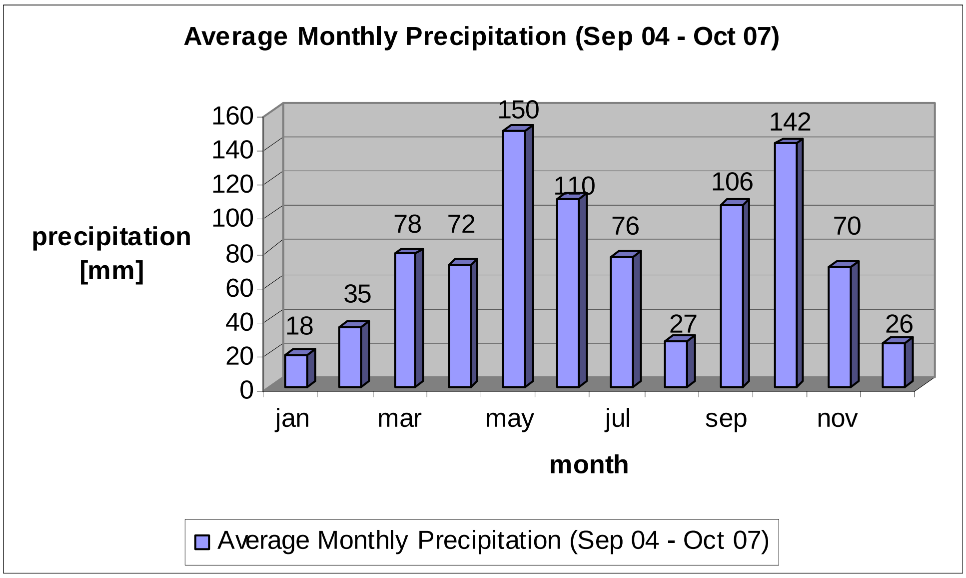

Figure 5.7: Average monthly precipitation as measured in the period: September 04 until October 07 at VVU (SARPONG, 2009b)

Rainwater is stored in underground tanks, next to the buildings were it is harvested. This source is either used in case of water shortage (no water from the main reservoir), as additional water supply to the groundwater from the Main Reservoir (Women Dormitory and Women Centre) or as process water (Sanitary Block at the Cafeteria, New Faculty Building).

<u>Quantitative evaluation</u>

Rainwater is collected at several buildings but the harvesting systems are not always functioning. Table 5.14 compromises all major buildings at VVU, states the actual status of rainwater harvesting systems and estimates the yearly average amount of collected rainwater per year (see also 5.2.2).

Table 5.14: Rainwater collection systems at VVU

	Cafeteria & Sanitary Block	**Administration Building**	**Bakery**	**8 Residential Houses**	**Faculty flats**	**J.J. Norty**
Gutters connected	Yes	Yes	No	5 out of 8	Yes	No
Rainwater tank	Yes	Yes/ Leaking/ Not in use	Yes/ Leaking/ Not in use	5 out of 8	Yes/ Leaking/ Not in use	No
Total roof size [m²]	1517	1077	480	1122	350	960
Connected roof size [m²]	1320 (87%)	324 (30%)	not connected	637 (56%)	not connected	not connected
Collected rainwater/ year [m³]	842	207	306	406 out of 715	223	613
Dry period: rainwater/ week [m³]	6,1	1,5	2,2	2,9 out of 5,2	1,6	4,4
Semi-dry period: rainwater/ week [m³]	16,8	4,1	6,1	8,1 out of 14,3	4,5	12,2
Rainy season: rainwater/ week [m³]	28,9	7,1	10,5	13,9 out of 24,5	7,7	21
	Guest houses	**Women centre**	**Women dormitory**	**New Faculty Building/ Columbia & Andrew Clark Hall**	**Baobab Centre surface & roof collection**	**New Men's Dormitory**
Gutters connected	Yes	Yes	Yes	Yes	Yes	No
Rainwater tank	Yes	Yes	Yes	Yes	Yes	No
Total roof size [m²]	340	1552	786	1495	1368	1785
Connected roof size [m²]	340 (100%)	400 (26%)	655 (83%)	1495 (100%)	1368 (100%) +1035,6	not connected
Collected rainwater/ year [m³]	217	255	418	953	872 + 705,1	1139
Dry period: rainwater/ week [m³]	1,6	1,8	3,0	6,9	6,3 + 4,8	8,2
Semi-dry period: rainwater/ week [m³]	4,3	5,1	8,3	19,0	17,4 + 13,2	22,7
Rainy season: rainwater/ week [m³]	7,4	8,7	14,3	32,7	29,9 + 22,6	39

5301 m³ of rainwater could be collected in one year if all buildings had a functioning system and if overflowing tanks are neglected. At the moment, 4256m³ or about 80% of rainwater harvesting systems are used. However, the actual use of rainwater is not 80%. At the Cafeteria for example, a pump broke, and since that no rainwater can be used at the Sanitary Block. Rainwater tanks of the residential houses are all, except one, not connected to the buildings. Thus, water is just fetched for irrigation purposes, sometimes in case of water shortage or it is not used at all. The overall perception was that rainwater is just used in case of water shortage but not regularly. So, the tanks overflow occasionally and water gets lost. Moreover, VVU prefers buying water from the public supplier to replacing pumps or repairing underground tanks. Thus, many broken rainwater harvesting systems remain unused for long.

Nevertheless, there are buildings at VVU that do not have rainwater harvesting systems. Beside some smaller buildings, the New Men’s Dormitory and the J.J. Norty Hall do not collect rainwater.

<u>Qualitative evaluation</u>

Rainwater harvesting is conducted at several buildings. Therefore, three different sites were chosen to analyse the rainwater quality. For rainwater collected at Columbia Hall/ New Faculty Building all parameters were analysed because this building is the major collector, distributor and user of rainwater. For two other rainwater harvesting sites, the Guest Houses and the Cafeteria respectively, only field measurements were conducted. In addition, the WRI and the BOKU laboratory conducted analyses.

There are two sites (Women Dormitory and Women Centre) where rainwater is mixed with water from the Main Reservoir. These two sites were also analysed and the results are stated in this part.

At the beginning, the rainwater quality at the New Faculty Building/ Columbia Hall is stated in Table 5.15, Table 5.16 and Table 5.17.

Table 5.15: Comparison of water quality analyses of the New Faculty Building/ Columbia Hall [2]

Laboratory	Comment	pH [1]	NH_4-N [mg/l] [1]	NO_3-N [mg/l]	NO_2-N [mg/l] [1]	PO_4-P [mg/l] [1]	Cl [mg/l]	Tot./ Diss. Fe [mg/l] [1]	Tot./ Diss. Mn [mg/l] [1]	Tot. Hardness [dH°]
On site	Median	8,1	0,02	1,2	<0,005	0,2	10	<0,03	Not measured	2
On site	Standard deviation	0,5	0,7	0,6	0,006	0,5	6	0,06		0
On site	Maximum	8,7+	1,99+	2,9	0,024	1,6	20	0,21		3
On site	Minimum	7,2	<0,02	0,7	<0,005	<0,05	3	<0,03		2
On site	Samples	12	9	10	10	11	9	11		11
BOKU lab	13.02.09	7,6	<0,03	0,7	<0,003	-	1	0,16	0,002	2
BOKU lab	13.03.09	7	0,1	0,9	0,02	-	2	<0,02	<0,002	2
BOKU lab	23.06.09	7,4	<0,03	0,6	<0,003	0,6	1	0,03	<0,002	1
BOKU lab	28.07.09	8,4	<0,03	0,7	0,009	0,05	2	0,04	<0,002	2
WRI	16.06.09	Not measured	<0,001	0,11	0,008	5,84	Not measured	0,02$_{Tot.}$	0,008$_{Tot.}$	
On site	16.06.09		<0,02	2,9	<0,005	0,33		<0,03	-	
WRI	07.07.09		<0,001	0,02	0,32	5,10		<0,01$_{Tot.}$	0,004$_{Tot.}$	
On site	07.07.09		-	1,7	<0,005	0,1		0,21	-	

[1] Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water
[2] On site analyses were conducted between May 21st, 2009 and December 8th, 2009

Table 5.16: Water quality parameters of rainwater at the Columbia Hall/ New Faculty Building measured on site [3]

	Temperature [°C]	Dissolved Oxygen [mg/l]	Dissolved Oxygen [%]	Electrical Conductivity [µS/cm]	Oxidation Reduction Potential [mV]	Turbidity [FAU] [4]
Median	27,4	4,9	65	70	146	<21
Standard deviation	1	17,3	10	26	127	-
Maximum	28,6	64,7	85	152	384	<21
Minimum	25,6	3,5	46	53	45	<21
Samples	12	12	12	12	11	10

[3] On site analyses were conducted between May 21st, 2009 and December 8th, 2009
[4] Values marked with < are lower than the detection limit

Table 5.17: Water quality parameters of rainwater at the Columbia Hall/ New Faculty Building measured by BOKU or WRI

BOKU LAB		WRI [1]	
TOC	**COD**	**E. coli [CFU/100ml]**	***Enterococcus* [CFU/1ml]**
0,7	-	0	5
1	-	372+	172
0,4	0,4	-	-
0,5	1	-	-

[1] *Values marked with + are not conform to the Ghana Standard Board requirements for drinking water*

At this site, two NH_4-N results of on site measurements differed distinctively. It is assumed that these two measurements (1,99 and 0,73 mg/l) are wrong due to analysing errors. NO_3-N values of the WRI differed from all other results. The WRI had the lowest values (0,11 and 0,02 mg/l), BOKU LAB was in the middle (from 0,6 to 0,9 mg/l) and on site analyses obtained the highest results with a median of 1,2 mg/l. Thus, the portable water laboratory comes closer to the BOKU LAB results than the WRI. NO_2-N are all similar, except one result of WRI (0,32 mg/l) that exceeds the result from the same sample analysed on site (<0,005 mg/l) and also, the highest values measured on site (0,024 mg/l) and at BOKU LAB (0,02 mg/l) distinctly. PO_4-P measurements of WRI exceeded results obtained on site by more than 50 times. The PO_4-P results of on site analyses were similar to those of the BOKU LAB. The chloride values measured by BOKU LAB and the HACH Test Kit were quite different again (see also chapter 4.3.1.3). The iron value from one sample of the WRI's measurements ($<0{,}01_{Tot.}$ mg/l) differed greatly with the on site analyses (0,21 mg/l) once. However, as both results could have been possible, when compared with results from BOKU, it cannot be identified which result was more accurate.

The rainwater collected at the Columbia Hall/ New Faculty Building fulfils the drinking water requirements of the GSB except for the E. coli counts (372 CFU/ 100 ml) and one pH value (8,7). To make this water safe for drinking, treatment would be necessary.

Subsequently, the Guest Houses' rainwater quality will be stated in Table 5.18, Table 5.19 and Table 5.20.

Table 5.18: Comparison of water quality analyses of the Guest Houses [1]

Laboratory	Comment	pH [2]	NH_4-N [mg/l] [2]	NO_3-N [mg/l]	NO_2-N [mg/l] [2]	PO_4-P [mg/l] [2]	Tot./ Diss. Fe [mg/l] [2]
On site	Median	9+	Not measured				
On site	Standard deviation	1					
On site	Maximum	9,6+					
On site	Minimum	5,8					
On site	Samples	14					
BOKU lab	13.02.09	9,1+	<0,03	1,3	<0,003	-	0,07
BOKU lab	23.06.09	8,5	<0,03	0,9	0,004	0,9	0,03
BOKU lab	28.07.09	8,4	<0,03	0,7	0,005	0,03	<0,02
WRI	16.06.09	Not measured	<0,001	0,26	0,008	2,61	<0,01
WRI	07.07.09		<0,001	1,60	0,021	<0,05	<0,01

[1] On site analyses were conducted between May 21st, 2009 and December 8th, 2009
[2] Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water

Table 5.19: Water quality parameters of rainwater at Guest House measured on site [3]

	Temperature [°C]	Dissolved Oxygen [mg/l]	Dissolved Oxygen [%]	Electrical Conductivity [µS/cm]	Oxidation Reduction Potential [mV]
Median	28,5	5	63,7	90	129
Standard deviation	1,1	0,9	11,3	81	96
Maximum	30,6	6,5	884	317	353
Minimum	26,8	3,8	49	71	63
Samples	15	14	14	15	14

[3] On site analyses were conducted between May 21st, 2009 and December 8th, 2009

Table 5.20: Water quality parameters of rainwater at the Guest House measured by BOKU or WRI

BOKU LAB [1]					WRI [1]	
Tot. Hardness [dH°]	**Cl [mg/l]**	**TOC**	**COD**	**Diss. Mn [mg/l]**	**E. coli [CFU/100ml]**	***Enterococcus* [CFU/1ml]**
9	1	0,3	-	0,002	465+	279
2	1	0,6	0,5	<0,002	72+	5
2	1	0,5	1	<0,002	-	-

[1] values marked with + are not conform to the Ghana Standard Board requirements for drinking water

One PO_4-P value of the WRI was explicitly higher than all other measured values.

The rainwater collected at the Guest House fulfils the drinking water requirements of the GSB except for the E. coli counts (465 and 72 CFU/ 100 ml) and pH values. To make this water safe for drinking, treatment would be necessary.

Subsequently, the Cafeteria's rainwater quality will be stated in Table 5.21, Table 5.22 and Table 5.23.

Table 5.21: Comparison of water quality analyses of the Cafeteria [1]

Laboratory	Comment	pH [2]	NH_4-N [mg/l] [2]	NO_3-N [mg/l]	NO_2-N [mg/l] [2]	PO_4-P [mg/l]	Tot./ Diss. Fe [mg/l]	Tot./ Diss. Mn [mg/l]
On site	Median	7,3	Not measured					
On site	Standard deviation	1						
On site	Maximum	7,4						
On site	Minimum	4+						
On site	Samples	11						
BOKU lab	13.02.09	6,7	<0,03	1	0,003	-	0,09	0,011
BOKU lab	23.06.09	6,8	0,04	0,8	0,003	0,8	0,03	0,008
BOKU lab	28.07.09	8,3	<0,03	0,6	<0,003	0,1	0,07	0,008
WRI	16.06.09	Not measured	<0,001	0,23	0,006	5,8	$0{,}03_{Tot.}$	$0{,}279_{Tot.}$
WRI	07.07.09		<0,001	0,43	0,105	5	$0{,}02_{Tot.}$	$0{,}186_{Tot.}$

[1] On site analyses were conducted between May 19th, 2009 and December 8th, 2009
[2] Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water

Table 5.22: Water quality parameters of rainwater at the Cafeteria measured on site [3]

	Temperature [℃]	**Dissolved Oxygen [mg/l]**	**Dissolved Oxygen [%]**	**Electrical Conductivity [µS/cm]**	**Oxidation Reduction Potential [mV]**
Median	26,7	4	51	45	118
Standard deviation	0,8	1,2	15,2	11	144
Maximum	27,9	4,8	58,6	76	440
Minimum	25,2	1,3	16	34	53
Samples	11	11	11	10	11

[3] On site analyses were conducted between May 19th, 2009 and December 8th, 2009

Table 5.23: Water quality parameters of rainwater at the Cafeteria measured by BOKU or WRI

BOKU LAB				WRI [1]	
Tot. Hardness [dH°]	**Cl [mg/l]**	**TOC**	**COD**	**E. coli [CFU/100ml]**	***Enterococcus* [CFU/1ml]**
7	3	0,7	-	279+	186
1	1,4	1,4	1,3	186+	252
1	2	0,9	1	-	-

[1] *Values marked with + are not conform to the Ghana Standard Board requirements for drinking water*

NO_3-N values of BOKU LAB and WRI differed slightly. NO_2-N values and PO_4-P values from the WRI were remarkable higher. The total manganese results of the WRI are much higher than the dissolved manganese results of the BOKU LAB.

The rainwater collected at the Guest House fulfils the drinking water requirements of the GSB except for E. coli counts (279 and 186 CFU/ 100 ml). The pH value was under 6,5 (GSB requirement) only one time.

Subsequently, the Women Dormitory's water quality will be stated in Table 5.24, Table 5.25 and Table 5.26.

Table 5.24: Comparison of water quality analyses of the Women Dormitory [1]

Laboratory	Comment	pH	NH_4-N [mg/l] [2]	NO_3-N [mg/l] [2]	NO_2-N [mg/l] [2]	PO_4-P [mg/l]	Cl [mg/l]	Tot./ Diss. Fe [mg/l] [2]	Tot./ Diss. Mn [mg/l] [2]	Tot. Hardness [dH°]
On site	Median	7,4	<0,02	1,2	<0,005	0,24	100	0	Not measured	5
On site	Standard deviation	0,2	-	0,8	-	0,5	49	-		2
On site	Maximum	7,7	0,12	3,4	0,050	1,7	200	0,04		11
On site	Minimum	7,2	<0,02	<0,8	<0,005	0,1	40	<0,03		3
On site	Samples	16	11	14	15	11	12	14		15
BOKU lab	13.02.09	7,4	<0,03	0,6	<0,003	-	96	0,17	0,007	8
BOKU lab	28.05.09	7	0,05	0,7	<0,003	-	51	<0,02	<0,002	5
BOKU lab	23.06.09	7,5	<0,03	0,4	<0,003	0,4	10	0,02	<0,002	2
WRI	16.06.09	Not measured	<0,001	0,24	0,006	5,64	Not measured	0,03 Tot.	0,015 Tot.	
On site	16.06.09		<0,02	1,6	<0,005	0,27		<0,03	-	
WRI	07.07.09		<0,001	0,45	0,014	6,00		<0,01 Tot.	0,012 Tot.	
On site	07.07.09		<0,02	1,2	<0,005	0,12		<0,03	-	
On site	16.10.09	7,2		-	0,012	-	120	-	-	
BOKU lab	16.10.09	-	<0,03	1	<0,003	0,02	83,8	-	-	

[1] On site analyses were conducted between May 21st, 2009 and December 8th, 2009
[2] Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water

Table 5.25: Water analyses of mixed water (rainwater and water from the Main Reservoir) at the Women Dormitory measured on site [3]

	Temperature [°C]	Dissolved Oxygen [mg/l]	Dissolved Oxygen [%]	Electrical Conductivity [µS/cm]	Oxidation Reduction Potential [mV]	Turbidity [FAU] [4]	Chlorine free [mg/l] [4]	Chlorine total [mg/l] [4]
Median	27,5	6,1	75	350	175	<21	<0,02	0,02
Standard deviation	1,3	21	27	161	82	-	-	-
Maximum	30,6	89	111	615	354	<21	<0,02	0,04
Minimum	25,5	3,5	1	122	102	<21	<0,02	<0,02
Samples	17	16	16	17	15	14	12	12

[3] On site analyses were conducted between May 21st, 2009 and December 8th, 2009
[4] Values marked with < are lower than the detection limit

Table 5.26: Water analyses of mixed water (rainwater and water from the Main Reservoir) at the Women Dormitory measured by BOKU or WRI

BOKU LAB		**WRI** [1]	
TOC	**COD**	**E. coli [CFU/100ml]**	***Enterococcus* [CFU/1ml]**
0,4	-	6+	2
0,6	-	168+	27
0,4	0,4	-	-

[1] Values marked with + are not conform to the Ghana Standard Board requirements for drinking water

NO_3-N values of the same sample varied greatly between the WRI and on site analyses. The results of the on site analyses were about 4 to 6 times higher. The WRI measurements come closer to the results of the BOKU LAB. NO_2-N values of the WRI and measured on site vary from 0,014 (WRI) to <0,005 (on site analyses). The BOKU LAB measurements were always under the detection limit of <0,003. The direct comparison of BOKU (<0,003) and on site analyses (0,012) showed a difference. PO_4-P results of the WRI and on site measurements differ greatly by 20 to 50 times. However, the lower values of on site measurements come close to the only PO_4-P measurement of BOKU lab. Chloride and hardness results differ also within the different laboratories. The reason could be the amount of rainwater in the respective sample. The direct comparison of chloride between on site measurements (120 mg/l) and BOKU (84 mg/l) was distinct (see also chapter 4.3.1.3). The water mixture at the Women Dormitory (only water from the public supply scheme is likely to have residual chlorine) and not appropriate analysis circumstances (as chlorine is very unstable, it should be measured as soon as possible but even that took often about half an hour at VVU) explain the rather low chlorine concentration of 0,02 mg/l. It is likely that the actual chlorine value of the public water is higher before it is mixed with water from the groundwater wells.

Rainwater collected at the Women Dormitory fulfils the drinking water requirements of the GSB except for the E. coli counts (6 and 168 CFU/ 100 ml). To make the water safe for drinking disinfection would be necessary.

Subsequently, the Women Centre's water quality is stated in Table 5.27, Table 5.28 and Table 5.29.

Table 5.27: Comparison of water quality analyses of the Women Centre [1]

Laboratory	Comment	pH	NH_4-N [mg/l] [2]	NO_3-N [mg/l] [2]	NO_2-N [mg/l] [2]	PO_4-P [mg/l] [2]	Cl [mg/l]	Tot./ Diss. Fe [mg/l] [2]	Tot./ Diss. Mn [mg/l]	Tot. Hardness [dH°]
On site	Median	7,4	<0,02	0,9	<0,005	0,5	150	<0,03	Not measured	10
On site	Standard deviation	0,2	-	0,6	0,002	0,4	32	-		2,6
On site	Maximum	7,8	<0,02	2,6	0,006	1,6	220	0,05		17
On site	Minimum	7,0	<0,02	<0,8	<0,005	0,3	100	<0,03		7
On site	Samples	16	11	14	15	11	12	14		15
BOKU lab	23.06.09	6,9	<0,03	0,5	<0,003	0,5	85	0,04	0,006	7
BOKU lab	28.07.09	7,5	<0,03	0,4	<0,003	0,04	109	0,03	0,004	10
WRI	16.06.09	Not measured	<0,001	0,24	0,014	4,24	Not measured	$0{,}09_{Tot.}$	$0{,}006_{Tot.}$	
On site	16.06.09		<0,02	<0,8	<0,005	0,36		0,05	-	
WRI	07.07.09		<0,001	1,14	0,017	4,00		$<0{,}01_{Tot.}$	$0{,}01_{Tot.}$	
On site	07.07.09		<0,02	1,1	<0,005	0,75		<0,03	-	
On site	16.10.09	7,4	-	-	<0,005	-	140	-	-	
BOKU lab	16.10.09	-	<0,03	0,8	<0,003	<0,02	116	$7{,}2_{Tot.}$	$3{,}9_{Tot.}$	

[1] On site analyses were conducted between May 21st, 2009 and December 8th, 2009
[2] Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water

Table 5.28: Water analyses of mixed water (rainwater and water from the Main Reservoir) at the Women Centre measured on site [3]

	Temperature [°C]	Dissolved Oxygen [mg/l]	Dissolved Oxygen [%]	Electrical Conductivity [µS/cm]	Oxidation Reduction Potential [mV]	Turbidity [FAU] [4]
Median	29,5	7,8	106	602	169	<21
Standard deviation	1,3	0,7	10	112	109	-
Maximum	31,6	8,2	110	814	438	<21
Minimum	26,9	6,3	81	333	86	<21
Samples	17	16	16	17	15	13

[3] On site analyses were conducted between May 21st, 2009 and December 8th, 2009
[2] Values marked with < are lower than the detection limit

Table 5.29: Water analyses of mixed water (rainwater and water from the Main Reservoir) at the Women Centre conducted by BOKU or WRI

BOKU LAB		**WRI [1]**	
TOC	**COD**	**E. coli [CFU/100ml]**	***Enterococcus* [CFU/1ml]**
0,4	0,3	0	6
0,6	1	34+	28

[1] *Values marked with + are not conform to the Ghana Standard Board requirements for drinking water*

NO_2-N values of the WRI and on site analyses vary from 0,017 (WRI) to <0,005 (on site). The BOKU LAB measurements were always under the detection limit of 0,003. Comparing on site (<0,005 mg/l) and BOKU measurements (<0,003 mg/l) directly, it can be seen that both are under the detection limit. PO_4-P results of the WRI and on site measurements differ greatly by 5 to 11 times. However, the lower values of the on site analyses, come close to the PO_4-P measurements of BOKU lab. Chloride and hardness results differ also within the different laboratories. The reason could be the amount of rainwater in the respective sample. A direct comparison of BOKU (116 mg/l) and on site measurements (140 mg/l) shows different chloride concentrations (see chapter 4.3.1.3).

The rainwater collected at the Women Centre fulfils the drinking water requirements of the GSB except for the E. coli counts (34 CFU/ 100 ml). To make the water safe for drinking disinfection would be necessary.

5.1.4 Water re-use (grey water, black water and yellow water)

Only estimations about the amount of water re-use were available. The average volume of weekly waste water accumulation, was calculated based on assumptions made by IÖV (2006) for each relevant building. However, a short explanation on the different water re-use techniques is subsequently given and the estimated quantity is stated. Additionally, some information can be found in chapter 5.2.

Quantitative evaluation

At the guesthouses, black water is mechanically pre-treated in three concrete chambers, followed by a treatment with a sand and laterite filter. The treated water had not been used for a long time because the pump from the treatment tank to the overhead tank broken. However, it was replaced in June. The care takers of the guest houses use this water for irrigating nearby plants. They used about 1,7m³ per week. However, it has to be stated that the pump is not working properly and the water remains unused for long periods. The water meter readings showed uses for the periods 03.12.08 until 04.02.09 and 02.09.09 until 23.09.09 only.

Black water is usually led into septic tanks where it percolates into the ground. An exception is black water from the New Men's Dormitory (25m³ per week), the Administration Building (5m³ per week), the Sanitary Block (7m³ per week) and the J.J. Norty Hall (13m³ per week) because this black water flows to the Biogas Plant. Produced gas is used in the Cafeteria's kitchen but as the yield is very low, just one stove can be supplied.

Grey water is used at the Cafeteria and at the Women Dormitory. At these buildings, the amount is sufficient to be economical for irrigation purposes. Grey water from the cafeteria (21m³ per week) is treated in a fat separator then used for irrigating the nearby Eco Farm. From the women dormitory, about 66m³ per week are led to a septic tank and from there it pumped to plantations for irrigational purposes. During the rainy season it is hardly used but in the dry season grey water is a welcome additional supply. However, the pumps easily break in the contaminated water or are incorrectly operated and maintained. Thus, the waste water often remains unused for long periods of time.

Yellow water is collected at the Sanitary Block (1,2 m³ per week), the Administration Building (0,4m³ per week), the New Faculty Building/ Columbia (1,3m³ per week) and the J.J. Norty

Hall (0,7m³ per week). The urine or urine water mixture is collected in tanks and periodically used for fertilizing the plantations and fields.

Thus, about 50m³ per week are led to the Biogas Plant. About 87m³ of grey water accumulate at the Women Dormitory and the Cafeteria per week but it is not known how much of it is used. At the Guest Houses, about 1,7m³ of black/ grey water are used for irrigation per week. A weekly amount of 3,6m³ yellow water is used as fertilizer on the agricultural fields.

Qualitative evaluation

The water quality of re-used water (see Table 5.30, Table 5.31 and Table 5.32) was just measured at the outflow of the sand filter at the Guest Houses. Thus, the parameters were measured after the treatment process.

Table 5.30: Comparison of water quality analyses of the Guest House's grey and black water after treatment

Laboratory	**Comment**	**pH** [2]	**NH_4-N [mg/l]** [2]	**NO_3-N [mg/l]** [2]	**NO_2-N [mg/l]** [2]	**PO_4-P [mg/l]**	**Cl [mg/l]** [2]	**Tot./ Diss. Fe [mg/l]** [2]	**Tot./ Diss. Mn [mg/l]** [2]	**Tot. Hardness [dH°]** [2]	**COD**
On site	Median	6,4	8,8+	78+	1,2+	41	160	<0,03	Not measured	18	Not measured
On site	Standard deviation	0,7	48	46	2	7	42	-		9	
On site	Maximum	7,7	146+	142+	6,6+	52	260+	0,07		50+	
On site	Minimum	5,7+	0	6	<0,02	29	140	<0,03		13	
On site	Samples	16	10	13	13	11	12	13		14	
BOKU lab	13.03.09	7,1	40,1+	60,7+	1,33+	-	40	0,11	4+	17	-
BOKU lab	28.05.09	7	36,7+	70,7+	0,75	-	179	0,02	3,1+	16	-
BOKU lab	23.06.09	8	65,5+	6,2	0,85	6,2	155	-	-	8	11
BOKU lab	28.07.09	7,4	48+	28,2+	39+	7,4	117	-	-	14	10
WRI	16.06.09	Not measured	10,4+	5,68	<0,001	4,44	Not measured	$<0,01_{Tot.}$	$3,7_{Tot.}$+	Not measured	57
On site	16.06.09		84+	33+	1,83+	44,5		<0,03	-		-
WRI	07.07.09	Not measured	8,7+	5,83	<0,001	5,2	Not measured	$<0,01_{Tot.}$	$2,5_{Tot.}$+	Not measured	40
On site	07.07.09		146+	6	30,72+	41		-	-		-
WRI	16.10.09	Not measured	4,5	<0,001	<0,001	2,84	Not measured	$0,14_{Tot.}$	$0,03_{Tot.}$	Not measured	
BOKU lab	16.10.09		6,6	81,9	2,5	8,4		$0,27_{Tot.}$	$4,07_{Tot.}$		

[1] On site analyses were conducted between May 21st, 2009 and December 8th, 2009
[2] Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water

Table 5.31: Water analyses of grey and black water after treatment at the Guest Houses that were conducted on site [1]

	Temperature [°C]	Dissolved Oxygen [mg/l]	Dissolved Oxygen [%]	Electrical Conductivity [µS/cm]	Oxidation Reduction Potential [mV]	Turbidity [FAU] [2]
Median	30,4	1,2	17	1291	142	<21
Standard deviation	1	0,8	11	123	99	-
Maximum	31,7	2,9	41	1558	395	30+
Minimum	27	0,1	1	1062	66	<21
Samples	17	16	15	17	16	13

[1] *On site analyses were conducted between May 21st, 2009 and December 8th, 2009*
[2] *Values marked with < are lower than the detection limit, values marked with + are not conform to the Ghana Standard Board requirements for drinking water*

Table 5.32: Water analyses of grey and black water after treatment at the Guest Houses conducted by BOKU and WRI

BOKU	**WRI** [3]		
TOC	BOD	E. coli [CFU/100ml]	*Enterococcus* [CFU/1ml]
12,9	34	558+	1023+
10,9	22	558+	465
11,6	-	-	-
10,1	-	-	-

[3] *Values marked with + are not conform to the Ghana Standard Board requirements for drinking water*

Comparing the results of the WRI and the on site analyses, all values except ferrous iron have large ranges. Especially the NO_2-N result of the WRI institute is noticeable because the concentrations are <0,001. A similar result (<0,02) was obtained only once on site. All other results exceed 0,72 mg/l. The direct comparison of WRI (<0,001mg/l) and BOKU (2,5 mg/l) shows great differences. Also NO_3-N differs remarkable between WRI (<0,001 mg/l) and BOKU (81,9 mg/l). Only one time analyses of the same sample conducted by the WRI (5,83 mg/l) and on site (6 mg/l) obtained similar results for NO_3-N. The other time, the concentration measured on site, was almost 6 times higher than the one of the WRI. The concentrations of this parameter cannot be compared to the BOKU LAB results as they also show large ranges. The PO_4-P results of the on site analyses are about 10 times higher than the results of the WRI. All measured PO_4-P concentrations of the on site measurements are by far higher than those of the WRI and the BOKU lab. However, the direct comparison between BOKU (8,4 mg/l) and WRI (2,8 mg/l) shows significant differences. The NH_4-N concentrations measured by the WRI are generally a lot lower than measurements conducted by BOKU lab. On site analyses showed large variations. The median hardness value of the on site measurements is higher than all analyses conducted by the BOKU LAB. The COD measured by the WRI is 4 to 5 times higher than the result of the BOKU LAB. A direct comparison of manganese concentrations measured by BOKU (4,07 mg/l) and WRI (0,03 mg/l) differs greatly, too. Especially the concentrations of NH_4-N, NO_3-N, NO_2-N, PO_4-P, Chloride and Hardness show large ranges when comparing all analyses results. Therefore, it can be assumed that the water quality is not stable. The WRI obtained completely wrong results for the parameters: NO_3-N, NO_2-N, PO_4-P and total Manganese.

As this water is not intended to be used as drinking water but for irrigation of plants, the drinking water requirements of the GSB are not suitable for comparison. Therefore, a guideline for water reuse was looked at. Reuse of water requires special considerations of water quality depending on its intended use. Irrigation of plants or agricultural crops does not require drinking water quality so grey water can be used as substitute.

To compare the water quality, guideline values from CAMP DRESSER and McKEE (2004) are stated in Table 5.33. The guideline values are differing depending on the use. Urban re-use relates to activities where public exposure is likely for example landscape irrigation or toilet flushing. Agricultural reuse 1 relates to food crops that are commercially not processed, including crops eaten raw. Agricultural reuse 2 accounts to food crops that are commercially processed. The stated parameters are the most common. Faecal coliform counts indicate the degree of disinfection. Turbidity is acting as performance indicator of the treatment facility.

Table 5.33: Guideline values for water re-use according to different uses (CAMP DRESSER and McKEE, 2004)

Use	**pH**	**BOD_5 [mg/l]**	**Turbidity [FAU]**	**Faecal coli/ 100ml**	**Cl_2 residual [mg/l]**
Urban reuse	6 – 9	≤10	≤2	Non detectable	1 (minimum)
Agricultural reuse 1	6 – 9	≤10	≤2	Non detectable	1 (minimum)
Agricultural reuse 2	6 – 9	≤30	-	<200	1 (minimum)

According to this guideline, the requirement for Agricultural reuse 2 (commercially processed food) is not met for the parameters BOD once and Faecal coli. Irrigation of plants is appropriate but it should not be used for agricultural irrigation.

5.1.5 Water lorry

The university owes a water lorry. It is used for delivering water to teachers' and staffs' residences off campus. Thus, the lorry goes to Accra four times a week. There, it is filled by the GWCL (using water from the Volta or the Densu River) from where the water is delivered to VVU's staff houses. Most consumers are at Adenta which is about 10 kilometres south of VVU. VVU charges 5 GhC/ m³. The storage volume of the lorry is 16 m³. The lorry is coming on request and fills tanks at the customers' houses. They receive a monthly bill from VVU (SARPONG, 2009a).

Earlier the lorry was used for emergency supplies in case of water shortage at VVU. However, since the installation of groundwater wells and the rainwater harvesting systems this service is rarely necessary. One problem is that the lorry is already quite old. Therefore, a replacement will be necessary soon (SARPONG, 2009a).

5.1.6 Future option

During the second field study, VVU has been starting to consider a connection to the GWCL pipeline passing the campus. VVU used to be connected to this pipeline before the Oyibi Water Supply Scheme was established. The pipeline supplies Adenta and some communities along the Adenta-Dodowa road with water from six groundwater wells located at Dodowa (about 15 kilometres north of VVU).

The GWCL delivers water towards Adenta six days a week and they supply parts of Dodowa only once a week. That implies that VVU can expect water from GWCL every day except Thursday. The amount to be received could not be verified but they pump about 1 800 to 2 200 m³ per day through their network. The water is continuously chlorinated. In general, the groundwater quality is considered to be good (no iron or salinity problems) (GWCL, 2009).

5.1.7 Summary and verification of the analyses

Quantitative evaluation

- The Oyibi Water Supply Scheme irregularly delivers on average 305m³ of water to VVU per week. However, this quantity is slowly decreasing.

- Two groundwater wells deliver almost 200m³ of water per week. Borehole 3 is currently not in use because the quality is not good enough. If the water of Borehole 3 was treated additional supply of about 47m³ per week would be possible.
- The rainwater harvesting potential is not fully used. This should be improved.
- The grey water system is not managed properly. Its potential is not fully utilized.

Qualitative evaluation

As the results of the BOKU LAB are considered to be correct, the most emphasise should be given to them.

Concerning drinking water, the problematic parameter is E. coli. E. coli was present in all rainwater sources. The reason could be that the rainwater systems are not properly managed (see chapter 5.3.2). The quality of the groundwater wells is good, except for occasionally high iron concentrations. However, the Main Reservoir's water has no drinking quality because of occasional E. coli counts. Treated black water at the Guest House is suitable for irrigating plants but not food crops.

Compared to the analyses conducted by BOKU, some remarkable measurement errors occurred during on site analyses as well as by the WRI. An interesting conclusion is that the analyses contacted on site obtained more accurate results than the WRI for the parameters NO_2-N and PO_4-P (except for the high concentrations of grey/ black water, there the WRI was closer). For the on site analyses, the largest differences from BOKU results occurred for chloride (see chapter 4.3.1.3) and NO_2-N. When the WRI was confronted with the measurement differences they stuck to their results. However, reasons can be imprecise working or damaged facilities. The errors of on site analyses are probably due to low concentrations (NO_2-N). The HACH Colorimeter obtains the most accurate results when the concentrations are in the middle of a measurement range (see Table 4.2).

5.1.8 Further verification of the water analyses

As the on site measurements could not be verified with the WRI, and direct comparison (not the same sample) with the BOKU LAB were not conducted in the first place, standard solutions were brought to Ghana for verification.

Table 5.34 shows the results of analysing blanc values.

Table 5.34: Verification of on site measurements with standard solutions

Parameter	Standard [mg/l]	Result [mg/l]	Parameter	Standard [mg/l]	Result [mg/l]
NO_2-N	0,3	0,315	PO_4-P	2	>2,75
NO_3-N	15	22 (1) and 21,2 (2)	PO_4-P	2	>2,75
NO_3-N	10	12,3	PO_4-P	2	>2,75
NO_3-N	10	10	PO_4-P	2	>2,75
NO_3-N	10	11,1	PO_4-P	1	1,04
NH_4-N	0,4	0,46	PO_4-P	1	1,06
NH_4-N	0,4	0,48	PO_4-P	1	1,24
NH_4-N	0,4	0,45	PO_4-P	1	1,05
NH_4-N	0,4	0,45	PO_4-P	1	1,03
Cl	200	240	Fe^{2+}	2	0,05
-			Fe^{2+}	2	0,08

These results partly verify the findings of the previous summary.

- Fe^{2+} was completely wrong but the reason is possibly that it is very unstable. It oxidizes fast to ferric iron which is not detected with the applied method.
- NO_2-N and NH_4-N were rather accurate.

- NO_3-N was differing twice from the standard. The measured concentration of the on site measurements was 1,4 times higher. However, at lower concentrations the results were rather good. Analysing NO_3-N concentrations of blank values resulted in 0,2 mg/l to 0,6 mg/l.
- The error for PO_4-P might be related to the circumstance that 2 mg/l are already close to the upper boundary (2,5 mg/l) of the range. The instruments accuracy is best in the middle of the range. It seems like the instrument has problems with higher concentrations.
- The chloride concentration was higher.

These results are similar to the observations made by comparing on site with BOKU results. Additionally, NO_3-N was tested with a blank three times. The results of the on site analyses were always under the detection limit. Thus, it appears that chloride and NO_3-N concentrations measured on site are always too high.

5.2 VVU's water balance and respective facilities

This chapter states results of the overall objective to investigate the current WS&S at VVU. The objectives are to:

- update the mid-term demand forecast
- compile and update the existing information and data about water facilities
- evaluate resource allocation, water balances and development scenarios

Therefore, this chapter is divided into three parts. The first part gives a brief introduction into VVU's water cycle management. A water flux chart illustrates the major flow paths of the different water sources. The second part compiles and updates information about water facilities (including rainwater tanks, septic tanks and water re-use facilities), states the water balances, gives a mid-term demand forecast for each building and summarizes the results. The third part compares the overall water consumption with the availability on campus (according to the investigations of chapter 5.1).

Data about water facilities are mainly based on on-site surveys conducted during the field study (see chapter 4.3.4). The water consumption was calculated with water meter data (4.2.1). Data about water re-use are based on on-site surveys and estimations of the IÖV (2006) (see chapter 4.1.1.1).

5.2.1 Water cycle management at VVU

Figure 5.8 illustrates VVU's water cycle management. The inflow is characterized by three water resources, namely rainwater and groundwater from the public water supplier and from three groundwater wells on site.

The groundwater resources are mixed in the Main Reservoir before the water is distributed over the campus to each building. More than half of the buildings have an attached rainwater tank but not all rainwater systems are in use (see also chapter 5.1.3). Rainwater is not collected at all buildings. Thus, rainwater is lost at buildings or surfaces without collection systems. Furthermore, rainwater tanks are overflowing occasionally because at some buildings this water is only used in case of water shortage and not as regular supplement.

At some buildings, grey water, yellow water and/ or black water is collected and re-used for irrigation of plants or farmland. Black water is also used for gas production at the Biogas Plant on campus. At the other buildings, unused grey and black water soaks away in septic tanks. Especially during the rainy season, collected grey water is lost. Rainwater for the farms is sufficient; thus, no grey water is used and grey water tanks at the Cafeteria or Women Dormitory overflow occasionally.

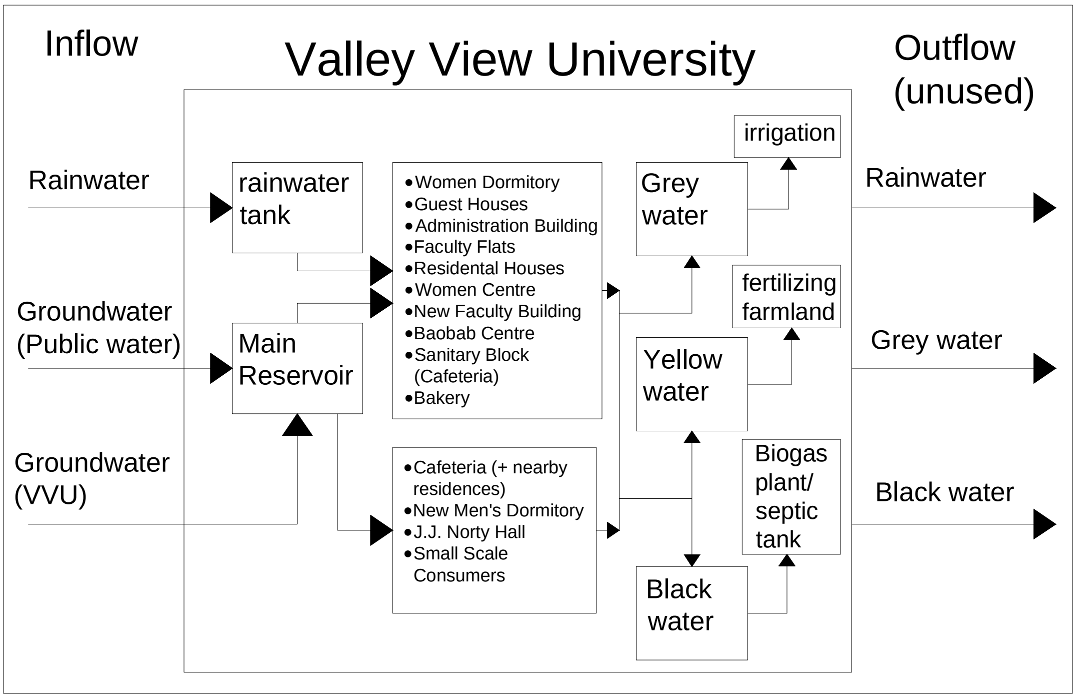

Figure 5.8: Water flux design for VVU's ecological water cycle management

5.2.2 Water consumption

Chapter 5.1.1 gives VVU's water consumption from the public water supplier. In school year 2008/2009 it was 325m³ per week during semester and 286m³ per week during summer school.

Assessing the exact water consumption from the rainwater tanks and the exact amount of re-used water is not possible. The reason is that almost no tanks and no water re-use sites are metered. However, at the most important buildings (depending on the approximate water consumption), water meters were installed and the amount of re-used water was approximated. Thus, these buildings (see Figure 5.9) are examined more closely.

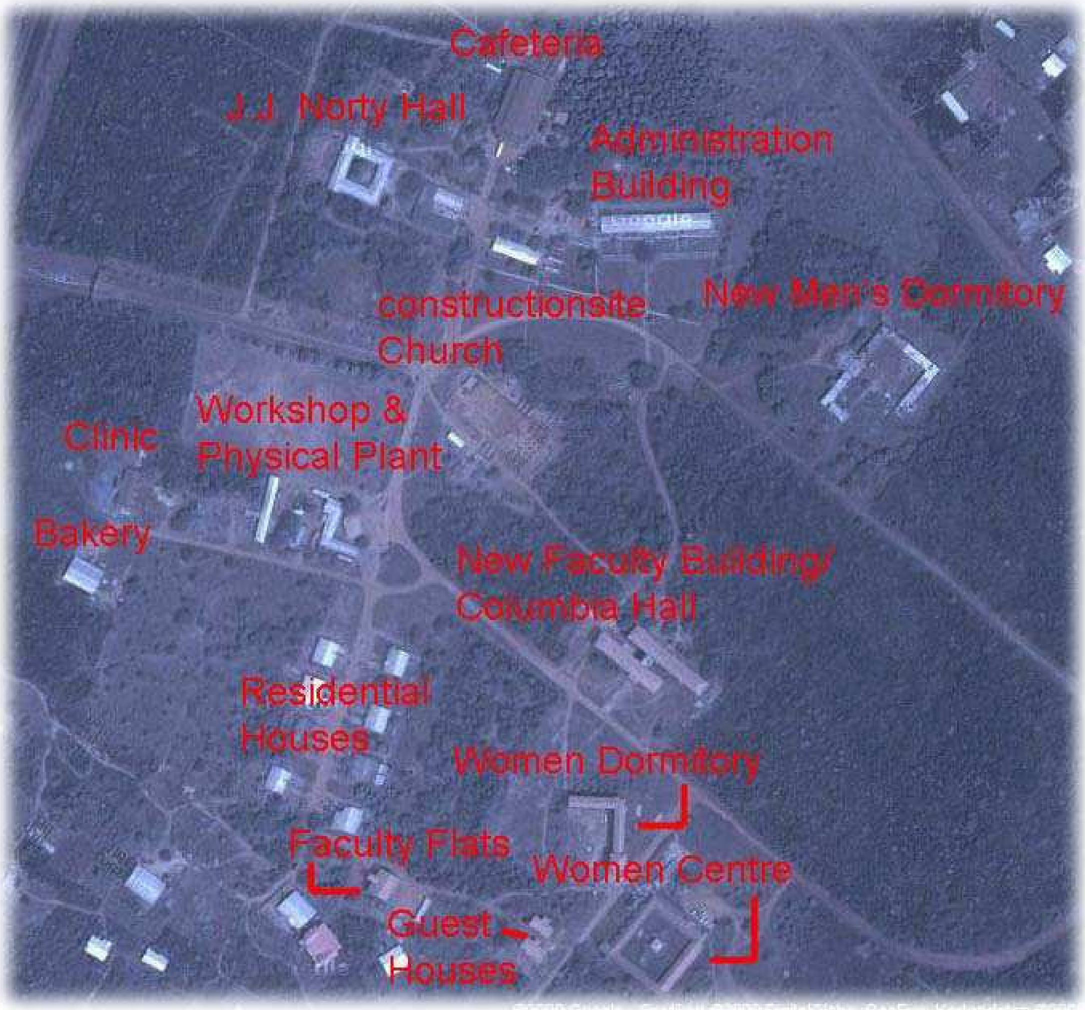

Figure 5.9: Buildings at VVU (GOOGLE EARTH, 2009, adapted by Lauterböck)

5.2.2.1 Women Dormitory

Facilities

The Women Dormitory has a large underground tank ($100m^3$) that is supplied with water from the Main Reservoir and with rainwater. Water from the tank can be pumped up into four polytanks on the fourth floor (each tank $5m^3$). These polytanks are filled up when enough water is available. Then they supply the third floor of the Women Dormitory and occasionally, (in case of water shortage) the whole building. The third floor cannot be supplied directly from the Main Reservoir because the pressure in the system is too low. If the polytanks are not used (in case of general water shortage on campus), women from the third floor have to fetch water on the second floor. Another connection supplies water directly from the Main Reservoir to the Women Dormitory (except third floor). Additionally, there is one polytank ($10m^3$) situated in the court of the dormitory. This tank can be supplied with water from the Main Reservoir or underground tank and is manly used for washing laundry or as emergency back up in cases of water shortage. Water coming from the Main Reservoir is metered at both connections.

About 80% or $655m^2$ of the roof is connected with gutters for rainwater collection.

Grey water is collected in a tank. It is pumped to the plantations in the south-east of the campus (see Figure 3.3). However, at the moment the pump is broken. Thus, grey water has not been used for a long time. Black water is led to a septic tank.

Balance

The water consumption from the main line (the main line refers to water supplied from the Main Reservoir) into an underground tank is 27,4m³ per week. 39,7m³ per week are supplied directly from the main line. During semester, the consumption is higher with 29,3m³ (underground tank) and 42,2 m³ (main line) compared to the consumption during summer school with 20,5m³ (underground tank) and 28,8m³ (main line).

The collected rainwater is on average 418m³ per year or about 3m³ (dry period), 8,3m³ (semi-dry period) and 14,3m³ (rainy season) per week.

The accumulated grey water and black water of 252 women was assumed to be 85m³ and 95m³ per week respectively (IÖV, 2006). In the second semester of 2009 (January to May) only 196 people lived there. Moreover, there are rooms for 228 people according to the Women Dormitory's caretaker. An approximate grey water and black water accumulation of 58m³ and 76m³ per week (IÖV, 2006) respectively can be expected for 196 people. Comparing the average water consumption from January 7th, 2009 until May 13th, 2009 (second semester of 2009 with 196 inhabitants, consumption ~84m³) with the estimated waste water accumulation (58m³ + 76m³ = 134m³), a difference can be observed. The waste water accumulation exceeds the water supply by 50m³. That implies that assumptions of IÖV (2006) about black (toilet as only source with 61,46 litre per day and person) or/ and grey water (wash basin: 3,5/ shower: 32,5/ laundry 34 litre per day and person) cannot be verified by the current water consumption. This difference might be due to occasional water shortages (no water supply) and the fact, that the third floor is rarely supplied with water (pressure too low). These circumstances were not properly considered by the IÖV (2006). Nevertheless, these values were taken as no better estimations were available.

Figure 5.10 illustrates the Women Dormitory's water balance.

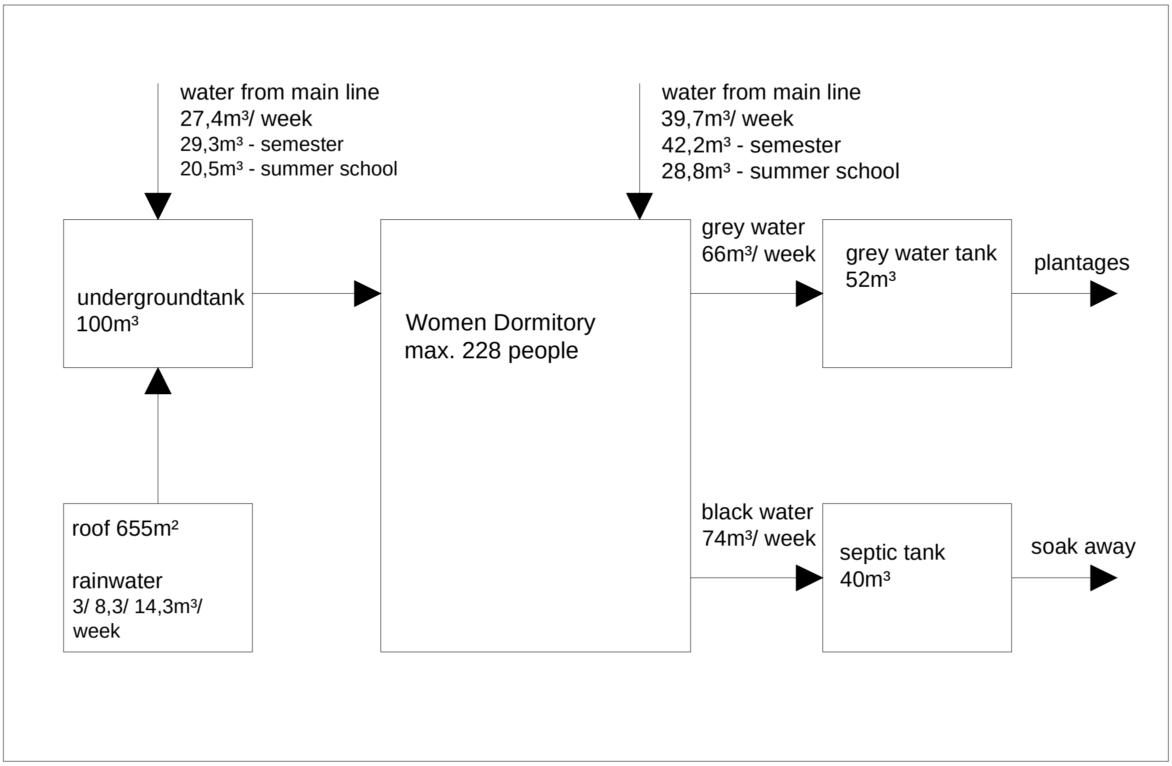

Figure 5.10: Women Dormitory's water balance illustrated as flow chart

<u>Midterm future demand</u>

As the building is already finished, no new rooms will be built. Therefore, the maximum number of students is 228 and previously presented values will not change significantly.

5.2.2.2 Guest Houses

Facilities

The Guest Houses are equipped with sand and laterite filters for black water treatment. The treated waste water is pumped into an overhead tank from where it is used for irrigation. Rainwater is collected on the roofs at both houses (340m²) and stored in an underground tank (bout 50m³). It can be pumped into one of two poly tanks (each 5m³) on the roof of the newer and more luxurious Guest House. Usually, the rainwater is only used in case of water shortage. The second poly tank is filled with water from the Main Reservoir.

The second and older Guest House is supplied via a large poly tank (10m³) that is filled with water from the Main Reservoir. As the tank is on the ground, a pump is used to supply this house with water.

Two water meters are installed. One measures the water consumption from the Main Reservoir of both Guest Houses. The second meter measures the use of treated waste water.

Balance

At the Guest Houses, water consumption from the main line is 5,4m³ per week. During semester the consumption is lower with 5,1m³ per week than during summer school with 6,9m³ per week. The reason is that during summer school, the Guest Houses are usually full (about 8 people, one in each room) because many external professors stay at VVU.

The collected rainwater on average sums up to 217m³ per year or about 1,6m³ (dry period), 4,3m³ (semi-dry period) and 7,4m³ (rainy season) per week depending on the period.

Approximately 2,7m³ (IÖV, 2006) of black water accumulate per week. The Guest Houses' caretakers use about 1,7m³ treated black water per week to irrigate nearby plants. The estimations of IÖV (2006) were wrong again (see also chapter 5.2.2.1) but in this case, the waste water accumulation (and water consumption) was under estimated. This might be due to overflows of the septic tank.

Figure 5.11 illustrates the Guest Houses' water balance.

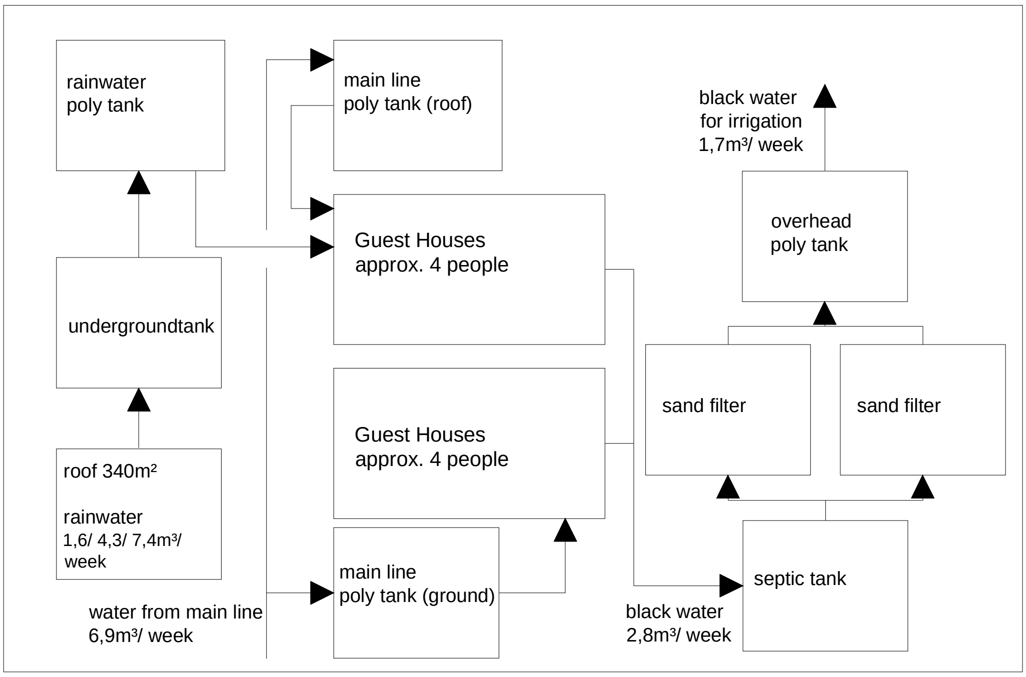

Figure 5.11: Guest Houses' water balance illustrated as flow chart

Midterm future demand

The midterm future demand is likely to increase because new buildings (two Guest Houses and a conference room) are planned. Each house will have rooms for four people. Thus, the water consumption will at least double. This implies that all Guest Houses would consume 10,8m³ per week from the main line, about 434m³ of rainwater would be harvested per year and 5,4m³ black water would accumulate per week. The conference room was not considered because no information was available.

5.2.2.3 Administration Building

Facilities

The Administration Building used to have a rainwater harvesting system for a third of its roof (324m²). However, it is not in use since February 2008 because the tank is leaking and the pump is broken. A poly tank on the roof of the building (3m³) can be filled up with rainwater or water from the Main Reservoir.

Yellow water from separation toilets and dry urinals is collected in poly tanks.

There are two water meters installed. One measures the rainwater consumption from the rainwater underground tank and one the water consumption from the Main Reservoir. However, the underground tank's water meter is broken.

Balance

Water consumption of the Administration Building from the Main Reservoir is 10,1m³ per week. A noticeable fact is that the average water consumption during summer holidays is higher (13,1m³) than the average consumption during semester (9,3m³). Moreover, without the water meter readings from school year 2006/2007, the average water consumption drops by almost half (6,4m³ instead of 10,1m³ per week). The difference between semester (6,3m³ per week) and summer school (6,9m³ per week) consumption decreases, too.

Approximately 207m³ of rainwater could be collected per year that would imply per week: 1,6m³ in the dry period, 4,1m³ in the semi-dry period and 7,1m³ in the rainy season. As long as the rainwater system was working, about 5,1m³ per week were used. This implies a share of 29% in the total water consumption within this period.

For 274 users approximately 4,6m³ of black water and 0,4m³ of yellow water accumulate per week (IÖV, 2006). Black water is led to the biogas plant and yellow water is stored in poly tanks and regularly used as fertilizers at VVU's farmland.

Figure 5.12 illustrates the Administration Building's water balance.

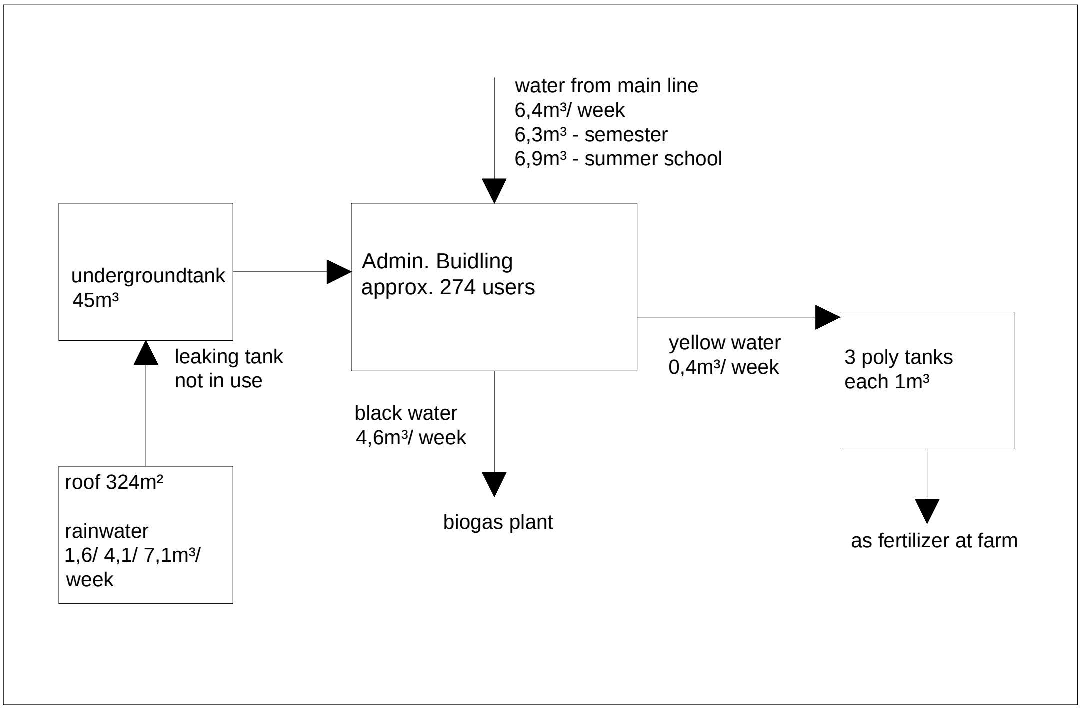

Figure 5.12: Administration Building's water balance illustrated as flow chart

<u>Midterm future demand</u>

The midterm future demand is hard to assess. It is likely that water consumption increases due to an increasing number of students. Therefore, the classrooms and washrooms are used more often. Nevertheless, it is important to repair the rainwater harvesting system because this source contributed a large share in the water supply.

5.2.2.4 Faculty Flats

<u>Facilities</u>

The Faculty Flats have a rainwater harvesting system for their whole roof (350m²). The rainwater tank has a storage capacity of 55m³. However, the rainwater tank is leaking; therefore, it is not in use anymore.

On the side of the building, there are four overhead poly tanks and four additional tanks are on the building's roof (each tank ~ 2,5m³). They are supplied with water from the Main Reservoir.

Black water is led to a septic tank.

There is one water meter installed, measuring the consumption from the Main Reservoir.

There are six flats in the building and approximately 21 people live there.

<u>Balance</u>

The water consumption of the whole building is 24,6m³ per week from the main line. The consumption during semester is slightly higher with 24,9m³ per week, compared to 23,3m³ during summer school.

The collected rainwater could be on average 223m³ per year or 1,6m³ (dry period), 4,5m³ (semi-dry period) and 7,7m³ (rainy season) per week.

Midterm future demand

For the future it is unlikely that the consumption from the Main Reservoir will change if the rainwater system is not fixed. The consumption would decrease by about 17% to 20,3m³ per week if the rainwater potential was utilized.

5.2.2.5 Residential Houses

Facilities

There are nine residential houses on campus, plus two additional houses that are not within the campus area but that are connected to VVU's water supply network. About 35 people live in ten houses. The remaining building is a student hostel for 30 to 36 students during semesters. The houses have one or two polytanks, each about 2,5m³.

Five out of nine residential houses on campus have rainwater harvesting systems (roof area: 637m²). Only one house is connected to the rainwater tank via a pump. The other houses fetch water from their rainwater tanks in case of water shortage or for irrigation if they use the rainwater at all.

Black water is led to septic tanks.

All buildings except two (one is the presidential house) have water meters installed measuring the water consumption from the Main Reservoir.

Balance

The water consumption from the Main Reservoir is 28,9m³ per week. But as the water meters were recently installed not many readings were available. Moreover, there are no water meter consumption data from the two houses without meters. Using an average consumption for the houses without water meters (average consumption of residential houses excluding the student hostel because of its high number of residences), the water consumption rises to 33,7m³ per week.

Approximately 406m³ of rainwater can be collected per year at the Residential Houses. That implies weekly collection of about 2,9m³ in the dry period, 8,1m³ in the semi-dry period and 13,9m³ in the rainy season. If the four missing houses on campus would have a collection system, overall about 764m³ (5,2m³, 14,3m³ and 24,5m³ per week respectively) of rainwater could be collected per year. If rainwater would be used properly, the residential houses' consumption of water from the Main Reservoir could almost halve.

Midterm future demand

For the future, it is unlikely that consumption from the Main Reservoir will change. However, installing pumps at all rainwater tanks and implementing rainwater harvesting systems at those houses without a collection system could decrease consumption from the Main Reservoir significantly. The actual overall rainwater collection potential is between 5,2m³ (dry season) and 24,5m³ (rainy season) per week. Therefore, water consumption from the Main Reservoir would be reduced significantly (about 49-85% in the semi-dry and rainy season) if pumps were installed and all houses supplemented with rainwater harvesting systems.

5.2.2.6 Women Centre

Facilities

The Women Centre is not VVU's property although it is located on campus. Nevertheless, it is supplied with water by VVU and it is a rather large consumer. Wastewater is not considered in VVU's water balance. It has 41 rooms for 60 to 80 people.

VVU's water is mixed with rainwater in an underground tank. From there, it is pumped into three polytanks (each 5m³). Rainwater is collect just on a small part of the roof (400m²). Before the Centre was connected to VVU's supply network, a water lorry was coming regularly to fill up the tank. Since the building is connected, this is hardly necessary.

Black water is led to septic tanks.

There is a water meter installed but the meter is not working since June 2008. In July 2009, the water meter got replaced. Though newer readings are available now, the readings previous to June 2008 are taken because more data are available from this period.

Balance

The water consumption from the Main Reservoir was 29,8m³ per week (before June 2008). During semester the consumption was lower (28,6m³ per week) than during summer school (35,8m³ per week).

About 255m³ of rainwater can be collected per year or about 1,8m³ (dry season), 5,1m³ (semi-dry season) and 8,7m³ (rainy season) per week.

Midterm future demand

For the future, it is unlikely that the consumption from the Main Reservoir will change if the current rainwater system is not extended.

5.2.2.7 New Faculty Building/ Columbia Hall and Andrew Clark Hall

Facilities

The New Faculty Building has a large underground tank supplying the whole building with rainwater collected on its roof (1495m²). Additionally, the rainwater is used for irrigating nearby plants and supplying nearby construction sites with water.

In case of water shortage, the Main Reservoir can also supply water. So far this was not necessary.

There are four poly tanks (each 5m³) on the roof of the building. Two tanks are for storing rainwater and two for storing water from the Main Reservoir. The water has to be pumped up.

Black water is led to a septic tank. Yellow water is collected and used as fertilizer on the farmland.

Four water meters are installed. One measures water consumption from the main line, one the amount of rainwater used for irrigation, one the amount of rainwater that is used for construction sites and one measures the amount of rainwater used within the building.

Balance

The overall rainwater consumption from the New Faculty Building was 9,5m³ per week. This does not consider the consumption at construction sites because those water meter data started a lot later. During semester, a lot more water is consumed (10,3m³ per week) than during summer school (6,4m³ per week). The rainwater consumption of 9,5m³ can be split into 1,7m³ for irrigation and 7,8m³ for the building itself.

The collected rainwater is on average 953m³ per year or weekly about 6,9m³ (dry period), 19m³ (semi-dry period) and 32,7m³ (rainy season). It was decided to use water from this building for nearby construction because a lot more rainwater was collected than used.

For 605 users about 1,3m³ of yellow water, 7,5m³ of black water and 1,1m³ of grey water accumulate per week (IÖV, 2006).

Figure 5.13 illustrates the New Faculty Building’s water balance.

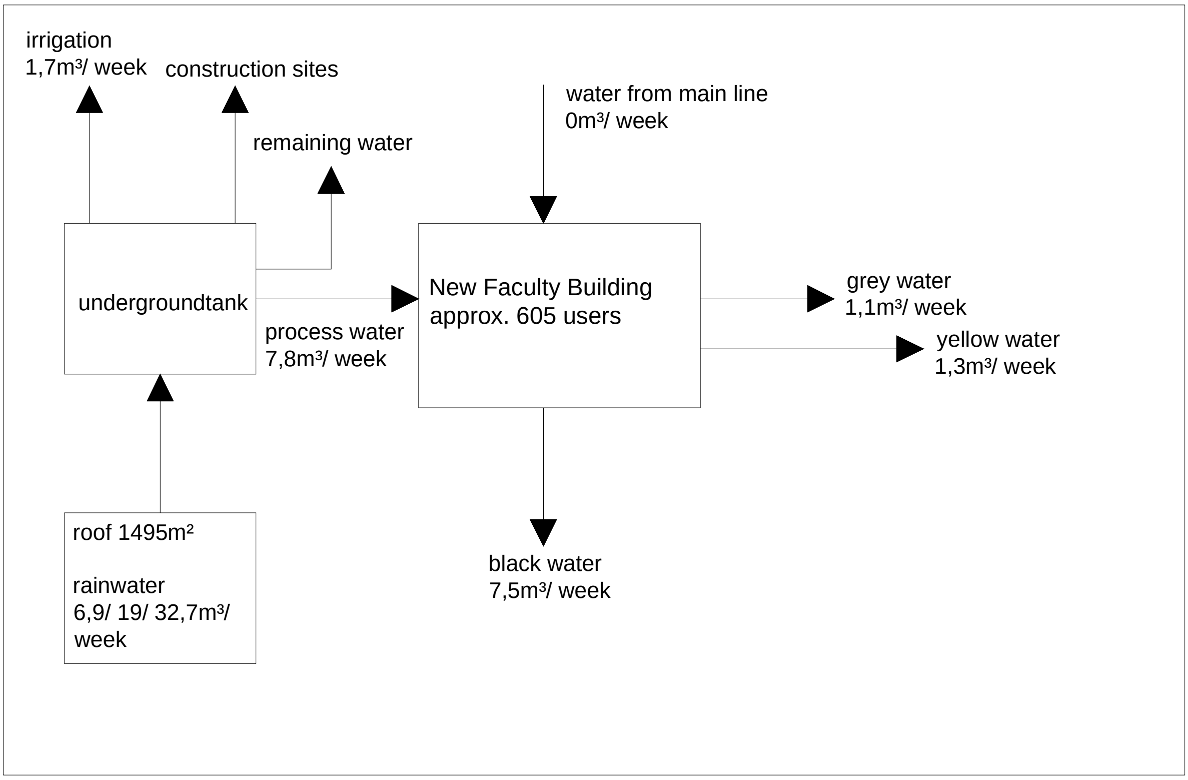

Figure 5.13: New Faculty Building's water balance illustrated as flow chart

Midterm future demand

For the future, it is unlikely that the water consumption will rise. The demand varies due to the use of rainwater at construction sites. However, it is unlikely that water from the main line will be needed at this building because the collected amount usually exceeds the needs.

5.2.2.8 Sanitary Block (at Cafeteria)

Facilities

The Sanitary Block is connected to a rainwater tank and to the main line. Water is pumped into a polytank (5m³) before it can be used. The pump for the rainwater tank is not working since end of April 2009. Therefore, the rainwater cannot be used. Before that, about 58% was supplied by the rainwater system. Rainwater that is fed into the underground tank (100m³) is harvested on the Sanitary Block's and on the Cafeteria's roof (1320m²). The water is used as process water for toilet flushing and hand washbasins.

There are two water meters installed. One meter measures consumption from the Main Reservoir and one consumption from the underground tank.

Balance

The water consumption of the Sanitary Block is 8,8m³ per week. During semester, the consumption is higher (9,6m³ per week) than during summer school (5,6m³ per week). As already mentioned, about 58% of the overall water consumption was supplied by the rainwater harvesting system, as long as the pump was working.

Approximately 842m³ of rainwater can be collected per year (weekly: 6,1m³ in the dry season, 16,8m³ in the semi-dry period and 28,9m³ in the rainy season) at the Cafeteria and the attached Sanitary Block.

The IÖV (2006) made two calculations for waste water accumulation, one for 492 users (assumed for 1400 students) and one for 999 users (assumed for 5000 students). With 492 users, about 1m³ of yellow water, 5,9m³ of black water and 0,9m³ of grey water accumulate per week. With 999 users, about 2,2m³ of yellow water, 12,5m³ of black water and 1,8m³ of grey water accumulate per week (IÖV, 2006). As the number of students is around 3000 at the moment, the waste water accumulation is probably somewhere in between. 3000 students would imply 60% of 5000 student or 60% of 999 are 599 users. 599 users accumulate 1,2m³ of yellow water, 7,2m³ of black water and 1,1m³ of grey water.

Grey water soaks away. Black water is led to the Biogas Plant and yellow water is used at VVU's farm.

Figure 5.14 illustrates the Sanitary Block's water balance.

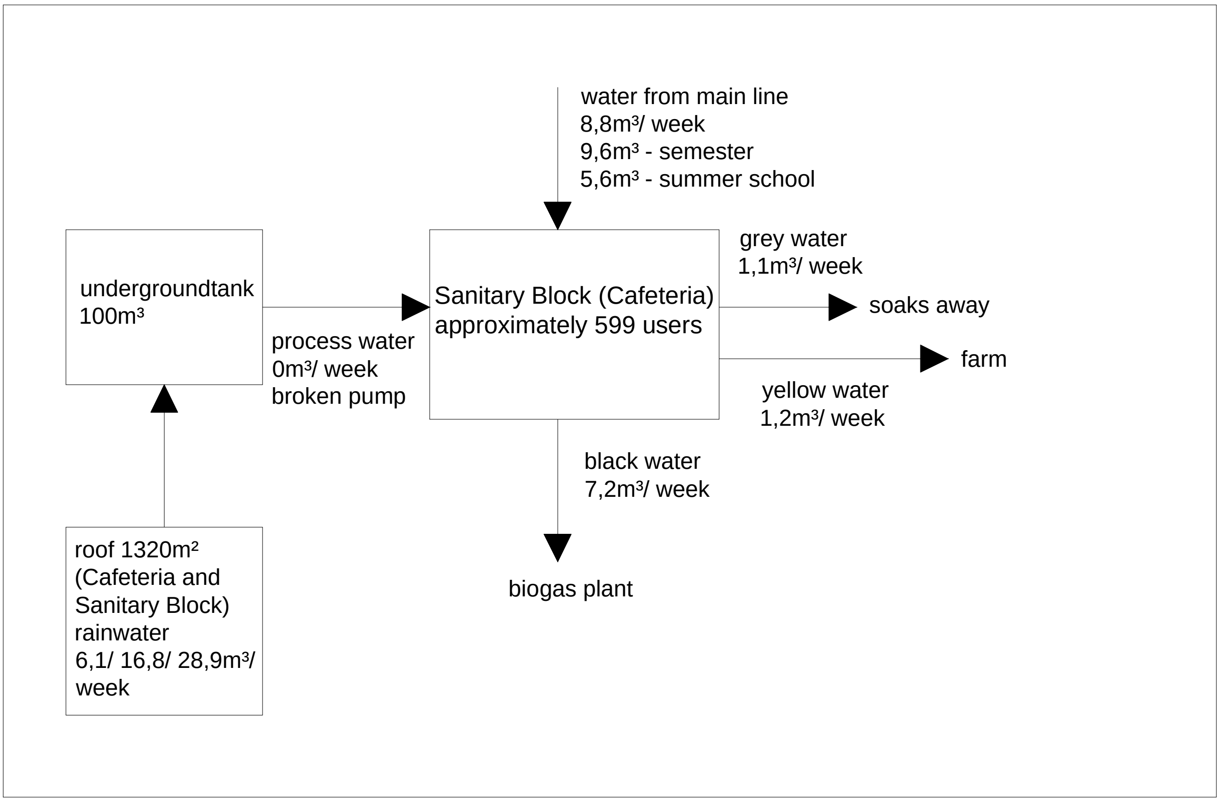

Figure 5.14: Sanitary Block's water balance illustrated as flow chart

Midterm future demand

For the future, it is likely that the water consumption will rise. Comparing the number of students, with the average water consumption at the Sanitary Block over the last five semesters and two summer schools (beginning of water meter data readings), an increase can be expected (see Table 5.35).

Table 5.35: Number of students at VVU and the average water consumption at the Cafeteria's Sanitary Block in the respective time of the school year

Time of the school year	**Number of students**	**Average water consumption [m³/week]**
Summer School 07/08	599	6,25
Summer School 08/09	1210	4,98
2nd Semester 06/07	1934	8,78
1st Semester 07/08	2408	14,075
2nd Semester 07/08	2581	8,44
2nd Semester 08/09	2833	9,27
1st Semester 08/09	3071	9,54

However, as the values during summer school 08/09 and during the first semester 07/08 highly deviate from the other values, they were excluded for the linear regression (see Figure 5.15). A distorted average is likely because of few higher values and little data from the first semester 07/08. A very low value probably relates to longer periods without rain or water supply from the public water supplier.

Using the trend (see Figure 5.15) with a coefficient of determination R^2 = 0 0,8956, the water consumption can be estimated. For 5000 students this implies an average weekly water consumption of 11,7m³. IÖV (2006) assumed an increase of 14,4m³ per week. Comparing these results with the average amount of harvested rainwater, the Sanitary Block could be fully supplied in the semi-dry and rainy period.

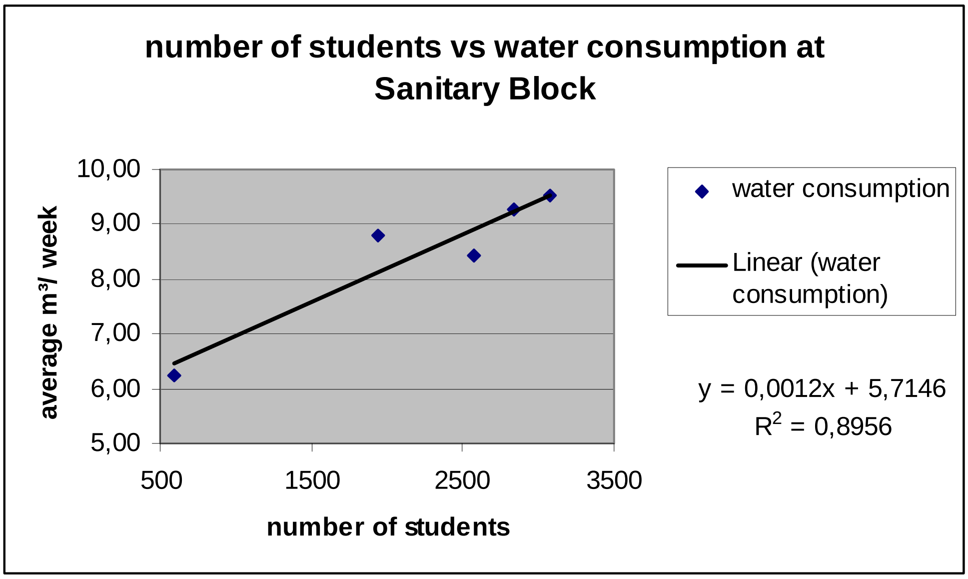

Figure 5.15: Water consumption at the Sanitary Block related to the number of students studying at VVU

5.2.2.9 Cafeteria (and nearby residences)

Facilities

The Cafeteria has a rainwater harvesting system that is supplying the attached Sanitary Block with rainwater (see: 5.2.2.7 Sanitary Block (at Cafeteria)). The residences do not collect rainwater.

Additional to the usual supply from the Main Reservoir, the Cafeteria has a large iron tank (44m³) nearby. From there, water can be fetched in case of no supply from the Main Reservoir.

Grey water accumulating in the kitchen is led to a fat separator. The treated water is used for irrigating the farmland in dry season. During rainy season, it is usually not needed.

There are toilets in the Cafeteria's room for guests, which are not used often. Therefore, they are not considered in this balance. The accumulated black water is led to the Biogas Plant.

There are two water meters installed. They measure the water consumption from the main line. One measures the farmland's consumption only and one the consumption of the Sanitary Block, the farmland, the Cafeteria itself and the attached houses. Thus, subtracting the readings from the Sanitary Block (main line) and the farmland from the overall reading (Sanitary Block, Cafeteria, farmland and nearby residential houses), it is possible to find out the consumption from the Cafeteria and the nearby residences.

Balance

The water consumption of the Cafeteria and the nearby residences from the main line is 23,3m³ per week. During semester, it is higher (23,9m³ per week) than during summer school (19,2m³ per week). The residences are probably contributing only a small fraction of the overall consumption because only two families live in the residences. Thus, this compound (Cafeteria and nearby residences) is considered as Cafeteria from now on.

As the rainwater collected at the Cafeteria's roof is used for the attached Sanitary Block, the respective balance is found in chapter 5.2.2.7 Sanitary Block (at Cafeteria).

With 599 users (see chapter 5.2.2.8) approximately 21,4m³ of grey water accumulate per week (IÖV, 2006).

Figure 5.16 illustrates the Cafeteria's water balance.

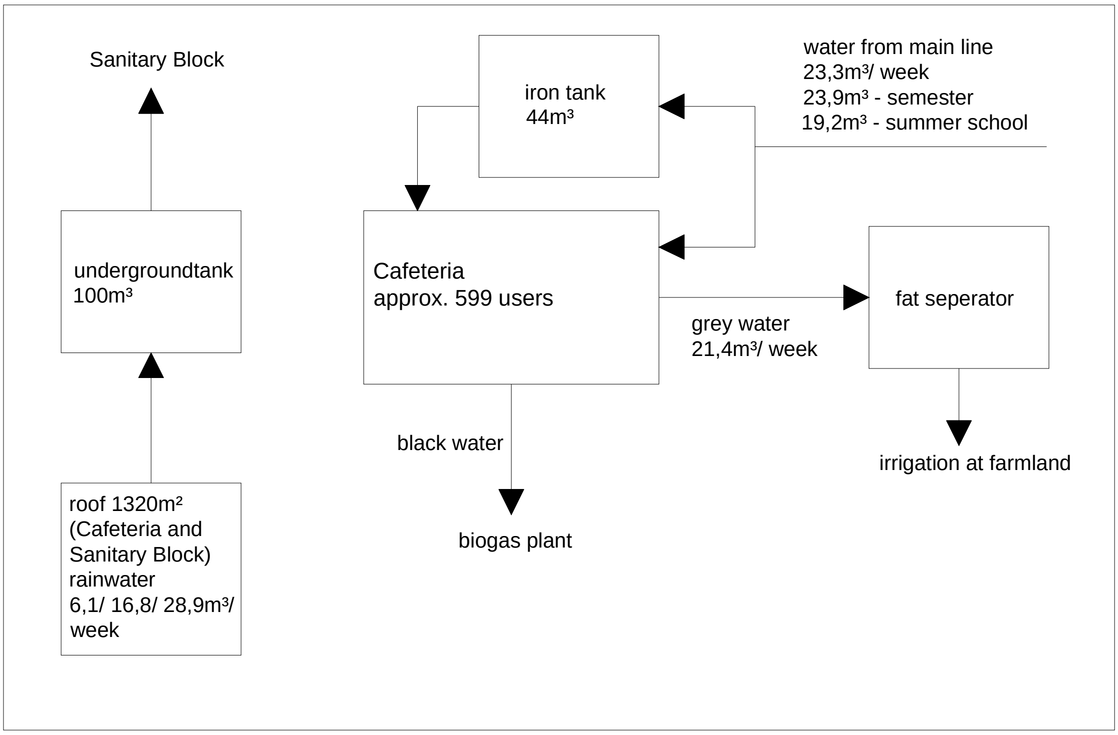

Figure 5.16: Cafeteria's water balance illustrated as flow chart

Midterm future demand

For the future it is likely that the water consumption will rise. Comparing the number of students with the average water consumption at the Cafeteria over the last five semesters and three summer schools (beginning of water meter data readings), an increase can be expected (see Table 5.36).

Table 5.36: Number of students at VVU and the average water consumption at the Cafeteria's Sanitary Block in the respective time of the school year

Time of the school year	**Number of students**	**Average water consumption [m³/week]**
Summer School 06/07	284	13,57
Summer School 07/08	599	21,65
Summer School 08/09	1210	21,43
2nd Semester 06/07	1934	22,86
1st Semester 07/08	2408	27,00
2nd Semester 07/08	2581	28,61
2nd Semester 08/09	2833	26,31
1st Semester 08/09	3071	24,43

Using a linear regression, an increase in water consumption (see Figure 5.17) can be determined. The coefficient of determination (R^2) is 0,6975. The formula estimates the water consumption of 5000 students. An average weekly water consumption of 34,8m³ or increase of almost 40% can be expected. IÖV (2006) calculated even more, an increase to 42m³ per week.

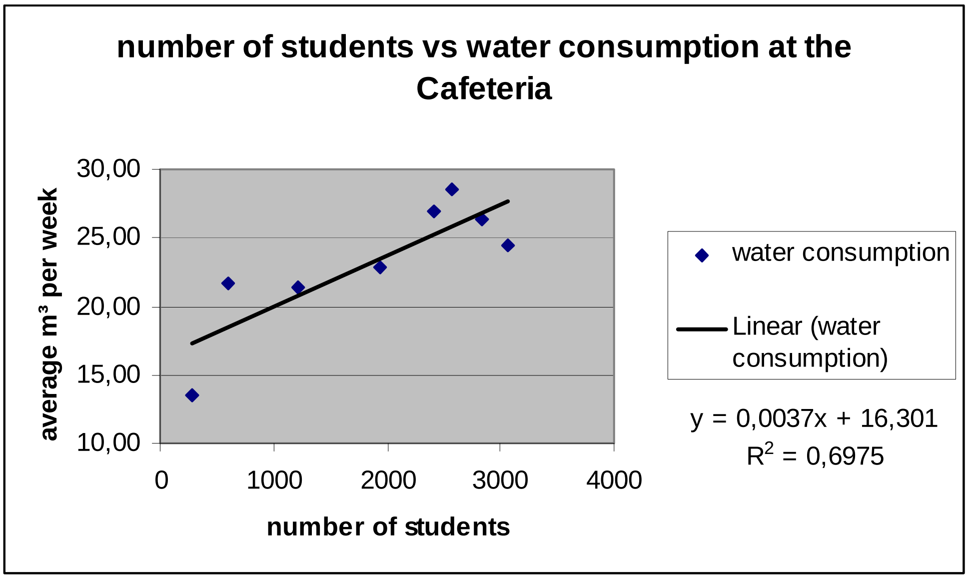

Figure 5.17: water consumption at the Cafeteria related to the number of students studying at VVU

5.2.2.10 Bakery

Facilities

The Bakery used to have a rainwater harvesting system for 480m². Nevertheless, this system was abandoned and the gutters were completely removed because of a leaking tank.

Black water is led to a septic tank.

There is one water meter installed that measures the water consumption from the Main Reservoir. Two overhead polytanks (each 3m³) are in use.

Balance

The water consumption from the main line is 4,6m³ per week. During summer school, the consumption is slightly higher (5,2m³ per week) than during semester (4,4m³ per week).

If the rainwater system was working, approximately 306m³ per year (weekly: 2,2m³ in the dry period, 6,1m³ in the semi-dry period and 10,5m³ in the rainy season) of rainwater could be collected. That would cover the bakeries need of water completely and remaining water could be used for irrigation.

Midterm future demand

As long as the bread production does not increase, it is unlikely that the water consumption will rise.

5.2.2.11 New Men's Dormitory

Facilities

The New Men's Dormitory is currently under construction. At the moment about 140 to 170 students live in 18 rooms. Sooner or later, six additional rooms for six to eight students will be finished. After that, the building will still not be finished. It is likely that in future the number of students living there will increase due to further extensions.

As the building is still unfinished and no roof is built yet, no rainwater is harvested. When finished, the roof area will be 1785m².

There is a poly tank (10m³) situated in the middle of the building, supplying the students in addition to their tab water with water for laundering and in case of water shortage. The tank would last for about 2 days. Water from the Main Reservoir is either directly supplied to the building or via two polytanks (each 5m³) on the roof.

There is one water meter measuring the water consumption from the Main Reservoir.

Balance

The water consumption of the New Men's Dormitory from the main line is 56,9m³ per week. During semester it is a lot higher (63m³ per week) than during summer school (34,8m³ per week).

Approximately 1139m³ of rainwater could be collected per year (weekly: 8,2m³ in the dry season, 22,7m³ in the semi-dry season and 39m³ in the rainy season) if the roof was finished and supplemented with a rainwater harvesting system. Thus, about 40% of the water need could be covered by rainwater.

125 people accumulate about 24,8m³ of black water and 31,2m³ of grey water per week (IÖV, 2006). For 180 people (7,5 people in 24 rooms) that would imply 35,7m³ of black water and 44,9m³ of grey water. Grey water soaks away. Black water is led to the Biogas Plant.

Midterm future demand

As this building is not finished yet, and it was not possible to find out how many people will be able to live there when it is done, it is not possible to estimate the exact future water consumption. Furthermore, the water consumption from the Main Reservoir depends on the construction of a rainwater harvesting system. If a system is build, the consumption is likely to be lower than the current one because it is unlikely that the student number will increase by more than 40%.

For the short term, the water consumption from the main line will rise to 78,9m³ per week (IÖV, 2006) because the number of rooms will increase to 24, 180 people respectively, and the roof will not be finished by then.

5.2.2.12 J.J. Norty Hall

Facilities

J.J. Norty Hall is another dormitory for men. There are 29 rooms for six persons each or 174 people in the whole building respectively.

The main line supplies water into four poly tanks (5m³). One polytank (5m³) is used for the computer laboratory next to the J.J. Norty Hall. The roof (960m²) is not connected to a rainwater harvesting system.

One water meter is installed. It measures the consumption from the main line.

Balance

The water consumption of the J.J. Norty Hall from the main line is 41,8m³ per week. During semester it is a lot higher (45,5m³ per week) than during summer school (27,9m³ per week).

Approximately 613m³ of rainwater could be collected per year (weekly 4,4m³ in the dry season, 12,2m³ in the semi-dry season and 21m³ in the rainy season) if a rainwater harvesting system was built. Thus, about 30% of the water need could be covered by rainwater.

151 people accumulate about 0,6m³ of yellow water, 11,6m³ of black water and 51m³ of grey water per week (IÖV, 2006). For 174 people that implies 0,7m³ of yellow water, 13,4m³ of black water and 58,8m³ of grey water. At this building, the difference between assumptions made by IÖV (2006) and the actual water consumption (water meter readings) is rather large again (see also chapter 5.2.2.1). The IÖV (2006) estimated the water consumption too high. However, as the actual number of students living in the hall was not verified, the error can not be clearly identified. Nevertheless, it can be assumed that the dormitory is usually fully occupied.

Yellow water is led to a septic tank. Grey water soaks away and black water is led to the Biogas Plant.

<u>Midterm future demand</u>

As this building is finished and the number of inhabitants will not increase, it is unlikely that the water consumption will change. The only possibility to decrease the consumption from the main line is to build a rainwater harvesting system.

5.2.2.13 Baobab Centre

This building is more closely investigated as it has been part of the project to construct this climate-neutral and environmentally friendly building. The Baobab Centre has been under construction during the field study. Therefore, an exact balance was not possible to determine because no water meter readings were available.

The Centre will be partly finished in December 2009. The construction was dived into two parts. It is unclear when the second part will be finished. This chapter considers only the first part of the Baobab Centre.

At the Baobab Centre, two rainwater collection systems will be in use. One will be rainwater harvesting on the roof of the Centre and its attached Sanitary Block, and another one will be surface water collection in the court. The water will be stored in a 300m^3 underground tank. Table 5.37 shows connected areas and their respective water collection potential.

Yellow water will be collected in poly tanks and used as fertilizer. Grey water and black water will be led to a septic tank and from there to a laterite filter (like at the Guest Houses) for treatment.

To estimate the collected rainwater (see Table 5.37), the formula from chapter 4.2.2 is applied. According to SMET (2003), the runoff coefficient of cement roof tiles was estimated to be 0,75 or 25% losses. The runoff coefficient of the surface collection was estimated to be 0,5 or 50% losses according to PACEY and CULLIS (1989) cited by CSE (s.a.).

Table 5.37: Collected rainwater at Baobab Centre [m^3]

Area [m^2]	**Monthly collection**	January	February	March	April	May	June
784 (35x14m + 21x14m)	Roof collection Baobab Centre	10,8	20,3	45,7	42,1	88,1	64,7
1368 (38x36m)	Surface collection	15,0	28,4	63,8	58,8	123,0	90,3
251,6 (4,8x4m + 14x16,6m)	Sanitary Block	3,5	6,5	14,7	13,5	28,3	20,8

Monthly collection	July	August	September	October	November	December	**Yearly**
Roof collection Baobab Centre	44,7	15,7	62,3	83,4	41,0	15,0	533,8
Surface collection	62,4	21,9	86,9	116,5	57,2	21,0	745,1
Sanitary Block	14,3	5,0	20,0	26,8	13,1	4,8	171,3

Weekly collection	Dry period	Semi-dry period	Rainy season
Roof collection Baobab Centre	3,6	10	17,1
Surface collection	6,3	17,4	29,9
Sanitary Block	1,2	3,2	5,5
Sum (weekly)	11,1	30,6	52,5

Rainwater will be used as process water for toilet flushing and wash basins. Planed are seven toilets in the Sanitary Block and one toilet in the Baobab Centre. This Sanitary Block has as many toilets as the one next to the Cafeteria plus an additional toilet in the Centre.

For estimating the Sanitary Block's water demand, the two Sanitary Blocks were compared. The Sanitary Block at the Cafeteria has an average weekly water consumption of 8,8m^3. KRÄMER (2007) estimated that students use 11% (1m^3) of water supplied to the Sanitary Block at hand washbasins. The remaining 89% (7,8m^3) can be divided by 7 toilets, which would equal to 1,1m³ per toilet. Using these values for the new Sanitary Block, water consumption for 8 toilets was estimated to be 8,8m³ per week or 1,3m³ per day. For wash basins the consumption will be about 1,1m³ per week or 0,2m³ per day.

Comparing this value (9,9m³ per week for toilet flushing and wash basins) with the possible amount of collected rainwater at roofs of the Baobab Centre and the Sanitary Block it can be assumed that the demand cannot be covered in dry season (4,8m³ per week collected, see Table 5.37). Therefore, toilets and wash basins need additional water supply.

Beside a roof collection system, a surface collection system will be established at the Baobab Centre. Summing up the amount of collected rainwater at both systems (roof and surface collection), 11,1m³ per week (see Table 5.37) can be harvested even in the dry season. This amount meets the demand of the Sanitary Block and surplus is obtained. Thus, especially in semi-dry and rainy seasons a lot more rainwater is collected than used. This water should be exported to other buildings nearby (for example New Men's Dormitory).

5.2.2.14 Small scale consumers

Some sites have no water meter data. Thus, their consumption is unknown. Anyway, they are considered to be small scale consumers as their water consumption is rather low. These buildings have few toilets and just few staff members or students work there. The following buildings can be considered as small scale consumers: Workshop Centre, the Old Cafeteria and the Leola Hall. Beside those three buildings, there are other small scale consumers like the Eco Farm (chapter 5.2.2.9), the Clinic, the bank on campus or the tower next to the Bakery.

<u>Facilities</u>

These consumers have no rainwater collection systems in use and black water, (if produced) is led into septic tanks on site.

<u>Balance</u>

Water consumption from the main line of the Eco Farm (2,7m³ per week), the Clinic (2,2m³ per week) and the Bank (1m³) are known because water meters were installed recently. The Leola Hall and the Old Cafeteria are assumed to have less consumption than the Administration Building as their utilizations are similar. However, they are a little bit smaller. Thus, their consumption was assumed to be 10m³ per week. 5m³ per week were assumed for the Workshop Centre.

The overall consumption of these Small Scale Consumers is 20,9m³.

<u>Midterm future demand</u>

As these buildings are finished and the number of users will not increase, it is unlikely that the water consumption will change. The only possibility to decrease the consumption from the main line is to build rainwater harvesting systems.

5.2.2.15 Sachet Water Production

<u>Facilities</u>

VVU plans to start sachet water production on campus. Groundwater from the wells on campus should be used as source water. A clean place would be necessary for the packaging as well as treatment of water.

<u>Midterm future demand</u>

The water availability on campus will be under severe pressure as a producer of drinking water. Mr. Kwandahor (2009) head of the EcoTec Centre estimated a total production of 10 000 sachets per day (5 000l or 5m³/day). This implies additional water consumption from the groundwater wells of 30m³ per week (6 production days a week). Even if all three groundwater wells were working properly, this water would have had to be replaced by other sources.

5.2.2.16 New rainwater collection system near the Women Centre

Three rainwater underground tanks (each 100m³) will be constructed under the street passing the Women's Centre and the Women Dormitory. Figure 5.18 highlights the approximate location in red. This concept is new for VVU as the tanks will be situated under a street. Therefore, the tanks will be filled with gravel so that pressure and weight (for example from cars) do not destroy the tank. As a result, the storage volume is decreased and will be about 40% or 120m³.

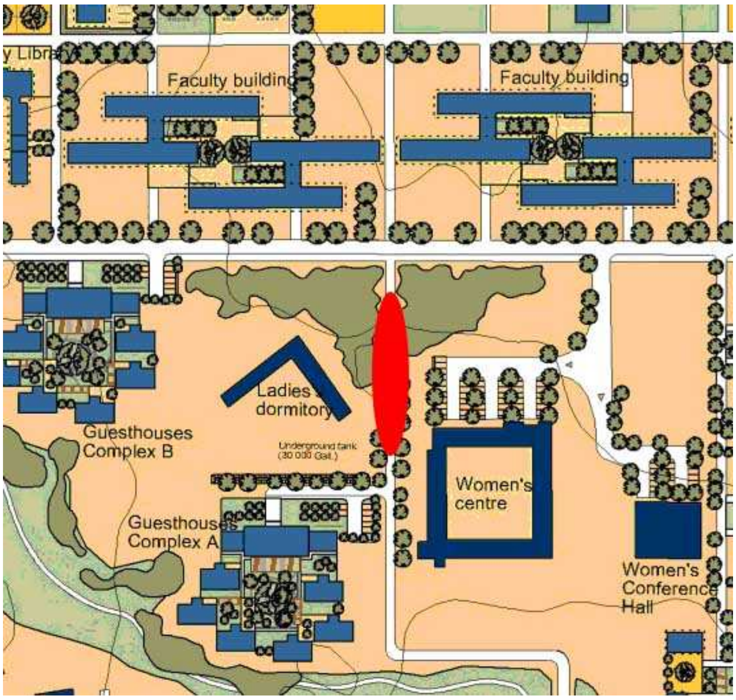

Figure 5.18: Site of new rainwater underground tank

During the field studies, the tank was in progress and the actual rainwater harvesting site not defined. Most likely are the connections of the remaining roof of the Women Centre and an overflow connection from the underground tank of the Women Dormitory. At the moment, only 400m² of the Women Centre's roof are connected. The remaining 1152m² could catch weekly 5,3m³ rainwater in dry season, 14,7m³ in semi-dry season and 25,2m³ in rainy season. Combining this amount of rainwater with the rainwater that is already collected at the Women's Centre, half of the demand could be covered in the semi-dry season. In the rainy season, rainwater would even meet the demand.

5.2.2.17 Daily water meter readings

Water meter readings were taken three times a week starting on October 19th until November 5th, 2009. It was observed that the water consumption was lower on weekends (Saturday and Sunday) than during the week. On weekends, daily consumption from the Main Reservoir of all metered buildings is about 26,9m³. During the week, the consumption rises to 45,3m³ (almost twice as high). All student dormitories, the cafeteria and the administration building consume distinctively less.

5.2.2.18 Summary

Facilities

Broken pumps and leaking rainwater tanks are a big problem at VVU (see Figure 5.19 and Figure 5.20). Thus, several rainwater harvesting systems do not work properly. A lack of finances makes it hard to replace these facilities.

Figure 5.19: Broken grey water pump

Figure 5.20: Broken rainwater tank

According to the pump attendant, the storage capacity (polytanks) is not sufficient at all buildings. Especially the Women Dormitory (30m³), the Administration Building (3m³) and the New Men's Dormitory (20m³) need additional storage capacities as emergency back ups.

Balance

For a better overview, the results of the previous chapter are summarized in the following tables. Table 5.38 illustrates the water consumption from the Main Reservoir and the amount of collected rainwater in the respective season. Table 5.39 states the accumulated waste water at each building and the respective treatment, use or re-use at each investigated building. Additionally, midterm future changes are stated if they are expected. For the midterm future demand changes of the Sanitary Block (Cafeteria) and the Cafeteria, assumptions of IÖV (2006) were taken. However, it has to be considered that the assumptions made by them were not always correct (see chapter 5.2.2.1, 5.2.2.2 and 5.2.2.12).

Table 5.38: Water consumption from the Main Reservoir and amount of collected rainwater in the respective seasons (dry, semi-dry, rainy) of each investigated building

Building	**Water consumption from the Main Reservoir** [2]	**Mid-term future change from the Main Reservoir** [2,3]	**Collected rainwater (dry/ semi-dry/ rainy)** [2]	**Mid-term future change of collected rainwater** [2,3]	**Remarks**
Women Dormitory	67,1	-	3/ 8,3/ 14,3	-	-
Guest Houses	5,4	≥ 5,4	1,6/ 4,3/ 7,4	≥ 3,2/ 8,6/ 14,8	conference room unclear
Administration Building	6,4	-	1,5/ 4,1/ 7,1 (NW[1])	-	Leaking tank
Faculty Flats	24,6	-	1,6/ 4,5/ 7,7 (NW[1])	-	Leaking tank
Residential Houses	33,7	-	2,9/ 8,1/ 13,9	-	Rainwater hardly used
Women Centre	29,8	-	1,8/ 5,1/ 8,7	-	-
New Faculty Building	0	-	6,9/ 19/ 32,7	-	-
Sanitary Block (at Cafeteria)	8,8	5,6	6,1/ 16,8/ 28,9 (NW[1])	-	Broken pump
Bakery	4,6	-	2,2/ 6,1/ 10,5 (NW[1])	-	Leaking tank
Cafeteria	23,3	18,7	-	-	-
New Men's Dormitory	56,9	22	8,2/ 22,7/ 39 (NW[1])	-	Building still under construction
J.J. Norty Hall	41,8	-	-	-	-
Baobab Centre	0 - ?	-	-	11,1/ 30,6/ 52,5	-
Small Scale Consumers	20,9	-	-	-	-
Sachet Water Production	-	30 (not sure)	-	-	-
New rainwater collection system near Women Centre	-	-	-	5,3/ 14,7/ 25,2	-
Total sum	323,3	51,7 (with sachet water: 81,7)	16,2/ 44,8/ 77 (+ NW[1]: 35,8/ 99/ 170,2)	≥ 19,6/ 53,9/ 92,5	-

[1] *NW – not working*
[2] *All values are weekly averages*
[3] *Mid-term future changes are stated, if expected*

Table 5.39: Accumulated waste water (yellow, black and grey water) and the respective treatment, use or re-use at each investigated building

Building	**Yellow water [m³/ week]** [1]	**Black water [m³/ week]** [1]	**Grey water [m³/ week]** [1]
Women Dormitory	-	74 (S)	66 (I), (NW)
Guest Houses	-	2,7 (I), (NW)	-
Administration Building	0,4 (F)	4,6 (BP)	-
Faculty Flats	-	(S)	-
Residential Houses	-	(S)	-
Women Centre	-	(S)	-
New Faculty Building	1,3 (F)	7,5 (S)	1,1 (S)
Sanitary Block (at Cafeteria)	1,2 (F)	7,2 (BP)	1,1 (S)
Bakery	-	(S)	-
Cafeteria	-	-	21,4 (I)
New Men's Dormitory	-	24,8 (BP)	31,2 (S)
J.J. Norty Hall	0,7 (S)	13,4 (BP)	58,8 (S)
Baobab Centre	-	-	-
Small Scale Consumers	-	(S)	-
SUMME	3,6	134,2	179,2

[1] *Abbreviations: F – use as fertilizer, S – treated in septic tank, I – used for irrigation (plants or farmland), BP – led to biogas plant, NW – not working (broken pump)*

The overall water consumption from the Main Reservoir at VVU is currently about 323m³ per week. During the week, consumption is almost twice as high as during weekends.

35,8m³, 99m³ and 217,2m³ of rainwater could be collected weekly (depending on the season) and used on campus if all systems were working properly. At the moment, only 55% are harvested (including the Baobab Centre). However, it is unlikely that even this amount is actually used (see 5.2.2.5). Buildings where rainwater harvesting systems are working well are the New Faculty Building, the Women Centre, the Women Dormitory and the Guest Houses.

About 3,6m³ of yellow water, 134,2m³ of black water and 179,2m³ of grey water accumulate per week. About 2,9m³ of yellow water are used at VVU's farmland. 52,7m³ of black water are used either for irrigation or are led to the Biogas Plant. 87m³ of grey water are used for irrigation (at the moment rather 21m³ as the pump at the Women Dormitory is not working). That implies that 0,7m³ of yellow water, 81,5m³ of black water and 92,2m³ of grey water remain unused. However, bear in mind that these results are mainly based on assumptions made by IÖV (2006) and not all assumptions were correct.

<u>Midterm future demand</u>

The overall water consumption will rise to 375m³ (or with sachet water production 405m³) per week. However, this is just an assumption because it strongly depends on future use of rainwater. If the rainwater is used properly (at those buildings where it has not been done yet) and all broken parts are replaced, it should be possible to keep the water consumption from the Main Reservoir at 315m³ per week.

In the near future, two major rainwater collection systems will be in completed, one at the Baobab Centre and one under the street near the Women Centre. Both systems will harvest rainwater that can be used to decrease the pressure on the Main Reservoir. At those sites, 16,4m³ (dry season), 45,3m³ (semi-dry season) and 77,7m³ (rainy season) of rainwater will be collected. This water can be partly used to decrease the current consumption. The Baobab Centre can export rainwater and the Women Centre will use less water from the Main Reservoir.

5.2.3 Water availability/ supply versus consumption

In this part of the chapter, the water availability as assessed in chapter 5.1 is compared with the water consumption as assessed in chapter 5.2.2. For the water consumption, data from the period June 2006 until May 2009 are used. The results are compared with water meter readings from August and September 2009 (see chapter 4.2.1).

5.2.3.1 Comparison with water meter readings from the period June 2006 until May 2009

Within this period, VVU consumed approximately 323m³ of water from the Main Reservoir per week. Additionally, about 16,2m³ (dry season), 44,8m³ (semi-dry season) and 77m³ (rainy season) of rainwater can be used per week. This is only 55% of the overall potential (all rainwater harvesting systems on campus work properly). This implies weekly losses of 19,6m³, 54,2m³ and 140m³ respectively.

The supply from Oyibi was about 305m³ per week. Additionally, 194m³ are supplied by the three groundwater wells. If comparing these values with the water consumption from the Main Reservoir (323m³ per week), the use of 176m³ is unknown.

Under these circumstances, already a rather low increase (coming from midterm future expansions) of the water consumption to 356m³ (or 9%) per week, can put the water supply at VVU under severe pressure. Additional water use for sachet water production would raise the consumption to 386m³ per week (6 days per week 5m³ per day, see chapter 5.3.2.5 Regulatory capacity).

Figure 5.21 illustrates the results.

It is likely that the rainwater use and the public water supply will not increase significantly. In addition, the water consumption from the Main Reservoir will rise by about 52m³ (82m³ with sachet water production). Under these assumptions, about 52m³ (82m³) of additional water supply per week, need to be provided in the midterm.

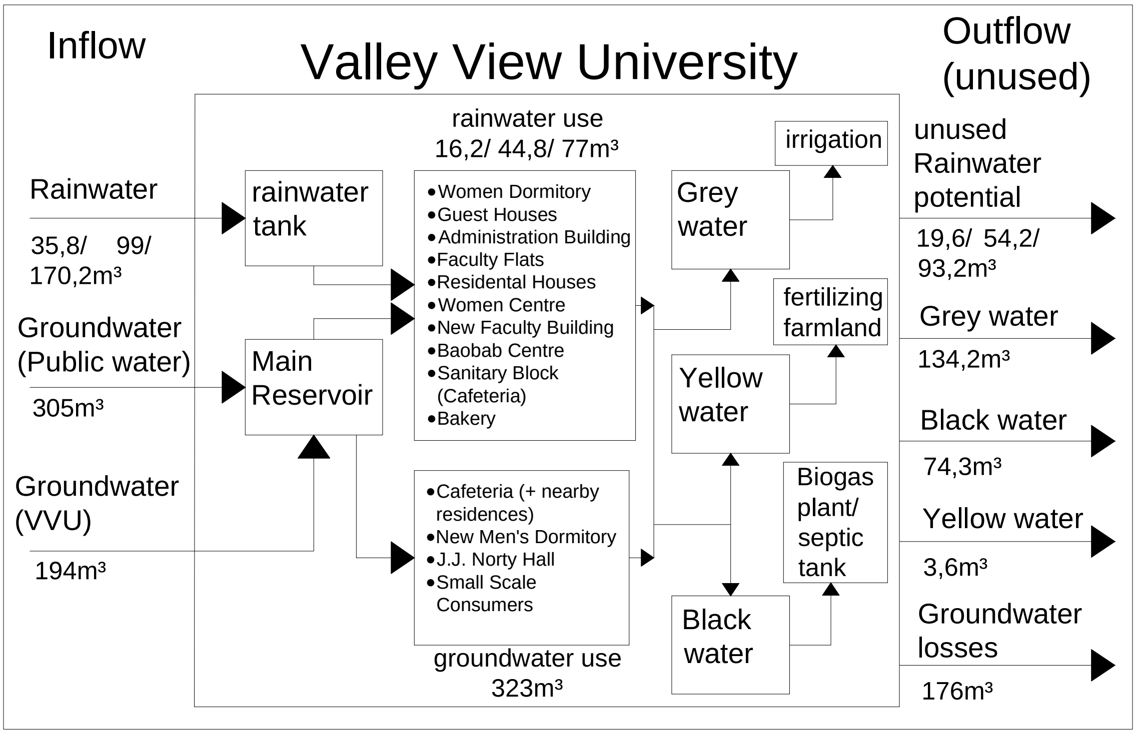

Figure 5.21: Water flux design for VVU's ecological water cycle management with major outflow and inflow amounts

5.2.3.2 Comparison with water meter readings from August 2009 and September 2009

Reviewing readings from August 2009 until September 2009, one major change was detectable. The water supply from the Oyibi Water Supply Scheme dropped to about 150m³ per week compared to 305m³ in the period between June 2006 and August 2009. The total amount of metered consumption remained similar with a weekly average of 323m³ (period June 06 to May 09) and 304m³ (August 09 and September 09). Thus, not metered water consumption and losses fell to 40m³ (from 176m³).

5.2.3.3 Discussion

Reviewing these data, differences between water consumption and water supply were obvious (between 176 and 40m³ per week). Thus, some possible reasons are subsequently stated.

As water is not stored, it can be assumed that this amount of water was weekly lost in the distribution network, used at construction sites or the block factory and partly taken from public tabs that are distributed over the campus. An investigation was conducted on the use of public tabs. Two tabs (one behind the Guest Houses and one at the entrance gate) were investigated for 12 hours. Both tabs were observed between 4pm and 8pm and the one at the gate was observed also between 5:30am and 9:30am. No illegal fetching was observed during this time. Additionally, the Guest Houses' caretaker and the guards at the gate stated that no illegal fetching is taking place. However, guests of the Guest Houses observed occasional fetching. Consequently, illegal fetching is seen as minor problem.

Construction sites on campus are usually supplied with water from the Main Reservoir without having a water meter. A block factory and irrigation (water from the public tabs) of plants and farmland on campus can be considered as additional consumers without water meter. The construction of the Baobab Centre was metered for five weeks having consumptions of 5,7 to 74m³ per week. Moreover, the block factory on campus is likely to use a lot of water. It would be necessary to meter all construction sites, the block factory and the tabs used frequently for irrigation, to find out how much water is lost within the system and how much is used at unmetered sites.

5.2.4 Water availability/ supply versus demand

It is not possible to estimate the exact water demand as the number of people working, studying or living within the buildings is mostly unknown or just roughly estimated by VVU's administration. KRÄMER (2007) estimated the average daily water consumption of students living in the student dormitories (see Table 5.40). Using the values for laundry, toilet (dormitory) and shower, it is possible to compare this demand with the actual supply to the respective building.

Table 5.40: water consumption [l/day] (KRÄMER, 2007)

		J.J. Norty Hall	New Men´s Dormitory	Women´s Dormitory	Average
Laundry		12,3	11,6	16,3	13,4
Toilet	Dormitory	2,1	11,6	30,8	14,8
	Sanitary Block	1,4	4,1	4,1	3,2
	Administration Building	2,3	3,6	8,6	4,8
Shower		48.5	79	45	57.5
Total		66.6	109.9	104.8	93.7

KRÄMER (2007) estimated the average weekly water demand of a Women's Dormitory student to be 0,64m³. This implies a water demand for 228 students (fully occupied) of 147m³ per week or for 196 students (occupation 2009) of 126,36m³ per week. The previously calculated consumption from the main line is about 71,5m³ per week during semester. As rainwater is also used at the Women Dormitory, this amount can be added up with maximal 14,3m³ per week (during rainy season). This implies that only about 44% of the actual demands (196 students) are met.

For the New Men's Dormitory KRÄMER (2007) estimated an average weekly water consumption of 1,02m³ per student. This implies a demand between 100,2m³ (140 students) and 121,6m³ (170 students) per week. During the semester about 63m³ are supplied by the university's water network. Thus, just 63% (140 students) or 51,8% (170 students) of actual demands are met.

For students living in the J.J. Norty Hall KRÄMER (2007) estimated a weekly demand of 0,44m³ per person. This implies a demand of 76m³ per week (174 students). However, during the semester only about 45,5m³ are supplied. Thus, just 60% of actual demands are met at the J.J. Norty Hall.

A comparison of water supply and water demand at the student dormitories points out that the demands are not met. This is most likely also true for other buildings. Often no water is supplied to buildings and showers or toilets cannot be used. Students have to fetch their water from public tabs located on campus. Thus, additional to the rising future demand the current demand is not met yet.

5.3 Water management

This chapter refers to the second overall objective of the thesis, which is to evaluate planned solutions for sustainable water supply within the climate project. It especially refers to the detailed objective to consider sustainability of water supply and sanitation at VVU.

In this chapter, VVU's current water management practices are described. Then proposals for management improvements are given, with special emphasises on ground- and rainwater management. At the end, a short summary is given.

5.3.1 Current situation at VVU

VVU's WS&S and its related facilities are currently managed by mainly three people (subsequently referred as water managers), namely the Ecological Sanitation Manager, one pump attendant and one plumber. They all have certain duties to maintain and manage VVU's water system. The major duties are subsequently stated.

Ecological Sanitation Manager's duties:

- Billing of water
- Organizing the water supply on and off campus
- Dealing with all WS&S and environmental issues on campus
- Coordination with project partners from Germany and Austria
- Managing work study of students
- Data collection
- Supervision of sanitary workers

Pump attendant's duties:

- Controlling the extraction from the groundwater wells
- Controlling the water amount pumped to each building
- Inspection of all water related facilities (rainwater tanks, pumps, poly tanks)

- Cleaning of water tanks
- Weekly reading of water meters

Plumber's duties:

- Replacing and connecting tubes
- Repairing connections, tabs and other water facilities
- Installing new water facilities like pumps, water meters, tank overflows,…

Beside these three persons responsible for the water system, also other people are helpful for the work at VVU. All relevant contact data are subsequently stated:

- Emmanuel Kwandahor – Head of the EcoTec Centre

  E-Mail: kwandahor@yahoo.com

  Telephone Number: 0244436113
- Daniel Sarpong – Ecological Sanitation Manager

  E-Mail: dsarpong2001@yahoo.com

  Telephone Number: 0244488440
- Mr. Wyo – Pump attendant

  Telephone Number: 0246533998
- Samuel Bamfo Ntiamoah – Plumber

  Telephone Number: 0242343231
- Bismark K. Adjanor – Electrician

  Telephone Number: 0243337936

Any problem, related to WS&S systems within the campus, has to be reported to one of these persons. Problems can be easily und rapidly solved, as long as financial expenditures are not necessary. To fix major problems, which require financial expenditure (e.g. pump replacements), requests to the financial administration have to be made. It seems that it often takes a long time or several requests until money is granted. Consequently facilities can remain out of operation for long. This fact was mainly experienced with the replacement of pumps at the grey and black water tanks of the Women Dormitory or Guest Houses, and the pump at the rainwater underground tank of the Sanitary Block. It appears that the use of rainwater and grey water is not of high priority as long as enough groundwater is available.

To get an idea of current problems and possible improvements of WS&S at VVU, semi structured interviews were conducted with the most important water stakeholders at VVU (see 4.3.3). The following list gives challenges and ideas for improving VVU's water system and its management.

<u>Challenges as mentioned by the stakeholders:</u>

- Occasional water shortages → increase water storage capacity, repair or replace rainwater tanks, better groundwater and rainwater management
- Low water pressure → higher water tower
- Lack of money (old water lorry, broken pumps) → VVU should sell sachet water

The current system cannot be seen as good yet. Water shortage is still a problem but not only because there is a general lack of water rather because the system is not working properly. Rainwater systems remain unused because they are broken or because of weak management. There are continuously problems with the groundwater wells (Borehole 3 cannot be used). Therefore, these sources are not used as they could. One of the biggest challenges is the lack of fund available for repair and maintenance of the WS&S systems.

5.3.2 Further improvement towards sustainable water management

VVU's water system is already based on incentives given by the previous projects (see chapter 3.3). However, there is still much improvement possible. This chapter gives recommendations for further improvement of the current water management.

5.3.2.1 Challenges at VVU

To take up the challenges, they are summarized again. Stakeholders at VVU especially mentioned:

- Water shortage
- Facility management
- Groundwater management

Beside that, following problems were also recognized during the field study:

- Human resources – especially participation
- Lack of money

To overcome those problems and challenges in VVU's current water management, recommendations by the GWP (2008) (see chapter 4.1.1.2) and a revision of the Oyibi Water Supply Scheme's management is considered and used for improvement proposals.

5.3.2.2 Case Study Public water supply – Oyibi Water Supply Scheme

The Oyibi Water Supply Scheme is the major supplier of water to VVU. The management structure of this small scale scheme could be similarly adapted at VVU to improve its WS&S. The information is based on a meeting with the Oyibi Water Supply Scheme's management and two copies that were handed out during the discussion. Unfortunately no author and no date were mentioned on one paper with the title: 'Abokobi Area and Oyibi Area Small Towns Water Supply Schemes, Greater Accra Region, Ghana'. The other copy was published by CWSA (s.a.a).

The Oyibi Water Supply Scheme was established by the Danish International Development Agency in co-operation with the CWSA in 2002. It runs two groundwater wells that have a yield of 11,9m³/hour and 9,7m³/hour with an approximate pumping regime of 13 hours each. The boreholes are 45 and 54 meters deep and the pumps are 40 and 44 meters below the ground. They supply more than 6.000 people in nine communities. The largest consumer among them is VVU.

Following objectives were implemented:

- Provision of a sufficient quantity of water
- Provision of good water quality (GSB & WHO Standards)
- Provision of water within the reach of the population
- Ensure reliability of the service
- Ensure economy in construction

<u>The Management</u>

To achieve good O&M management, principles of sustainability, and community ownership and management are followed. Therefore, a Water and Sanitation Development Board was established. This Water Board oversees the O&M of the scheme. Additionally, Water and Sanitation (Watsan) committees were set up for the responsibilities of each community. The

Watsan committees consist of 7 members and the Water Board consists of 3 representatives of each Watsan committee. Moreover, two members of the District Assembly have an observer status in the Water Board.

The Water Board is the major decision making body and is responsible for the management of the scheme. The following list consists of some of the major duties:

- Assistance in the implementation of water supply facilities
- Held regular Meetings
- Setting of water tariffs
- Promotion of sanitation and hygiene practices
- Financial planning and budgeting of the scheme
- Staff management
- Working together with private companies for O&M
- Monthly reporting to district assemblies

The Watsan committees assist the Water Board and they are responsible for communication between the Water Board and water users.

The basic idea is that the communities themselves operate and maintain the system through their water board. Additionally, operating staff is employed by the Water Board including a technical coordinator, an operator/ caretaker, an accounts clerk and several water vendors.

The payment method, that the Oyibi Water Supply Scheme uses, is called ‘Pay-As-You-Fetch’. The vendors receive 20% of the revenue. 75% go into the Water Board’s account and 5% into the local Watsan committee’s account. Some of the funds are used for O&M, replacements and future expansions. A trend of income and expenditure from February 2004 to February 2005 indicated that the income exceeded the expenditure by 25%.

The water quality management is assured by the GWCL. They analyse the water quality three times a year at the boreholes as well as at the end of the supply lines. According to these measurements, the water is conform to the WHO guidelines and GSB requirements for drinking water. Moreover, chlorine is added on a weekly basis for disinfection.

<u>Challenges</u>

In 2002, the system was designed for a ten year horizon. The population was estimated to reach 5940 in 2012, with a demand of 271m³/ day. Due to an unexpected fast population growth, this horizon was already met after about five years in 2007. The current population is unknown. After six years (2008) the system showed first signs of deterioration. The maintenance coasts started to rise. Especially the generator operating one pump has broken often. Moreover, the system is suffering under corrosion because of the waters’ relative high salt concentration (magnesium and total iron) (see also chapter 3.4.2.2).

To overcome those problems goals were set. One is to replace the generator or connect the pumps to the electricity supply network. A connection to the passing water pipeline (Dodowa to Accra) that is owned by the GWCL is planned. A long term goal is to drill a third borehole. Nevertheless, estimating the future demand is not possible. There are no regular population growth rates available. Another problem is that a lot of people still fetch water from ponds, instead of using the water from public tabs. They consider it as too expensive. However, it is likely that increasing wealth and public education will also lead those people to the public supply scheme.

The interaction with VVU is not a problem according to the Scheme’s management. However, VVU is at the end of the supply network and on a rather high elevation. The fact that VVU’s water consumption from the public water supplier is decreasing could be a result from the increasing water demand in the whole region and its particular position in the supply network.

5.3.2.3 Building institutional capacity – developing human resources (conclusions that can be drawn from the previous case study)

To guarantee a well working system, human resources have to be available, trained and informed. Especially participation, water professionals and regulatory capacities are necessary. At VVU, especially participation is weak or nonexistent at all.

VVU does not have a Watsan committee, although it is a requirement of the Oyibi Supply Scheme for each community and a recommendation of the NCWSP. VVU itself is a small scale water supplier to its staff, students and buildings. Thus, an institutional capacity similar to Oyibi's Water Board seems practical. This capacity could, at the same time, serve as Watsan committee. At the moment the staff members of the EcoTec Centre act as Watsan committee. This system is based on reports and requests from external persons or the water managers (see chapter 5.3.1). However, this does not necessarily guarantee good participation.

The GWP (2008) recommends active participation of the public as water users' associations, consultative groups, community groups or lobby groups. However, these groups need information, skills and water awareness. Moreover, the ToolBox gives these guidelines:

- All relevant categories of water users should be represented in the association.
- Public participation needs to be carefully managed to avoid capture by minority or particularly articulate groups.
- Sustainability also depends upon the existence of an agreed set of rules as well as reliable mechanisms to enforce such rules and settle dispute.

For VVU a committee should include students or student deans of the dormitories, an ambassador of staff, an ambassador of VVU's residents, the Ecological Sanitation Manager, a plumber and/ or the pump attendant and a leading member of the administration. Gender equity should be considered. Oyibi's Water Board for example requires that at least one third of the members are female. The committee could meet every semester or once a year to discuss general problems of VVU's WS&S, additional to general reports or requests at the EcoTec Centre. It is unlikely that students communicate their perceptions of the water system. Nevertheless, they could give new incentives for development or help to set priorities. However, the EcoTec Centre should be responsible for actual duties (compare with major duties of Oyibi Water Supply Scheme at chapter 5.3.2.2).

5.3.2.4 Training to build capacity in water professionals

As university promoting sustainability and ecological cycle management, VVU should incorporate WS&S as wells as water management courses in their programmes. During the field study, the president of VVU, Dr. Laryea, expressed interest in establishing co-operations with universities teaching ecological and environmental studies. However, it appears that these plans are not of high priority yet, although VVU would have the best preconditions to establish such programmes because of the projects that have been running on campus since 2003.

Learning by doing combined with theory (assistance of VVU's water managers, participation in decision making – Watsan committee) would ensure capacity building and development of human resources, especially for VVU but also for Ghana. A good example for successful training is that during the field study, a student was trained to assist water quality measurements. Appropriate courses could advance such collaborations with VVU's water managers. Students and VVU would mutually benefit from these incentives.

Useful recommendations given by the GWP (2008) that are appropriate for VVU are:

- Provide specific courses on participatory approaches and gender awareness.

- Encourage multi-disciplinary education involving all kinds of water practitioners like environmentalists, economists, engineers and social scientists.
- Including water management in degree programmes like the Bachelor of Science in Development Studies and departments like the Department of Development Studies or add water as major in these studies.
- Add water management or environmental studies with water as major as academic programme.

5.3.2.5 Regulatory capacity

According to the GWP (2008), a clear regulatory framework is of great significance for IWRM. Human and technical capacity for monitoring and implementation is necessary for success. Monitoring requires appropriate equipment and knowledge how to interpret data. Implementation needs clear defined responsibilities (see 5.3.3 Management Plans). For VVU, it is important to gain regulatory capacity in the fields of economic assessment, water management and if drinking water production is considered for water quality analysis.

All these requirements (appropriate equipment, knowledge of interpretation, incentives for responsibilities and regulatory capacities for the three stated fields) were or are provided, implemented or suggested by the project partners like BOKU University or by this thesis.

Regulations for economic assessments are necessary to enable proper O&M. Revenues from water selling (water lorry, residential houses and a certain amount of study fees) should be saved and exclusively used for funding of O&M. Thus, the water related revenues and expenditures should be accounted separately. The long term objective has to be benefit of course. With this benefit, also larger expenditures like a new tank lorry, replacement or repair of rainwater tanks, replacement of pumps and repair Borehole 3 would be possible without chronological delays.

VVU is considering to start drinking water production (see also chapter 5.2.2.15) as additional revenue generator. This is certainly a good idea to overcome current financial constraints. However, as producer of drinking water the water availability on campus would be under severe pressure. Mr. Kwandahor (2009) head of the EcoTec Centre Services estimated a total production of 10 000 sachets per day (5 000l or 5m³/day) and a revenue of about 0,04 GhC by sold sachet (0,01 GhC production costs per sachet) or 400 GhC per day. The production facility is about 25 000US$ or 37 500GhC (1GhC ~ 1,5 US$). Under these conditions a break even would be possible in 94 days. However, this implies additional water consumption from the Main Reservoir of 30m³ per week (6 production days a week). Even if all three groundwater wells were working properly, additional water resources have to be found (see chapter 5.2.3).

Considering drinking water production as option, this should also include the thinking of regular water quality analyses. Trained employees could regularly analyse the drinking water with the instruments provided by BOKU. Trainings on how to use these instruments were conducted during the field study. Moreover, explanations on how to interpret data were given. Analyses will give an approximate overall state of the water sources. Changes in the water quality will be observed if data are stored in a database and regularly compared.

This requires clear defined responsibilities like who conducts the analyses (two people) or who manages the database (storing and interpretation). Recommendations for how to implement such responsibilities are given in chapter 5.3.3.

5.3.2.6 Water resources knowledge base

This tool implies the collection and storage of data. Data collection already started at VVU. Water meter data are available since 2006. Rainfall data of VVU are available for a three year period from 2004 to 2007. However, data about water quality, state of the groundwater wells and rainfall data beyond 2007 are not available.

For VVU it is very important to create a good knowledge base as data relevant for VVU's water management are not easy accessible or not available at all. The database should include:

- Water quality (especially groundwater, but also for the other sources)
- Water quantity available (groundwater extraction and supply of public supplier)
- Water meter readings (universal)
- Rainfall data (data logger)
- Groundwater data (data loggers) and information (on campus and regional)

Data should be collected regularly and over a period of many years and stored electronically. Moreover, an exchange with other institutions (WRI, GWCL, CWSA, meteorological institutions) conducting similar measurements, should be suggested and implemented. Furthermore, water meter readings should be universal on the whole campus so that an exact water balance can be determined and possible water losses estimated (see chapter 5.2.3). Such a knowledge base would help to make more informed, transparent and better decisions and would assist the management in defining investment priorities. Of course, this requires regulatory capacities, especially clear defined responsibilities.

5.3.2.7 Improved efficiency of use

To improve efficiency, it is necessary to change "peoples' attitudes and behaviour towards water use" (GWP, 2008). Good mechanisms for VVU could include economic incentives, education and communication.

VVU recently started to use prices per m³ for water sold and does not apply flat rates anymore. This should be a good economic incentive for people to use water wisely. A flat rate like applied before, encourages uncontrolled water use.

At the same time, use of rainwater should be promoted where possible. People living in residential houses could increase their use of rainwater and save money. VVU would benefit of less water consumption and the consumer would benefit from smaller monthly bills. Installation of pumps at the rainwater tanks of the residential houses would contribute to an easier change of attitude and behaviour. A subvention for inhabitants who buy pumps could help.

5.3.2.8 Raising public awareness

"The aim is to engage the public in such issues as: water conservation; hygienic water use; preservation of wet ecosystems; water user awareness; developing self-regulating water institutions; increasing the willingness to pay or contribute to water services; awareness for planning for emergencies; and strengthening political will (…)" (GWP, 2008).

Following actions help to raise awareness in scientific communities, public institutions or interested students and teaching staff; hence, they bring public awareness and economic benefits due to increasing students in the long-term.

- The research that was conducted by BOKU, other project partners and during the field studies is suitable for water campaigns on campus and on regional or national level. Obtained information about water quality or quantity (groundwater, rain water, grey water) can draw more attention to VVU and promote its status as ecological university when made public. However, the information must be available. A good way would be access to information over the internet or distribution via public media like news papers, radio or television.
- Incentives like the ECOSYS 09 and a planned workshop in February 2010 (chapter 5.5.4) are a good example for what is necessary, to increase public awareness and build networks of stakeholders.

- Product labelling is another good tool to raise public awareness. If sachet water is produced it definitely should be certified by the GSB to guarantee good quality water.

5.3.2.9 Pricing of water services

Water should be appropriately priced. The price should reflect the scarcity value of water and the provision costs. Furthermore, it should be possible to generate revenues for O&M, as well as modernisation and expansion of the system. Nevertheless, the tariff should be affordable and acceptable (GWP, 2008).

As already mentioned in chapter 5.3.2.7 VVU introduced volumetric tariffs. They charge 2,8 GhC per m³. Thus, VVU makes 1,15 GhC revenue per m³ as compared with the public supplier’s tariff of 1,65 GhC per m³.

These revenues should be saved in a separate account and exclusively used for O&M and future expenses for WS&S system. In addition, a share of revenues from student fees should be used for O&M of the system. This would guarantee proper O&M, fast replacement and repair of necessary facilities like rainwater tanks or pumps.

5.3.3 Management plans

To fulfil the recommendations mentioned by the ToolBox (see chapter 5.3.2.5), the implementation of management plans with clear defined responsibilities is necessary. Explicit responsibilities and work plans can improve the knowledge base and function as regulatory capacity. Some of the proposed duties are already implemented and executed at VVU; however, there are no written plans. Plans would give clear regulatory frameworks that could improve the whole system.

5.3.3.1 Groundwater wells

Proper groundwater management includes demand- side management and supply- side management. For groundwater supply management, it is necessary to understand the aquifer system and its sensitivity as well as interactions between the groundwater body and connected surface waters. The demand- side management includes social development goals (agricultural irrigation, food production), regulatory interventions and economic tools (TUINHOF et al., 2002) (see also Figure 5.22).

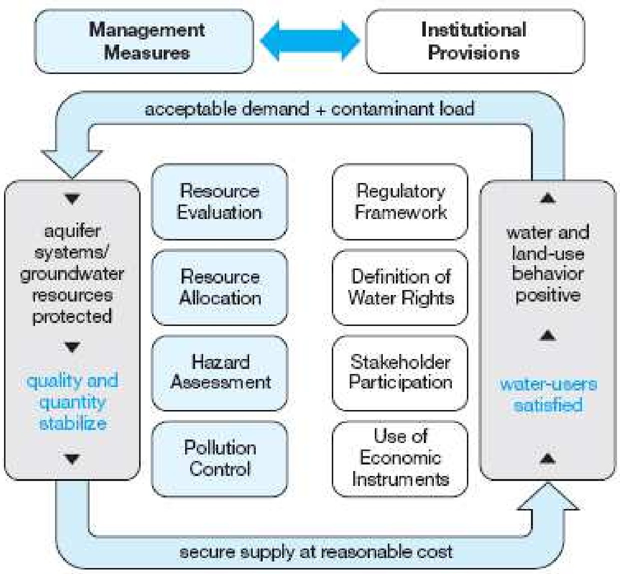

Figure 5.22: Integrated groundwater resource management (TUINHOF et al., 2002)

Looking at Figure 5.22, VVU's responsibilities in groundwater management include:

- Resource Evaluation
- Hazard Assessment
- Pollution Control
- Stakeholder Participation

Resource evaluation was implemented during the field study. Data loggers, water quality analysis and water meter readings provide data that can be used to evaluate the groundwater wells. Any variations in these data should be questioned and investigated. However, as the database is still rather small, profound interpretation is not possible yet. Thus, it is important to continue with the measurements and data collection for exact evaluation.

Hazard assessment helps to use data correctly. Data can be used as early indicators for hazards like pollution of the aquifer or yield reduction. For VVU, these two possibilities are potential hazards. As waste water treatment is not properly executed around VVU and there is always the chance of leaking septic tanks, pollution due to waste water intrusion is possible. Percolation of pollutants from waste dumping or waste incineration could also have impacts on the groundwater's quality. Parameters like nitrogen compounds, chloride or phosphorous indicate pollution from waste water. Variations in electrical conductivity relate to salinisation or groundwater pollution, too.

Next to pollution, yield reduction can be a hazard. Water meter and water level readings can help to indicate yield reduction. However, seasonal variations are possible. Thus, measurement results from longer periods have to be available, to determine if it is just seasonal or already a general interference.

When assessing the hazards, pollution control seems to be an obvious need but also hard to realize. A proper waste disposal system is not available for VVU. Nevertheless, especially for hazardous waste like batteries or pharmaceutics, alternatives to dumping on site have to be found, to prevent irreversible groundwater pollution. Collaboration with the EPA, who is collecting industrial waste, is maybe extendable to other hazardous wastes.

Stakeholder participation implies collaboration with other institutions managing groundwater. Especially the Oyibi Water Supply Scheme could be a good partner for knowledge and information sharing. Although it is unlikely that VVU and Oyibi share the same aquifer or that they influence each other when extracting water (OYIBI SUPPLY SCHEME, 2009), both institutions depend on each others success. Other stakeholders can be neighbouring villages, the district assembly, the WRI or other institutions, NGOs or universities dealing with groundwater.

The Plan

- Regular download of data from data loggers (monthly), storing of data in a computer based database and comparison of results
- Regular analysis of water quality on site (every two or three weeks) and storing the results in a computer based database (see Annex 8). As the water is considered to be used as drinking water, this would increase the credibility of VVU and would help to detect deterioration early
- Investigation of possible hazards and defining countermeasures and corrective measures (distribution of information to other stakeholders)
- Investigation of save waste disposal opportunities, especially for hazardous waste like batteries or pharmaceutics (distribution of information to other stakeholders)

- Regular meetings and discussions of new developments concerning groundwater with relevant stakeholders

First results of groundwater data logging and interpretation guidelines

The first results of the installed data loggers are presented in this part and interpretation incentives are given. For the presented level measurements, it has to be considered that they have not been compensated with barometric files as these files have not been available. Nevertheless, trends can be observed. Problems also occurred with conductivity and temperature measurements. As soon as the water level (blue line) dropped to a certain level at Borehole 2 (see Figure 5.23) or as soon as the pump started pumping at Borehole 1 (see Figure 5.24), the conductivity measurements (red line) were not correct anymore. Also the temperature measurements (black line) were influenced by the pumping (see Figure 5.25). Trends can be observed for temperature and conductivity measurements if the extreme outliers are not considered. However, these temperature and conductivity measurements are not considered in this thesis as conductivity and temperature measurements were taken also for the water analyses (see chapter 5.1).

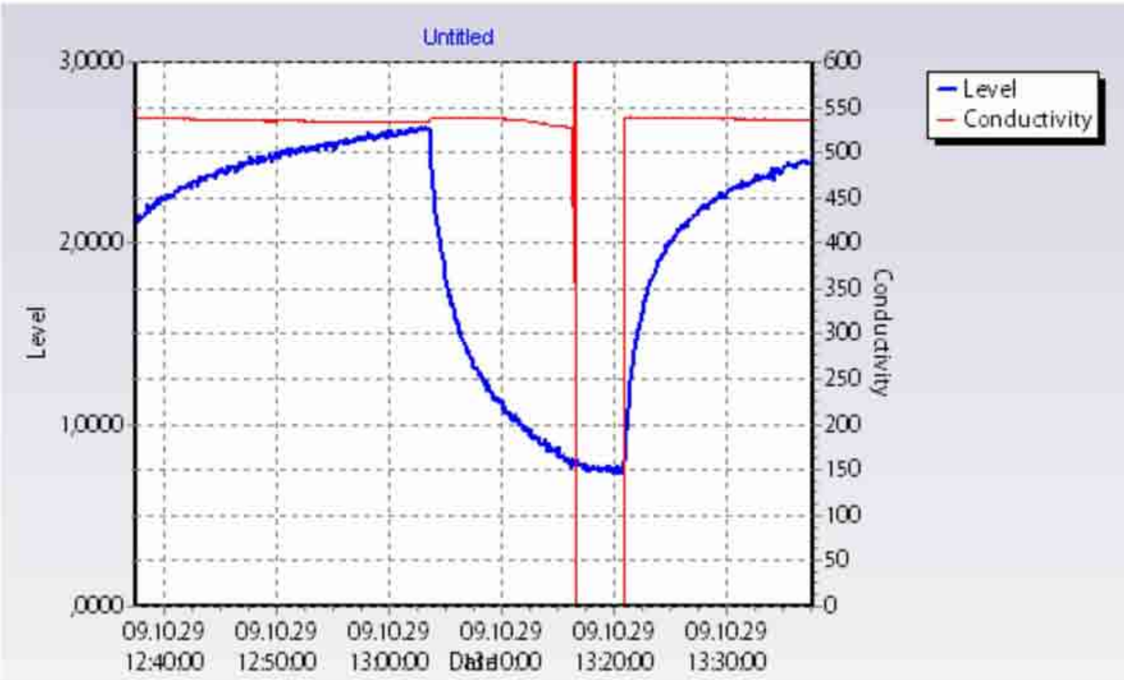

Figure 5.23: Comparison of level and conductivity measurements at Borehole 2 during a test where the measurement rate was set to 5 seconds

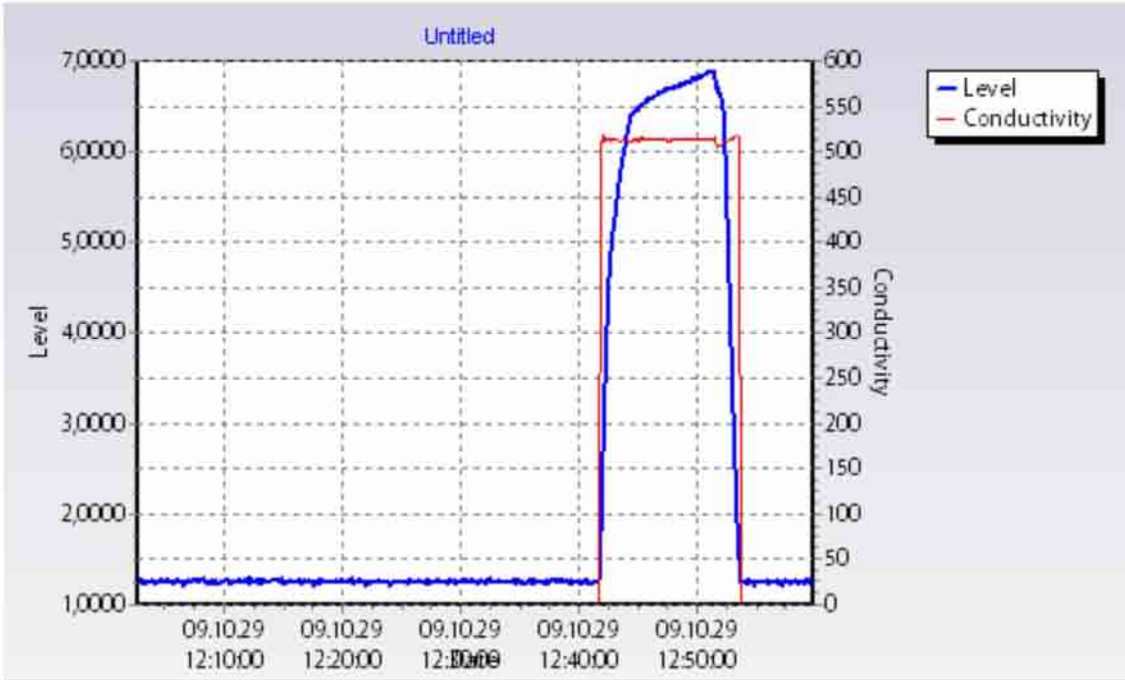

Figure 5.24: Comparison of level and conductivity measurements at Borehole 1 during a test where the measurement rate was set to 5 seconds

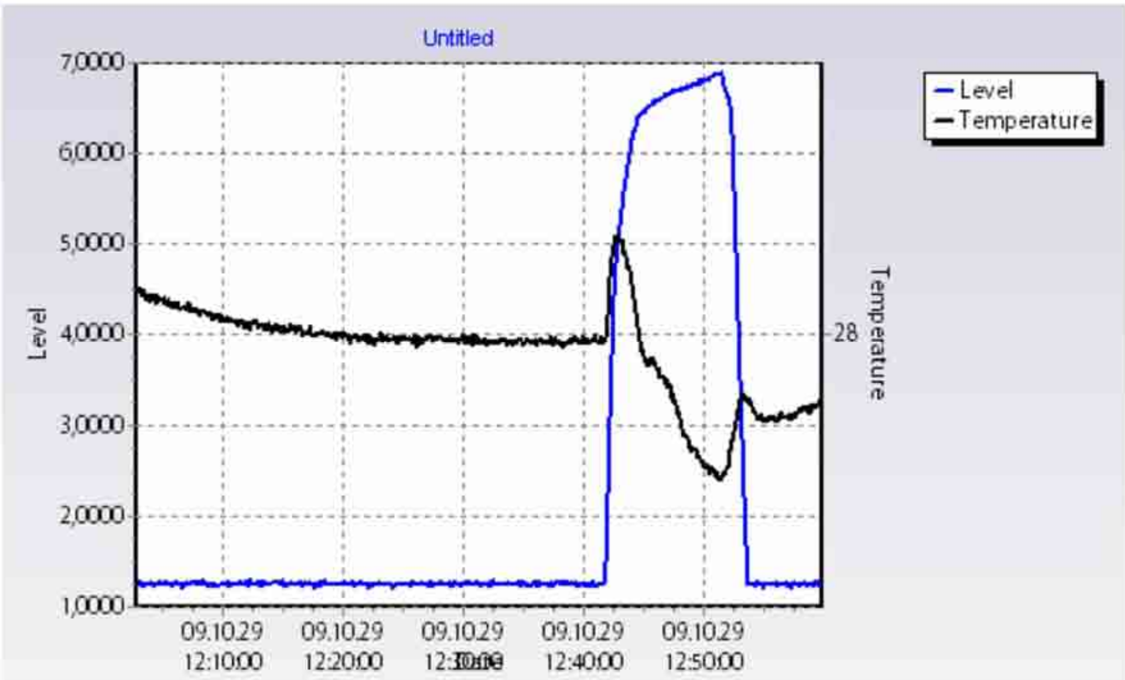

Figure 5.25: Comparison of level and temperature measurements at Borehole 1 during a test where the measurement rate was set to 5 seconds

For all three pumps, it has to be considered that they are manually and automatically operated. Each pump has automatic start and stop devices installed, so that the pumps are not running dry. The pump stops as soon as the lower device is above water level and starts again when the upper device is covered with water again. Additionally, the pump attendant occasionally turns the pumps on and off, depending on the water level in the Main Reservoir (see chapter 5.1.2) or depending on the running time of the pump.

The following three figures (Figure 5.26, Figure 5.27 and Figure 5.28) show the pumping schedule of all three groundwater wells during one month (starting on October 29th until November 30th). Borehole 1 is pumping almost continuously (see Figure 5.26: blue line on the bottom). During the day, the pump attendant usually turns off the generator of all pumps for about one hour (see Figure 5.26: thin vertical lines up to 9,0000 to 10,0000). Occasionally the generator is turned off for longer periods of more than one day, e.g. on November, 20th. The generator was turned off at around 6pm, on November 20th, and turned on again on November 22nd, at around 10am.

As previously stated, a yield reduction is a possible hazard for VVU. An early warning sign is water level reduction. To identify water reduction, the peaks of longer periods without pumping should be compared regularly. One possibility would be to not pump for two days a month and record the highest water level. Comparing these results over a longer period of time should indicate a water level reduction if present. However, it has to be considered that seasonal influences are possible. Constant recording for at least two or three years would be necessary to see first results. Looking at Figure 5.28, it is obvious that the actual water level is hard to determine. Comparing the water level of Borehole 3 before and after a long pumping period (09.11.06 until 09.11.14), it is obvious that the pumping strongly influences the recovery of the groundwater. The water level after the pumping period is remarkable lower than before, even after four days without pumping (end of November) the previous level is not reached (beginning of November).

Comparing the actual levels, it seems like that Borehole 1 and Borehole 3 seem to be more reliable sources for the future. Whereas Borehole 1 and Borehole 3 reach levels of 13,0000 to 12,0000, Borehole 2 reaches only 4,0000 (see Figure 5.27).

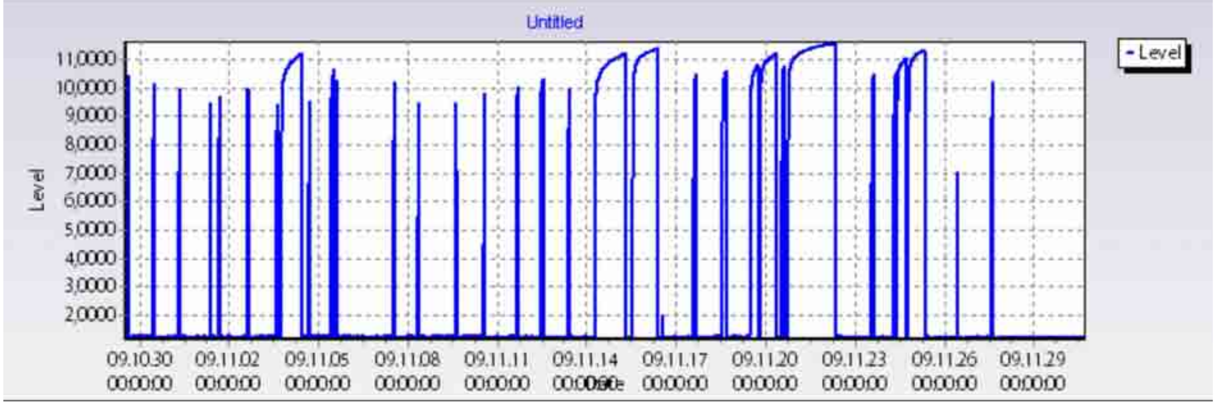

Figure 5.26: Pump schedule of Borehole 1

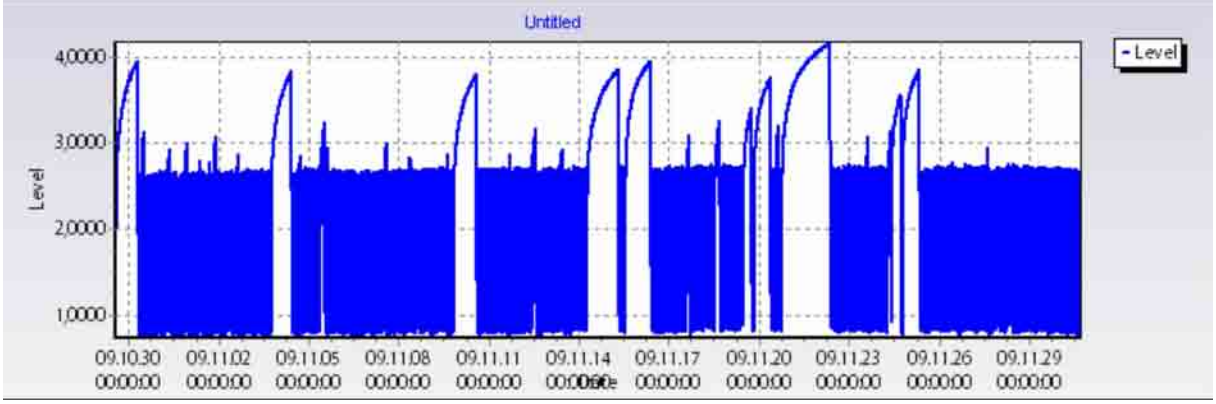

Figure 5.27: Pump schedule of Borehole 2

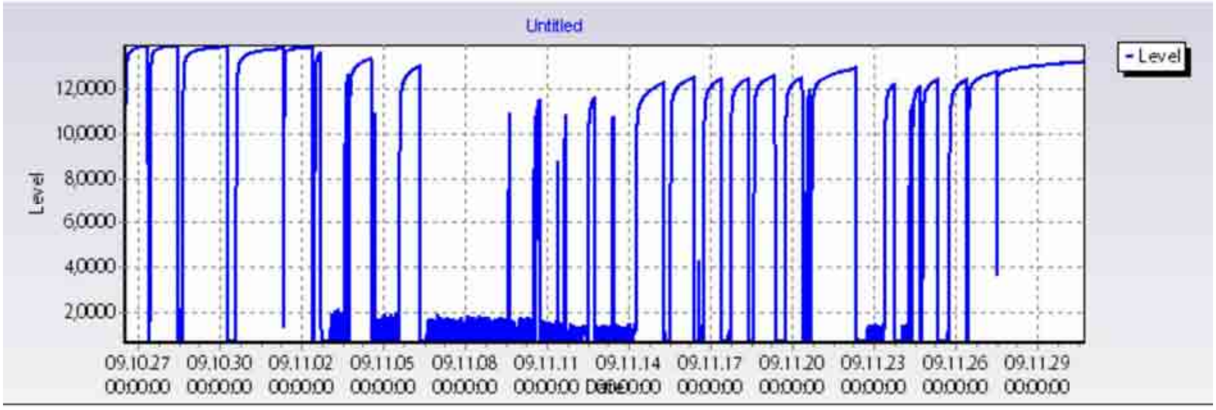

Figure 5.28: Pump schedule of Borehole 3

5.3.3.2 Rainwater

Rainwater management is already conducted at VVU. Several rainwater harvesting systems are installed and collected rainwater is partly used. However, the management has room for improvement. Subsequently, some points are stated that were observed during the field study. They should be considered when improving the system.

- Repair the rainwater tanks at the Faculty Flat, the Administration Building (plus pump) and the Bakery (plus gutter connection and pump). This implies savings of 14,2m³ per week of water from the Main Reservoir or 23GhC per week when this amount of water is not consumed from the public supplier. First, a quotation for the repair should be requested, then a cost benefit analysis has to be evaluated. If a repair is too expensive, building new tanks should be considered.
- Installation of pumps at the residential houses. This would imply savings of 7,8m³ per week of water from the Main Reservoir or 12,5 GhC respectively.
- Finding proper usage for the rainwater collected on the surface at the Baobab Centre. Supplying the New Men's Dormitory with rainwater could be an option, as it is nearby and represents a large consumer.
- Analyses of water quality should be conducted because rainwater is quite vulnerable to chemical, physical and microbial contamination (ENHEALTH, 2004). However, it cannot be recommended as drinking water if not disinfected or boiled before usage. Nevertheless, it is suitable as process water for toilets or showers.
- The general condition of rainwater tanks is rather poor. Therefore, they should be repaired and improved. Especially holes and gaps are omnipresent (access points, pump entry,…).

  "Tanks should have impervious covers and all access points, except for the inlet and overflow, should be provided with close-fitting lids which should be kept shut unless in use" (ENHEALTH, 2004). The inlet to the tank and the overflow should be covered with an insect-proof mesh (ENHEALTH, 2004).

<u>The Plan</u>

For maintenance and monitoring, ENHEALTH (2004) recommends a procedure consisting of a range of regular visual inspections. ENHEALTH (2004) favours this to laboratory testing of rainwater quality as the quality often varies a lot. The list was adapted to suit VVU's environment. The components of roof catchments and tanks have to be inspected at least every six months:

- Gutters: Cleaning and inspection. If large amounts of debris are found, the frequency should be increased.

- Roof: Clearing of debris like leafs or other plant materials. Overhanging trees should be pruned.
- Tank inlets: More frequent inspections, especially after heavy precipitation.
- Tank and tank roof: Repairing of any holes or gaps.
- Internal inspection: Check for presence of any animals or insects. If any are present identify and close access points. Check for presence of algae. If any are present find and close points of light entry.
- Inspection of tanks for accumulated sediments. If the bottom is covered, the tank should be cleaned.

Additionally, the following steps are necessary:

- Occasional water quality analyses on site (rainy season twice, dry season once) and storing of data in a computer based database (see Annex 8). As the rainwater cannot be used as drinking water without treatment, regular quality analyses are not necessary. However, occasional analyses can indicate problems of the harvesting system. At sites where rainwater could be used as drinking water, it should be clearly stated and visible for all users that the water is not safe for drinking without additional disinfection or boiling (hygiene promotion).
- Regular downloading of data from data loggers (monthly) and storing of data in a computer based database.

<u>First results of rainlogger data</u>

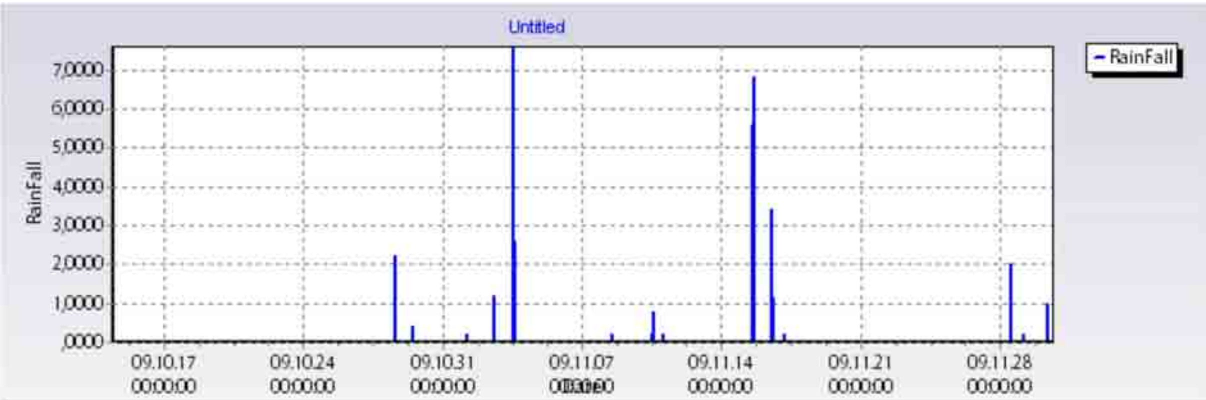

Figure 5.29: Rainfall October 14th, 2009 until November 30th, 2009

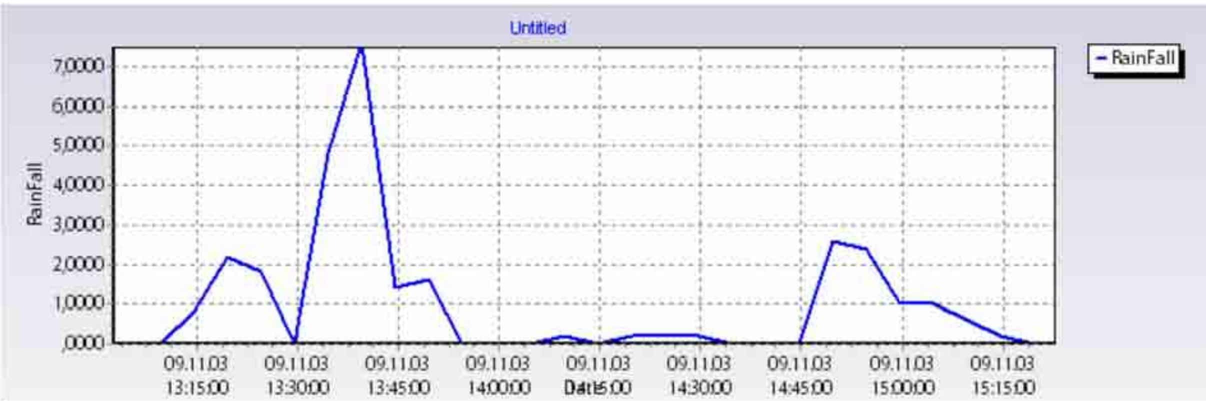

Figure 5.30: Rainfall on November, 3rd 2009

Figure 5.29 illustrates the rainfall in November. The total rainfall was 95,8mm. This can be easily calculated when the data are transferred into a Microsoft Excel table (see Annex 7). Figure 5.30 shoes the chronological distribution of the rainfall on November 3rd. This figure illustrates the usual rainfall pattern as a hydrograph because a hyetograph is not provided by the software when using a daily resolution. Rain usually falls in a rather short period (here in about two hours).

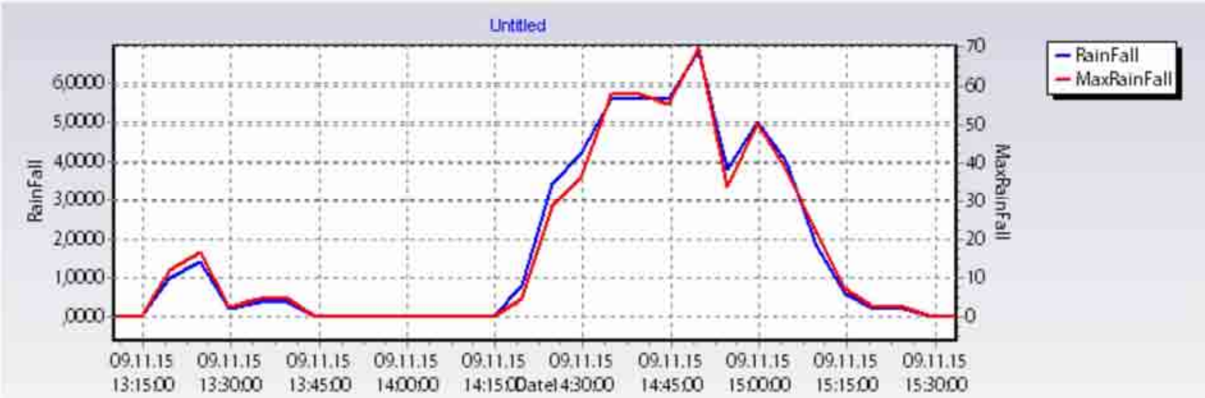

Figure 5.31: Rainfall intensity versus rainfall on November, 15th 2009

The rainfall intensity is strongly depending on the actual rainfall as both are based on 5 minute measurements (see chapter 4.2.2). The intensity is rather high because the peak intensity per hour can go up to 70mm or more. That is almost equal to the rainfall amount in the whole of November (95,8mm) (see Figure 5.31).

5.3.3.3 General management

Table 5.41 summarizes the findings from above in a management plan that should be implemented at VVU. Beside the actions for the groundwater wells and the rainwater system, also general actions are stated.

Table 5.41: Management Plan for water management at VVU

Management Plan for water management			
Where?	What?	Who?	Notes
Groundwater wells			
All three groundwater well sites	Downloading of data from data loggers and storing in a database	Ecological Sanitation Manager	Monthly (every 1st Monday per month)
Pumping station	Fill in pump schedule and store in a database	Pump Attendant	Daily
Institutions around Accra	Investigation of possible hazards and finding countermeasures	Ecological Sanitation Manager	Immediately
Institutions around Accra	Investigation of save waste disposal	Ecological Sanitation Manager	Immediately
Institutions around Accra	Meetings and discussions of new developments concerning groundwater	Ecological Sanitation Manager	Every six month

Rainwater			
Gutters	Cleaning and inspection	Gardeners	Inspection monthly (cleaning according to inspections)
Roofs at buildings with rainwater harvesting systems	Clearing of debris and prune overhanging trees	Gardeners	Every six month
Tank inlets of rainwater tanks	Regular inspection	Plumber	Especially after strong precipitation
Tank and tank roof of rainwater tanks	Repairing of holes and gaps	Plumber	Every six month
Internal inspection	Check for presence of animals, algae or sediments	Pump Attendant	Close access points. If bottom covered with sediments, the tank should be cleaned.
Rainfall measurement site	Downloading of data from data logger and storing in a database	Ecological Sanitation Manager	Monthly (every 1st Monday per month)
General			
Each site + laboratory	Water quality analysis, storing data in a database and comparison	Ecological Sanitation Manager + 2nd person	Rainwater (rainy season two times, dry season once) Groundwater and water from the Main Reservoir (every two weeks) Grey water sites (occasionally)
Complete campus	Water meter readings and storing data in a database	Pump attendant	Weekly (every Wednesday)
Complete campus	Exchange broken water meters or repair those not working	Pump attendant	On demand

General problems are that responsibilities are not defined clearly so far. If they are not written down in the work contract, people do not fill responsible. Therefore, management plans, with certain duties that are given out by the university, could help to improve the system.

Another problem is that most of the data are written down in books. However, it would be very helpful for other people working with VVU or also for future purposes, to store them in databases on the computer.

5.3.4 Summary

The major improvement recommendations according to VVU's five challenges are stated in Table 5.42. This table can be similarly adapted as regulatory capacity framework and implemented as management plan.

Table 5.42: Plan for sustainable development of VVU's water management

Plan for sustainable development			
Where?	What?	Who?	Chapter
Water Shortage			
On campus	Water quantity data (availability) collection and storage in database	Ecological Sanitation Manager	5.3.2.6 Water resources knowledge base
Water consumers	Change peoples attitudes towards water	Ecological Sanitation Manager	5.3.2.7 Improved efficiency of use
Facility management			
All buildings at VVU with rainwater systems	Implementation of Management of rainwater system	Ecological Sanitation Manager	5.3.3.2 Rainwater
On campus	Implementation of General management of the water system	Ecological Sanitation Manager	5.3.3.2 General management
Groundwater management			
On campus	Water quantity data collection and storage in database	Ecological Sanitation Manager	5.3.2.6 Water resources knowledge base
Groundwater wells	Implementation of Groundwater management plan	Ecological Sanitation Manager	5.3.3.1 Groundwater Wells
Human resources – especially participation			
Ecological Sanitation Management	Establishment of a Watsan committee	Head of EcoTec Centre	5.3.2.3 Building institutional capacity – developing human resources
University Level	Establishment of multi-disciplinary and environmental courses and study programmes	University Administration	5.3.2.4 Training to build capacity in water professionals
Lack of money			
University Level	Generation of benefit for O&M and improvement	Business Administration	5.3.2.5 Regulatory capacity and 5.3.2.9 Pricing of water services
Regional, National	Raising public awareness	Head of EcoTec Centre	5.3.2.8 Raising public awareness

For success it is necessary that all mentioned persons in charge work closely together. This should start on the lowest staff level and end at the highest administrative levels. For example a Watsan committee does not make any sense if requests are never answered without any statements or reasons. Thus, especially communication and participation has to be fostered.

5.4 Filtration technologies

At the technical laboratory of the Institute of Sanitary Engineering and Water Pollution Control (BOKU) the following filtration technologies were tested:

- Evers Easy Filtration®
- SkyHydrant$_{TM}$
- Rain-PC^{TM}
- a sand filtration unit

The purpose was to find the appropriate filtration unit for VVU. The main objective for VVU was to obtain good quality water that can be used for drinking. For this purpose, a low energy (project requirement) treatment unit should be used. To compare the four units and choose the right alternative, a simplified multi-criteria approach was applied. Thus, relevant criteria or indicators were defined and weighted according to their importance. It has to be considered that these criteria, indicators and weights were subjectively chosen and before actual application, they should be discussed with VVU's decision makers.

This chapter briefly introduces the tested filtration units, describes the criteria and indicators used for decision making and comes up with training and education proposals for involved staff.

5.4.1 Filtration units

5.4.1.1 Evers Easy Filtration®

This unit was especially designed for decentralized water treatment in development countries. The filters have a high filtration capacity due to a one-layer material called EVERZIT® N. EVERZIT® N is a biofilter that is suitable to treat turbid water and water contaminated with solid or suspended matter like iron and manganese. The system is very robust and easy to handle. The energy consumption is rather low because of a gravity flushing system. The filter material allows long running times which implies additional savings in energy and in flushing water. It is possible to treat about 400 litres per hour (EVERS, 2006).

5.4.1.2 SkyHydrant$_{TM}$

This unit "is intended for affordable community water supply or disaster relief applications for production of potable water. (…) The SkyHydrant$_{TM}$ process combines microfiltration for primary disinfection and particulate removal with chlorine disinfection to produce a safe supply of water from the majority of non-saline surface and ground waters" (SKYJUICE, 2007). The membrane is robust, cleanable and long lasting. Maintenance is simple and manual. The unit operates at low pressure heads and it does not need electrical power. The filter is suitable to reduce virus levels and to remove solids and bacteria (SKYJUICE, 2007). However, salt or dissolved chemicals and minerals will not be remover (SKYJUICE, 2009).

Depending on the raw water quality, the wash cycle (duration about 90 seconds) has to be conducted every 1 to 12 hours. In addition, a chemical cleaning sequence for the membrane is necessary on a daily to weekly basis (SKYJUICE, 2007).

5.4.1.3 Rain-PC^{TM}

This unit converts rainwater into drinking water. It "is developed by scaling down the multi-staged water treatment method (MST), which involves screening, flocculation, sedimentation and filtration and incorporating existing technologies like upward flow fine filtration, absorption and ion exchange" (UN-HABITAT, 2005). It is easy to operate and maintain. The unit operates at low pressure heads and needs no power. The Rain-PC^{TM} treats about 40 litres per hour at costs of US$ 2 to 3 per 1000 litres (UN-HABITAT, 2005).

5.4.1.4 Sand filtration unit

This unit was set up as upflow sand filter. The raw water ascends the filter unit and suspended solids get removed. This unit is easy and cheap to maintain and operate but according to the water quality demands, it is not appropriate. This unit was just used within the benchmark test to compare the results with the other filtration units. Thus, the sand filtration unit is left out in subsequent considerations.

5.4.2 Relevant criteria for VVU

To find the appropriate filtration unit for VVU, decision criteria were defined for the four chosen alternatives or filtration units respectively. According to chapter 3.1, these criteria take into account the economy, the society and the environment (three pillars of sustainability) in addition to equity, replicability, effectiveness and efficiency (principles of appropriate technology).

To assess economic criteria the indicator "operation and maintenance costs" is the most essential as the acquisition costs are covered by the project.

Social criteria have to assess the availability of human resources and competence. Therefore, one indicator was chosen that assesses the "maintenance requirements/ feasibility for VVU's staff". As the maintenance requirements are strongly influencing the feasibility, they can be combined to one indicator.

Environmental criteria are assessed with the indicator "waste production" as waste is a fundamental problem in Ghana.

An equity indicator is left out because each filtration unit is aiming for improving the water quality and overall water situation at VVU. The university and all its staff and students will profit from the improved water quality.

Replicability can be seen as given, too. The choice of technology is based on scientific research conducted at BOKU. Documentations and publications imply transparency and replicability.

Effectiveness and efficiency are combined in the indicators "amount of treated water per hour" and "water quality".

5.4.3 Comparison of the three filtration units

It has to be considered that the use of the filtration unit was not clearly defined at the beginning of the project. Thus, a multi-criteria decision making technique was developed that allows the decision maker to find the appropriate unit for the respective utilization.

As the water quality of the Main Reservoir is rather good and water is usually not drunk from the tab, a filtration unit is not necessary. However, water from Borehole 3 should be treated if use is considered. Another possible use would be to produce drinking water from rainwater at a separate tab and give students the opportunity of free drinking water; however, rainwater needs to be treated before. A treatment unit for the Cafeteria could also be an option as the water for cooking and dish washing should be free of any contaminants to guarantee safe food production.

Two examples how to apply this technique are subsequently given. The first is the treatment of water from the groundwater wells and the second that the Cafeteria is supplied with safe drinking water for cooking and washing purposes.

5.4.3.1 Example: Treatment of water from the groundwater wells

Borehole 2 shows high ferrous iron concentrations and once the dissolved ferrous concentration exceeded the GSB drinking water requirements (see chapter 3.6.1) by far. If Borehole 3 is also considered to be used as additional supply, this source has to be treated, too. Especially because VVU is planning to set up sachet water production, the groundwater should be of high quality.

- The most important factor is economy. As a lot of water has to be treated the operation and maintenance costs should be low.
- The criteria effectiveness and efficiency do not play a major role when it comes to water quality issues as all three units should be feasible to remove iron and turbidity. However, the amount of treated water per hour should be rather high to cope with the yield of the two or three groundwater wells.
- Society has the third highest priority. Maintenance requirements should be as little and simple as possible as VVU is lacking experts and workforce.
- Environment is given the lowest priority. The chosen filtration units themselves can be considered already to be ecological as they do not need electrical power.

According to the observations during the field study, a subjective weighting and ranking is given for the mentioned priorities (see Table 5.43). It has to be considered that applied criteria, indicators and weights were subjectively chosen and before actual application they should be discussed with VVU's decision makers. It has to be considered that applied criteria, indicators and weights were subjectively chosen and before actual application they should be discussed with VVU's decision makers. Table 5.43 presents points considered for the decision making, too. Boldface numbers represent respective ratings.

It has to be considered that applied criteria, indicators and weights were subjectively chosen and before actual application they should be discussed with VVU's decision makers.

Table 5.43: Impact table for the three filtration units

Criteria (weight)	**Indicator**	**Evers Easy Filtration®**	**SkyHydrant™**	**Rain-PC™**
Economy (0,45)	operation and maintenance costs (1)	• Filter material • Washers (seldom) **100**	Chlorine (often) **90**	• Cartridge • Mf filter • Pre-filter **70**
Society (0,20)	maintenance requirements/ feasibility for VVU's staff (1)	• Backwashing at least once a week • Weekly inspection of unit • Yearly inspection of flocculant dosing pump and disinfection • Cleaning of unit every 6 to 24 month • Exchange of filter material and washers every 6 to 8 years **100**	• Manual cleaning: daily • Chemical cleaning: depending on water quality weekly to monthly **70**	Exchange after: • Cartridge: 35.000 litres • Mf filter: 10.000 litres • Pre-filter ~ 10.000 litres (exchange more often than once a day) **50**
Environment (0,1)	Waste production (1)	• No waste production **100**	• No waste production **100**	• Filter disposal **80**
Effectiveness and efficiency (0,25)	amount of treated water in l per hour (0,9)	Easy 400 for removal of iron 400 -1000 **100**	500 – 700 **70**	240 **40**
	Water quality (0,1)	Satisfying treatment **100**	Satisfying treatment **100**	Satisfying treatment **100**

The formula from chapter 4.4 transfers the impact table (Table 5.43) to an efficiency table (Table 5.44).This results in an overall utility value for each filtration unit.

Table 5.44: Efficiency table for the three filtration units

Criteria (weight)	Indicator	Evers Easy Filtration®	$SkyHydrant_{TM}$	Rain-PC^{TM}
Economy (0,45)	operation and maintenance costs (1)	0,1731	0,1558	0,1212
Society (0,20)	maintenance requirements/ feasibility for VVU's staff (1)	0,0909	0,0636	0,0455
Environment (0,1)	Waste production (1)	0,0357	0,0357	0,0286
Effectiveness and efficiency (0,25)	amount of treated water in l per hour (0,9)	0,1071	0,075	0,0429
	Water quality (0,8)	0,0083	0,0083	0,0083
Sum		**0,4151**	**0,3384**	**0,2465**

Under the predefined circumstances, the Evers Easy Filtration® would be the best alternative to treat groundwater at VVU. For each attribute, it scores higher or equal utilities as the other treatment units.

5.4.3.2 Example: Drinking water for Cafeteria

The Cafeteria uses approximately 23,3m³ water per week from the Main Reservoir. Of course not all water is used in the kitchen. Nevertheless, the assumption is made for the whole building. This water is not completely safe for drinking as E. coli (2 CFU/ 100ml) were measured once. Furthermore, pollution in the distribution network could occur, too.

- Thus, the criteria effectiveness and efficiency have the highest priority, especially water quality. The amount of treated water is not important for this case as the water consumption per hour is small.
- The second highest priority is the economic criteria. VVU has little money; thus, as little expenses as possible are the best.
- Society has the third highest priority. Maintenance requirements should be as little and simple as possible as VVU is lacking experts and workforce.
- Environment has the lowest priority. The chosen filtration units themselves are environmental friendly as they do not need electrical power.

According to the observations during the field study, a subjective weighting and ranking is given for the mentioned priorities (see Table 5.45). Table 5.45 presents points considered for the decision making, too. Boldface numbers represent respective ratings.

It has to be considered that applied criteria, indicators and weights were subjectively chosen and before actual application, they should be discussed with VVU's decision makers.

Table 5.45: Impact table for the three filtration units

Criteria (weight)	Indicator	Evers Easy Filtration®	SkyHydrant$_{TM}$	Rain-PC^{TM}
Economy (0,35)	operation and maintenance costs (1)	• Filter material • Washers (seldom) **100**	Chlorine (often) **90**	• Cartridge • Mf filter • Pre-filter **70**
Society (0,15)	maintenance requirements/ feasibility for VVU's staff (1)	• Backwashing at least once a week • Weekly inspection of unit • Yearly inspection of flocculant dosing pump and disinfection • Cleaning of unit every 6 to 24 month • Exchange of filter material and washers every 6 to 8 years **100**	• Manual cleaning: daily • Chemical cleaning: depending on water quality weekly to monthly **70**	Exchange after: • Cartridge: 35.000 litres • Mf filter: 10.000 litres • Pre-filter ~ 10.000 litres **90**
Environment (0,1)	Waste production (1)	• No waste production **100**	• No waste production **100**	• Filter disposal **80**
Effectiveness and efficiency (0,40)	amount of treated water in l per hour (0,2)	Easy 400 for removal of iron 400 -1000 **100**	500 – 700 **80**	240 **50**
	Water quality (0,8)	No bacterial treatment **0**	Disinfection **100**	Removes E. coli **100**

The formula from chapter 4.4 transfers the impact table (Table 5.45) to an efficiency table (Table 5.46).This results in an overall utility value for each filtration unit.

Table 5.46: Efficiency table for the three filtration units

Criteria (weight)	**Indicator**	**Evers Easy Filtration®**	**SkyHydrant$_{TM}$**	**Rain-PC^{TM}**
Economy (0,35)	operation and maintenance costs (1)	0,2188	0,1969	0,1531
Society (0,15)	maintenance requirements/ feasibility for VVU's staff (1)	0,0577	0,0404	0,0519
Environment (0,1)	Waste production (1)	0,0357	0,0357	0,0286
Effectiveness and efficiency (0,40)	amount of treated water in l per hour (0,2)	0,0347	0,0278	0,0174
	Water quality (0,8)	0	0,16	0,16
Sum		**0,3469**	**0,4608**	**0,411**

Under the predefined circumstances, the SkyHydrant$_{TM}$ would be the best alternative to supply the Cafeteria with drinking water. The main reasons are that it is more economically then Rain-PC^{TM} and achieves better water quality then the Evers Easy Filtration®.

Similar to these examples other scenarios can be developed to find the right filtration unit for other purposes. Though, the weights and criteria should be adapted to the intended use of water then.

5.4.4 Education and training of involved staff

As each filtration unit has a precise manual in English, training of involved staff should not be a problem. Nevertheless, after assembling the units a short workshop is advised.

The construction itself should be conducted or supervised by VVU's water managers (especially by the plumber). Additionally, each work step (filter or cartridge exchange, backwashing, manual cleaning,…) should be tried out a couple of times by each water manager under the supervision of a person who worked already with these instruments.

The education of involved staff should include personal hygiene and health topics like:

- Adequate and continuing hygiene training (hygienic handling and personal hygiene)
- Communicable diseases or injuries (if ill or injured, excluded from work)
- Proper hand washing practices
- Personal cleanliness
- Personal behaviour
- Dealing with visitors

(GSB, 2005b)

These practices should guarantee the delivery of water with drinking quality. However, when this effort is taken, the consumers should also be aware of the water quality. If water is treated with the Rain-PC^{TM} or the SkyHydrant$_{TM}$, it can be drunk. This should be communicated to the consumers with respective signs.

5.5 Impacts of water supply and sanitation projects at VVU

This chapter refers to the second overall objective to evaluate planned solutions for sustainable water supply within the BMU project and the following detailed objective.

- **Impacts of WS&S projects at VVU**: discussion with regard to issues such as water resources (e.g. ground water extraction), communication with other relevant WS&S stakeholders and demonstration of activities to contribute to the improvement of WS&S outside VVU

5.5.1 Impacts on groundwater

Although VVU is located in an area where groundwater is often not of good quality and not easy to find (see 3.4.1 Geology, Hydrology and Soils and 3.4.2 Groundwater Quality), the university has three groundwater wells. The university's water supply is strongly depending on these wells. Thus, a long-term use of this source is desirable. Previous to this project, no investigations of quality and quantity assurances were available. However, this would be necessary to recognize any deterioration in time.

On campus as well as nearby, problems like septic tanks as sole treatment for black water, dangers of leaking septic tanks, use of chemical fertilizers in agriculture and waste dumping are imminent dangers for the quality of groundwater bodies. Especially measurements of electrical conductivity (high salinity) and nitrogen, chloride and phosphate concentrations are indicators for intrusion of pollutants from such sources.

The number of groundwater wells and the amount of extracted groundwater are unknown in the region. Thus, an overuse of the groundwater is a possible danger and should be considered. Keeping records of regular water level measurements and of extraction rates helps to recognize decreasing water availability.

This leads to the point that all results about water quality and quantity should be communicated with other stakeholder in the region.

5.5.2 Impacts of rainwater supply

Rainwater harvesting has increased within the climate project. However, nobody has conducted an exact economical, environmental and social analysis. Subsequently, some points of interest are presented that should be considered when it comes to decision between rainwater systems or conventional drinking water supply.

Jolliet et al. (2002) provide an eco-balance for drinking water supply and rainwater utilisation. They compared sustainability of toilet flushing, washing laundry and the size of tanks and systems with rainwater or drinking water supply. It has to be considered that the different scenarios represent Swiss circumstances and conditions for living, energy consumption or water treatment. Nevertheless, this study highlights relevant sustainability considerations concerning rainwater utilisation that are also relevant for VVU.

Five different scenarios were developed for toilet flushing: a conventional scenario (only drinking water supply), a scenario with a rainwater share of 57%, a scenario with drinking water supply but the use of water saving toilets, a scenario with a rainwater share of 97% and the use of water saving toilets as well as a scenario with a rainwater share of 100%. Results of this investigation were that water saving toilets are environmental friendlier and cheaper. Drinking water supply for toilet flushing should be preferred to rainwater supply as long as the energy demand for drinking water supply is not too high. Thus, water saving toilets should have the highest priority. However, in certain circumstances (e.g.: cisterns already existent), rainwater utilization might be favourable (JOLLIET et al., 2002). As VVU has already some water saving toilets as well as cisterns in place and drinking water supply is not reliable, the economic and environmental criteria are most likely not as important as additional water supply. Thus, under VVU's circumstances, rainwater supply and at the same time the use of water saving toilets is sustainable.

Concerning washing the laundry, different scenarios were developed ranging from conventional drinking water supply to rainwater supply and ion exchange in the washing machine. The recommendation was that rainwater should be promoted in areas with hard water (JOLLIET et al., 2002). VVU's drinking water has medium hardness. Thus, the positive effect of using rainwater instead of the conventional water is probably negligible.

Jolliet et al. (2002) compared a university and a family home, two scenarios for each (conventional and rainwater supply). The overall energy consumption is lowest for the university's rainwater supply scenario. The best solution for the environment is also to supply the university with rainwater. Each criterion, energy consumption and environment, benefits from larger rainwater collection areas and an optimal cistern size (JOLLIET et al., 2002). Thus, for VVU, rainwater harvesting is a possible solution from an economical and environmental perspective.

Rainwater utilisation does not necessarily provide economical and environmental benefits compared to conventional drinking water supply. However, with increasing size of the institution it is more likely. VVU is a medium size institution. Thus, rainwater utilisation probably influences sustainable development positively. However, for an exact determination of the pros and cons of rainwater harvesting at VVU, an eco-balance would be necessary. This balance has to take Ghanaian circumstances into consideration (e.g.: electricity demand for drinking water supply or environmental impacts). Nevertheless, the social component (left out in the study by JOLLIET et al., 2002) has to be considered, too. For example that rainwater harvesting at VVU helps to provide a more reliable water supply. This increases living standards of people living on campus.

Beside these considerations for using rainwater as process water, VVU and project partners are thinking of using rainwater as additional drinking water supply for VVU's water system. However, this requires treatment due to particles or bacteria that can occur in rainwater (see e.g.: HELMREICH and HORN, 2009 or chapter 5.1.3 Rainwater). If sachet water production is started, required treatment technologies could be used for rainwater treatment, too.

5.5.3 Communication with relevant stakeholder

During the field study, it appeared that information and data were very scarce or non-existent at all. Furthermore, stakeholders did not communicate their information and data.

VVU should set up a communication strategy. With the instruments that were provided by the project, VVU obtains a lot of good data that could help to improve the water management in the region if shared with other institutions. In return, VVU can expect information or knowledge that is still missing because there are no water experts on campus for issues like groundwater, rainwater, water management or water quality.

The GWP (2008) gives recommendations on how to implement good communication with relevant stakeholders.

Establishing water partnerships should be one of the major goals for IWRM. “A partnership is often characterized as a working relationship between stakeholders with mutual and equal participation, joint interest and shared responsibilities. Processes in a partnership are typically transparent and based on an open dialogue” (GWP, 2008).

However, establishing partnerships is not easy. Major work steps are stakeholder analysis, development of common goals, planning, program design, social changes accompanied by social capacity building, cooperative inquiry, conferencing, supporting self-organization and organizational development. Additionally, the partnership has to stick to a framework with working modalities and a scope of content. A neutral person should act as a moderator (GWP, 2008).

Thus, the first step has to be stakeholder analysis. Beside the mentioned institutions (see 3.5.2 Institutions), several other interest groups are existent. It is important to find them and gather their available information (groundwater, rainwater, water management in general, water quality). Then collaborations with the identified stakeholders should be sought.

VVU has perfect conditions to act as a facilitator to start such partnerships. On campus, conference rooms, accommodation and food are available. The main goal should be the improvement of institutional water management and information, knowledge and data exchange. Therefore, also institutions like other colleges, universities but also project implementing parties like NGOs, private companies or villages are possible participants beside the stakeholders introduced in chapter 3.5.2.

In addition to start meetings at VVU, participation in training programmes, workshops, seminars, study tours and conferences should be fostered (GWP, 2008). The benefits of such methods are knowledge sharing and can lead to partnerships and networking.

5.5.4 Demonstration of activities

VVU already gave some incentives to communicate the project itself but not VVU's water management in particular. However, so far these demonstrations were triggered from outside, the project coordinators.

5.5.4.1 ECOSYS 09

Project partners and VVU organized an international symposium on sustainable ecosystems in Africa on July 19th until 23rd, 2009. This was the closing event of the first project conducted at VVU.

The presentations included highlights of successful ecosystems like:

- Shanghai: Centres for training, production, research and development of sustainable agricultural practices
- African examples of Integrated Watershed Management
- Tongji: a sustainable eco-campus
- Namibian case study: living in an arid ecosystem
- holistic eco-sanitation examples from East Africa
- examples of eco-villages from Senegal
- VVU: holistic, sustainable and climate-friendly-eco-university

Additionally, workshops were held with the targets:

- Discover positive examples
- Dream about human activities in harmony with nature
- Design of sustainable eco-systems
- Design of an international study on integrated design and management of human eco-systems
- Design of sustainable eco-systems and projects and studies in harmony with nature
- Destiny: First measures and responsibilities generally and eco-study

The project management had expected up to 100 people. Only about 40 persons attended the symposium. Most participants were project partners, people addressed by them or students from VVU. Thus, VVU did not succeed in communicating this project to relevant stakeholders like Ghanaian NGO's, representatives of communities or people and companies implementing projects or conducting research in similar fields (GELLER, 2009).

Nevertheless, this symposium is good example of how VVU can improve public awareness (chapter 5.3.2.8) and communication with relevant stakeholders (chapter 5.5.2).

In February 2010, a second symposium is planned for the new project. This time, VVU should analyse possible stakeholders well to address the right persons. First the importance of the project and the symposium should be announced on the whole campus so that VVU's students and staff can function as multipliers to promote this symposium among friends. Especially people working in the EcoTec Centre should have several former study colleagues that could be interested in the topic, as these people probably work in similar fields. Beside that, existing networks (for example other Seventh Day Adventist universities or schools) should be utilized. Then, like stated before, Ghanaian NGO's, representatives of communities or people and companies implementing projects or conducting research in project relevant fields should be invited. During the field study, some stakeholders were met personally. As they expressed their interest in the project during personal communications or conducted similar research in Ghana, they definitely should be addressed among other persons or institutions.

- WRI
    - Ph.D. Dapaah-Siakwan
    - Dr. Issac O.A. Hodgson
- Legon University
    - Dr. Narty, Head of Chemistry Department
- Oyibi Water Supply Scheme
- Danish International Development Assistance

5.5.4.2 Inquires at the EcoTec Centre (Physical Plant)

Occasionally institutions, students or other interested persons come to inspect or discuss the project. These visits are good possibilities to build up networks of stakeholders.

The Ecological Sanitation Manager explains the concepts and shows the people around. Contact information should be exchanged with those persons so that they can be informed about initiatives like symposiums or work shops.

One good example is that a representative of the International Water and Sanitation Centre Netherlands, Resources Centre Network Ghana, came to VVU requesting for a presentation of VVU's projects. The institutions aim is to promote knowledge management, establish learning alliances and bring stakeholders together. Such events are suitable to establish networking and get to know relevant stakeholders. Participating people should be invited for field visits on campus and contact information should be exchanged for later collaborations.

Especially at the end of the project, when all water related facilities are installed, it would be good to invite interested stakeholders like NGOs, village water committees or Oyibi's Water Board and other persons who showed interests. These stakeholders can profit from various implementations like rainwater harvesting concepts at the Baobab Centre, water analyses and sustainable filtration technologies for quality management, data logging and water meter installations for quantity management, sachet water production for financial benefits or water management recommendations. VVU on the other hand can profit from networking, knowledge exchange and public relations.

6. Discussion

<u>VVU's water sources</u>

Data about water sources at VVU were scarce before this project. Quantitative and qualitative evaluation was mainly based on assumptions or non existent at all. Considering quantitative issues the most important fact is that the water supply from the public water supplier is decreasing slowly. This will not change as the population is growing fast. Moreover, more and more people are changing their attitude towards public water (at the moment still a lot of people stick to polluted surface water resources). Additionally, the targets given by previous projects are not well implemented. Especially the rainwater potential is not taken full advantage of (many broken rainwater systems) and water cycle management is still not well considered as broken grey and black water pumps remain unused for long periods. However, rainwater and water re-use should be given more priority. Rainwater can function as emergency supply in dry seasons (when enough water is stored in the rainy season) and during the rainy season a big share of the demand could be covered. Overflows have to be avoided by all means. In the dry season, especially grey water can be an important substitute too and decrease pressure on the groundwater resources (public and on site). The groundwater wells are yielding slightly more than estimated after their drilling but Borehole 3 is not used although its yield is good. For additional groundwater supply, it has to be thought of treatment or utilization possibilities for water from Borehole 3. Generally speaking, all four resources (public water, groundwater wells, rainwater and water re-use) have high potential water yields but these potentials are not fully utilized yet. Thus, water shortage is still a problem.

Only few water quality data were available previous to this project. Some data were found about general groundwater conditions in the Greater Accra Region, the near surroundings of VVU and VVU itself. Comparing these data with the data from this study the groundwater quality at VVU is rather good. The only problem is that turbidity at Borehole 3 and high iron concentrations cannot be excluded as the drinking water requirements for this parameter were at least once exceeded for each groundwater well. As high iron concentration is a problem in the whole region that was no surprise. However, considering chloride or electrical conductivity the groundwater wells at VVU show low concentrations compared to other wells in the region. To make the groundwater save for drinking it has to be treated. The water quality of the Main Reservoir was analysed once before this project. At that time total coliform counts exceeded drinking water requirements. This was verified by more recent measurement during the project. Thus, the water from the Main Reservoir has no drinking water quality, too. Considering rainwater quality, no quality measurements were conducted previous to this study. Rainwater at VVU is not safe for drinking purposes as the E. coli counts always exceed the drinking water requirements. This should be communicated at the Women Centre, the Women Dormitory, the New Faculty Building and the Baobab Centre as there, rainwater is or will be regularly used as process and tab water supply. The water quality of black water is suitable for irrigation of plants but should not be used for irrigating food crops as E. coli counts and BOD concentrations exceed standards for food crop irrigation.

Further water quality measurements should include occasional bacteriological tests with simple field test equipment, especially at the Main Reservoir, to find out the extent of bacteriological contamination. Additionally, the field measurements should be carried on as they give a good picture of VVU's general water quality.

<u>VVU's water balance and respective facilities</u>

The water system is based on several different facilities that are essential for proper working of the system. The major constraints are that even the most important parts like rainwater tanks or pumps are not well operated and maintained. Thus, the full potentials of water resources like rainwater and grey water are not utilized. This decreases also emergency back-ups as especially rainwater tanks are important supplements in times of water shortage. Newly constructed rainwater tanks (Baobab Centre and near Women Centre) will partly compensate broken rainwater tanks. Nevertheless, also existing rainwater harvesting systems should be repaired and maintained properly. The same applies to pumps. They should be repaired or replaced as soon as they break.

The water balance showed that there are still significant amounts of water losses that could be related to not metered water consumption at construction sites and the block factory or leakages in the pipe network. To improve this knowledge, more water meter should be installed, especially for constructional uses and the block factory.

For the future, an increasing water demand is expected mainly due to an increasing number of students, further extensions of VVU and sachet water production on campus. Looking at the current situation it is unlikely that this demand can be covered by existing water resources. Newly constructed rainwater harvesting systems at the Baobab Centre and at the Women Centre will provide some additional water to VVU but it will not be enough to meet the future demand. Existing water resources should be improved but new water sources should be thought about, too. One idea is the reconnection to the GWCL pipeline passing the campus. VVU was already connected to this line some years ago. However, after the Oyibi Water Supply Scheme was established the university changed to this supplier. Recent developments showed that GWCL would connect VVU again.

Beside a future increase in water demand, the current demand is not met most of the time. A continuous water supply is not guaranteed at VVU. Thus, people at VVU cannot use as much water as the want to.

<u>Water management</u>

VVU's water management faces challenges like groundwater management, facility management, water shortage, lack of money and human resources. For a sustainable development it is necessary to combat these challenges. So far VVU has mainly reacted on requests or shortcomings this should change to acting and precaution. Especially implementation of management plans, establishment of water relevant programmes, datalogging and generation of income would help to do so.

Of course this has to be supported by the university's administration which has not been the case so far. O&M of water resources like grey and black water or rainwater is not considered to be important. Thus, especially a great part of financial revenues gathered through water selling and sachet water production (if established) should be used for O&M of the whole water system (including water re-use and rainwater harvesting) to qualitatively and quantitatively meet the water demand.

Sachet water production would be a good source of income. However, it has to be thought about impacts and responsibilities. There is no guaranteed drinking water quality on campus and the quantity is not sufficient. Implementation of sachet water production would put high pressure on the whole system. Thus, deterioration of the whole WS&S system can be expected. For sustainable development the revenue has to be used for O&M and savings have to be made for future expenses.

<u>Filtration technologies</u>

The objective was to find a sustainable filtration technology for harvested rainwater and if possible making this water safe for drinking. However, as rainwater is mainly used as process water and the quality for that purpose is good enough, treatment of other sources would bring more benefit. The groundwater wells should be treated because of their occasional high iron concentrations. Additional sites that would require treatment are the Women Dormitory, the Women Centre or the Cafeteria as the water is bacteriological unsafe. At these sites many people are exposed to water and it is likely that some use it as drinking water.

The Cafeteria should be supplied with drinking water as it serves food. Contaminations with bacteria cannot be excluded as water from the Main Reservoir was contaminated with bacteria in two measurements. For the Women Centre and the Women Dormitory the water should be treated or communicated to the users that water is not safe for drinking there.

Additionally, people working with the filtration units should be trained and educated in hygienic and health issues. This should guarantee proper handling of drinking water related facilities according to GSB standards.

Impact of WS&S projects at VVU

Groundwater use and rainwater use have to be investigated more closely to identify the impacts from a sustainable perspective.

So far the impacts of WS&S seem to be marginal. Beside occasional visits from interested persons or institutions, only the ECOSYS 09, which was organized within the first project, drew attention to VVU. From the WS&S perspective VVU has not become a role model of ecological and sustainable development yet. Although good incentives are existent, they are not communicated well. From this project, it should be thought about promoting sustainable filtration technologies, rainwater use, proper management practices, water quality analyses, data logging, collaboration, networking and information sharing. Especially data collection and spreading should be emphasized because there are only little data available on WS&S issues in the Greater Accra Region. However, they would be important for sustainable development of this sector.

7. Summary

The aim of this thesis was to investigate the current WS&S at VVU and to evaluate planned solutions for sustainable water supply within the project. This was mainly done during the two field studies at VVU in the period of May 14th to June 6th and October 11th to December 11th in 2009. On site most of the data were collected and an insight into socio-economical and cultural circumstances was got. Water quality analyses, on site surveys and public participation were conducted as well as data loggers (groundwater, rainwater) installed. Thus, a comprehensive picture of VVU's current WS&S was obtained and planned solutions could have been evaluated.

Major findings were:

- VVU's water resources have a good potential but this potential is not fully taken advantage of. Especially the utilization of rainwater and water re-use could be improved. Beside that, Borehole 3 and GWCL should be considered as additional water sources.
- One reason for this is that the O&M of water facilities is not practiced well. Rainwater harvesting systems or pumps do not get repaired or replaced when broken. Generally speaking water related facilities seem to be considered as not important for VVU.
- The water balance is not exactly measurable. Not all consumption is measured. Thus, it is not determinable if water losses occur within the system. However, it can be assumed that in case of future water increase (increasing number of students, sachet water production) additional water sources have to be found. Moreover, supply from the Oyibi Water Supply Scheme is decreasing and an increasing extraction from the groundwater wells cannot be seen as guaranteed.
- Considering sustainability of WS&S at VVU there is still much to develop. The water management at VVU is lacking clear defined responsibilities (management plans), a good knowledge base, human resources, good economic practices and training of water professionals. Additionally, efficiency of use and practices to raise public awareness have to be improved. Current problems will deteriorate with increasing water demand if the water management practices do not change.
- As the water quality is not safe for drinking on campus (groundwater wells with high iron concentrations, Main Reservoir and especially rainwater bacteriological contaminated), sustainable filtration technologies should be used for improving the water quality. As the water to be treated was not clear, a simple multi criteria decision technique was developed using four criteria and five indicators. This method can be applied to estimate an appropriate technology. Two scenarios were developed. The first was to improve the water quality of the groundwater wells and the appropriate filter would be an Evers Easy Filtration®. The second was to deliver safe drinking water to the Cafeteria and the appropriate filter for that purpose would be SkyHydrant$_{TM}$.
- Considering impacts of WS&S projects at VVU the communication to other stakeholders and demonstration of activities has to be improved as so far VVU is just reacting on requests or incentives given from outside. The university itself has not taken incentives yet to contribute to the improvement of WS&S in the region. Impacts of groundwater and rainwater use have to be investigated more closely.
- Looking at the impacts on groundwater, a clear statement cannot be given yet. Groundwater level measurements and quality analyses should be conducted to observe changes in time. Additionally, communication with other stakeholders should be conducted.

8. Recommendations

VVU has still a lot to do for sustainable development of their water management. If this process is not well considered the development becomes unsustainable and water shortage is likely. Considering following recommendations will promote sustainable water management and it will help to solve many water related problems.

VVU's water sources

- Increase the use of rainwater and foster water re-use (especially grey water use).
- Find appropriate use for groundwater from Borehole 3.
- Connect VVU's water network to the GWCL pipeline.
- Communicate the water quality on campus to staff, students and residents.

VVU's water balance and respective facilities

- Prioritise O&M of water facilities.
- Install more water meters to obtain a complete water balance.

Water management

- Implement (water) management plans that define responsibilities.
- Start water relevant study programmes at VVU.
- Continue data, information and knowledge collection of water issues relevant for VVU.
- Increase the priority of water related projects within the university's administration.
- Improve the financial situation for water related projects.

Filtration technologies

- Improve the water quality on campus with appropriate filtration technologies.
- Use the Evers Easy Filtration® unit for groundwater treatment.
- Use the SkyHydrant$_{TM}$ unit for bacterial removal.

Impact of WS&S projects at VVU

- Improve communication with all relevant stakeholders.
- Investigate groundwater thorough in the Greater Accra Region. This will help VVU to observe qualitative and quantitative changes of this resource in time.

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10. Annex

A CD is provided with the data:

11. Curriculum Vitae

Benjamin Lauterböck

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Personal Data

Date of birth: 17.12.1985

Place of birth: Tulln (Austria)

Citizenship: Austria

Martial status: unmarried

Education

1992 - 1996: primary school

1996 - 2004: grammar school

2004 - 2007: Bachelor of "Umwelt- und Bio-Ressourcenmanagement" (Environment- and Bio-Resourcesmanagement) at University of Natural Resources and Applied Life Sciences, Vienna

2007 - 2010: International Master of "Natural Resources Management and Ecological Engineering" (Double Degree Programme with Lincoln University, New Zealand) at University of Natural Resources and Applied Life Sciences, Vienna

July – October 2008: semester abroad at Lincoln University, New Zealand

May – June and October – December 2009: 14 weeks of field study at Valley View University, Ghana for diploma thesis "Sustainable Water Management at Valley View University, Ghana – Evaluation and Further Development"

Work Experience

Since 2001: regularly working at farm Doppler, details: selling (eggs & vine), stock farming, delivery service, customer service, farm management, agricultural work

July 2006: four weeks practical experience abroad – Orchid Practical Training at "Soerjanto Orchid" in Indonesia, details: floriculture

August 2007: five weeks practical experience at the Austrian Federal Railways (ÖBB) in the bureau "Natural Hazard Management", details: risk management, protection forest management, implementation of a data base

August, September 2009: six weeks practical experience at AB-Filtertechnik a company dealing with water treatment and filter techniques, details: construction of test filtration units, AutoCAD flow charts, translation of official documents

Research initiatives

January 2007: baccalaureate paper "Der Naturpark Raab in Hinblick auf seine regionale Entwicklung" (The Nature Park Raab in Terms of its Regional Development), details: interdisciplinary investigation of the Nationalpark Raab and proposals for improvement

January 2007; baccalaureate paper "Unterschiede zwischen hypothetischer und realer Zahlungsbereitschaft für ökologische Produkte: Forschungsdesign für eine empirische Untersuchung am Beispiel MSC (Marine Stewardship Council) zertifizierter Fischprodukte" (Differences in Hypothetical and Real Willingness to Pay for Ecological Products Using the Example of MSC Certified Fish Products), details: preparation of an empirical research design concerning willingness to pay for ecological products, design consists of a questionnaire, the Contingent Valuation Method and the Vickrey Auktion

June 2007: seminar paper "Hochwasserfrühwarnung im Donaueinzugsgebiet Wien-Niederösterreich" (Early Warning of Floods in the Danube Catchment Basin Vienna-Lower Austria), details: investigation of early warning systems in Vienna and Lower Austria, investigation of technical devices for early warning, investigation of preventive measures

July – October 2008: participation in the class "Conservation Biology" at Lincoln University, New Zealand, details: project management, research proposal, data collection (field and laboratory), presentation of results and submission of the paper "Prevalence and intensity of the parasites *Curtuteria australis* and *Acantoparyphium* in cockles at the beaches of Heathcote Estuary, Barry's Bay, Duvauchelle, Governors Bay and Port Levy at Banks Peninsula, New Zealand"

Since March 2009: participation in a development project that is financed by the German Government of Environment, 14 weeks of field study at Valley View University, Ghana and writing of diploma thesis "Recommendations for Sustainable Development of Water Management at Valley View University, Accra, Ghana", details: water quality and quantity assessment (groundwater, grey water and rainwater sources), investigation of hydrogeological circumstances, data logging and interpretation, management and storing of ground- and rainwater data, investigation of management structures and sustainability evaluation of the universities' water supply system, project management

Areas of expertise

- Integrated Water Resources Management
- water quality and quantity assessment
- water supply and water treatment
- on site solutions for water supply and sanitation
- interdisciplinary resources management - sustainability (economic, social, ecological and technical considerations)
- working in international and multi-disciplinary teams
- development co-operation

Skills

<u>Languages:</u> German – native language, English – very good, French and Spanish – basic knowledge

<u>Computer literacy:</u> Yes

Microsoft Office – very good

AutoCAD – basic knowledge

ArcView GIS – basic knowledge

Adobe Photoshop – good

<u>Driving licence:</u> B