

THE IMPACTS OF RURAL SMALL-COMMUNITY WATER SUPPLY INTERVENTIONS IN RURAL SOUTH AFRICA

Report to the
Water Research Commission

by

Paul Jagals

Department of Environmental Health
Tshwane University of Technology

WRC Report No. 1700/1/12

ISBN 978-1-4312-0319-2

Set No. 978-1-4312-0320-8

September 2012

Obtainable from
Water Research Commission
Private Bag X03
Gezina 0031
South Africa

orders@wrc.org.za or download from www.wrc.org.za

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Executive summary

1 INTRODUCTION

Socioeconomic development, in particular protection and improvement of public health, is linked to safe drinking-water. Yet the majority of the world's population lacks this. Much evidence exists to show that, where communities use poor quality water, improving water supply services such as access, availability and portability generally leads to a significant reduction in morbidity as well as premature mortality from water-related infectious disease. The purpose of this work was to develop an understanding of the socioeconomic value of improving water supply services and ultimately produce a framework from which to develop a tool for assessing and monitoring the extent of these benefits. The focus was especially on small community water systems serving people who would otherwise be difficult to reach and therefore often left outside of large-scale schemes.

The water service sector in South Africa, and in particular the government, has over the last 15 years implemented its programme of making water accessible to all, spending billions of Rands to establish new water supply services. In doing so, it strived to meet backlogs as well as implement new, as well as upgrade existing water supply services in smaller communities in rural areas as well as for those in fringe-areas of established larger urban settlements. While substantial progress was evidently being made with interventions to improve access to safe drinking water in terms of the hardware (water distribution systems and taps), very little work was being undertaken to date to periodically assess or continually monitor the subsequent impact that these improved water supply services would have on recipient communities throughout the country. The full extent of their impact (beneficial or detrimental) is therefore not known.

A major reason for not doing assessments or monitoring is a lack of suitable measuring instruments – possibly because of the complexity of what needs to be measured. Local and international activities including that of World Health Organisation-network for small-community water supply systems, suggest that such instruments do not readily exist, especially not a comprehensive type of impact assessment instrument for developing country settings. At international level, the WHO and World Bank have attempted over time to provide generic methodologies to quantify the benefits of water improvement interventions which, while useful instruments, are usually based on wide ranges of assumptions that might or might not have been tested at developed and/or developing country level such as in South Africa.

The original question that spurred this work was whether small community water supply interventions in South Africa were beneficial to their recipients and to what extent?

The South African Water Research Commission solicited and funded this research with the terms of reference requiring an assessment of the sociological, economic, technical, and health impacts and benefits of 10 years of water supply and sanitation interventions in South Africa (Project WRC Project K5/1700 named “*A toolkit to measure sociological, economic, technical and health, impacts and benefits of 10 years of water supply interventions in South Africa*”). The purpose of the research was two-fold – ❶ to develop a methodology to ❷ measure impacts of small-community water supply service interventions. This report presents the method and the research to develop and apply it.

The majority of small-community water supply service interventions before as well as during the time of the research were aimed at providing at least a basic water supply for communities who previously had none, as well as upgrade rudimentary supply services in other communities. This guided the decision to develop the method on a case study basis within a selected suite of small rural community settings. Water supply service interventions in these communities were varied in implementation and also diverse in technology, offering the optimal environment for developing and applying such a method and at the same time providing the preliminary evidence of the impacts of these interventions.

By establishing new water supply systems in rural small communities in developing-country settings, a water service provider usually aims for improving whatever water supply or undeveloped water source a community might have used. This could be untreated (and often contaminated) surface water, or upgrading an already (technically) improved but nevertheless still rudimentary water supply. The improvement would usually consist of providing an appropriate technology (a water supply system) supported by a set of service functions. With such a system (and supporting functions), the water service provider hopes to see optimal and sustainable use of the system (technology) to the benefit of the community. Since no two communities respond in a similar way to the

intervention, a system might be working in one area but not in another. This makes for a complex impact measurement approach as this report will illustrate.

The impact categories for this project were *health*, *sociologic* and *economic* (HSE) benefits for the community that receive the new or upgraded water supply service. A water supply service must bring a shift away from (impact on) resident (possibly detrimental) circumstances (such as drinking faecally-polluted water) to bring about sustainable health, social and economic benefits for the household and the community. An impact is caused by an effect. Before the HSE impacts can be measured therefore, suitable *effect* indicators had to be defined. For this study a suite of effects were selected that would most likely be induced by a change of water system and its service. These included effects such as saving time, increasing the family's daily water quantity for domestic use, reducing the risks of infection and disability as well as reducing disease as measured by the incidence of diarrhoea in the recipient communities.

At a first glance, these effect indicators do not appear to be complex to measure – especially not from a research perspective. However, a generic assessment tool is not intended for doing extensive research as it cannot be expected from potential users to undergo the rigours of a true research endeavour. Moreover, effects might not be directly linked to an intervention. What was required was first measuring *changes* brought about in the *water service functions* by the change in water supply.

Impact measurement was therefore based on the *effects* of the intervention, which were measured for effectiveness using *indicators of water service functions*.

2 PROJECT PURPOSE, BACKGROUND, AIM AND OBJECTIVES

The main purpose of the project was to produce a generic tool sufficiently generic (and simple) to be used for assessing the impact of improving small community water supply services. The assumption was that the potential users from these sectors would not be in a position to measure all potential variables such as were researched for this project. It would simply be too elaborate. This means that the tool had to provide a realistic measure of impact without the requirement of gathering large volumes and types of data. This also initially meant that research had to be done and assumptions made for the variables to be used in the tool, and that these variables had to be tried and tested against real-time research data before inclusion in the tool.

While the selection of variables were being researched at the project onset, small communities were identified where it was possible to assess, over time, concurrent HSE scenarios of *before* and *after* the participating communities received water supply service interventions. The target communities received a variety of water supply systems which offered real time research scenarios where communities were being provided with a new basic service from no-service as well as being upgraded from rudimentary service situations. *System management* and *container based water distribution* were assumed as default confounders that would be encountered in any basic small-community water supply service.

The study communities in rural Limpopo province, South Africa provided data for this project over a period of more than five years (2004-2009). These communities numbered from 6 to 15 village-level communities with populations varying from 200 to more than 5,000 people with a total of approximately 10,000 people being affected by the various levels of water supply services addressed in this study.

While the results are therefore by no means presented here as an accurate and total assessment of situations elsewhere in the country, it nevertheless should be a plausible reflection of what can be expected from similar situations elsewhere. This report does not provide definitive answers on the impacts on a country or global scale nor is it intended to be the ultimate research done on the topic. It is hoped that researchers elsewhere will do more work with especially the methods that were used during the research to refine them and increase the resolution of the results.

The toolset that was developed as a single and much simplified monitoring-level instrument based on suites of more elaborate impact assessment tools that were developed and used for the research. The research results provided the basic information for developing the tool. It is hoped that by using the tool, service providers can determine for themselves whether the small-community water supply services they provide are in some way beneficial (or not) for the health, social and economic circumstances of people in their respective constituencies without requiring the extent of research data that were produced for this study.

3 OVERALL PROJECT AIMS

The project had a two-fold aim. The primary aim was to research and document the changes in the functions, effects and impacts brought about by basic water supply interventions in small and rural communities in a selected area in rural South Africa. Then the tool was developed based on the findings from this research.

4 WATER SERVICE FUNCTIONS AND CHANGES

A sustainable water supply service for a small rural community requires a fully functional and technologically manageable system to support the functions of water service delivery such as providing easy and sustainable access to a consistently available, good quality water supply. As such the functions required to suit a particular setting (conditions in a community), will determine the scale and calibre of the system. The result of this is that almost no two small systems are, or will be alike and it will therefore be difficult to generalise the findings of this components of the project. The team nevertheless strove to select a suite of small systems that should, in the South African context, be reminiscent of a vast majority of these systems throughout, and the conditions under which they function.

The research activity focussed primarily on the three primary water service functions (access, availability and potability). The secondary research activity focussed on technical assessment of the actual basic water supply systems services after the upgrade process. The basic water supply service at this particular level of service is the flagship of small-community water supply services in South Africa.

The functions measured in this project were seen as those that will ensure beneficial HSE impact from a water supply service. These are access to and availability of potable water. For this project, access was measured by four indicators namely distance from water point, sourcing technology (i.e. a tap), source point density and sourcing conditions. Availability was indicated by three conditions namely availability of water at source both in terms of being there as well as sufficient quantity, and then flow rate. Potability refers to parameters such as the microbial and chemical safety of the water delivered at the water point, with *E. coli* as the primary indicator of water safety.

Water supply services in South Africa are generally more developed in urban than in rural areas where water services are still non-existent (no service) with basic services being established, or rudimentary services being upgraded to basic water supply services. The context of no water supply provided the “non-service” scenario for this project. With an estimated 5% of the total South Africa population still without a water supply services at all – the majority being rural people, water source points are often quite distant, with the water at the source point (dams, rivers and streams) often not available and mostly contaminated when it is available. Households from such communities collect water from open sources such as rivers and streams, and carry it in containers back to their homes often over distances of several kilometres, with individuals spending several hours to collect water.

Rudimentary water supply services are being used by approximately 7% of the South African population (mainly rural), which are yet to be upgraded to basic services. A rudimentary water service provides a water supply at communal water points typically located between 200 and 500 metres from households, with elementary sourcing technology such as handpumps and windmills and some elementary management activities such as source protection. Containers are still required to collect water, and quantities collected vary between 5 to 15 l/cd. Community tank services, used in several rural South African communities, such as the ones in this research, where also seen as rudimentary water services

A basic water supply service is seen as the supply 25 litres of potable water per person per day supplied within 200 metres of a household and with a minimum flow of 10 litres per minute (in the case of communal water points). It also should be a sustainable operation with water available at supply points for at least 350 days per year and not interrupted for more than 48 consecutive hours per incident.

All three these water supply scenarios have the common issue of the use of small vessel/domestic containers to move water from source to home. The more advanced services may supply water of good quality but water source points are still off-site (not in the home). This required the water to be collected in containers, carried home and stored in the containers while being used. These activities re-contaminate the stored supply.

4.1 Assessing changes in the service functions following upgrades (and breakdowns)

The research was conducted in six rural community clusters – ultimately consisting of up to 15 villages in the Nwanedi River basin in the north-eastern parts of the Limpopo Province, South Africa. Several small-community water supply services were being established in the area at the time, offering the opportunity for this work. The

overall period of study was from 2004 to 2009, with this particular project commencing in 2006. During this time several pilot community discussion group and household survey activities were conducted to prepare and construct the questionnaires, observation sheets, water sampling protocols, and finally also provided the basis for community group discussions conducted throughout this particular study. All the studies spanned all four seasons of the year.

The communities participated, on several occasions, in a total of seven sampling and six groups of survey activities.

- Early on cross-sectional surveys collected demographic and socio-economic data. This was done once at the beginning of the study of each participating community, i.e. the baseline;
- The second round of survey activities saw periodical cross-sectional surveys conducted of the function indicators. These cross-sectional surveys covered the baseline and post-upgrade periods;
- The third round of activities was group discussions in the communities during which times feedback from the function indicator surveys were given and problem issues clarified. The sampling activities were for collecting water samples from the containers at the household as well as from the various sources.

The same data collection tools were used throughout for each of the survey activities and the same protocol for water sampling and testing. The interview-based survey tools were first constructed in English then translated into the local language of TshiVenda and then back-translated to English to ensure clarity and accuracy of the questions. The data collection tools, including the contents of questionnaires and data capture sheets, as well as the capture of data are described later on under the sections about the respective indicators.

4.1.1 The water supply services

The water supply services for the study communities as they were during the baseline period as well as after the upgrade are summarised. The “upgrade” in the context of this study was the change from ① no service to a full basic by water supply service with communal taps on standpipes and ② upgrading from no service to handpumps and communal tanks (rudimentary water supply service) and then to communal taps (basic water supply service).

The alternative sources were the original sources that the upgrade communities would revert to whenever the rudimentary or basic water supplies were interrupted. Technology refers to the means by which water was accessed from the source, such as a hand-pump on a borehole and or communal tap on a standpipe connected to a piped water supply network. It also refers to the containers and their peripheral devices (scooping vessels) used when collecting water from the open sources during “non-service” circumstances.

4.2 Benchmarking the functions and their indicators

4.2.1 Results and discussion: Assessing changes in the functions after upgrades

In terms of *access* the overall effect was that the water source points were moved closer from as far as 742 and 1,380 metres afield (to the open sources) to between 171 and 280 metres (at the taps) – significant relief in terms of carrying water from the source to home. Upgrading to basic services also improved the source point density substantially with the smaller communities being significantly advantaged with the number of taps they eventually could use to source water. The improved sourcing technology, when water was available at these points, significantly reduced the filling time at the source point because of increased flow-rates at the taps.

Availability referred to the temporal and physical presence of water at the water source point (availability at source), the flow or filling rate of water at the water point (depending on the sourcing technology) and also the quantity of water that could be collected from that water point. Results of the quantity of water collected are presented as litres per capita per day (ℓcd). Availability *at source* was reported as the percentage of the number of days during the study period when the water supply service was operable or, in the case of rivers, the number of days in the study period when the river was not dry and water could be collected from it. The upgrade to basic service and the consequent improvement in sourcing technology *increased the filling rates* to almost twice and sometimes more than that of no service and the rudimentary service. This was over the minimum of 10 ℓ/min benchmark and therefore complied with the guidelines.

Results of *potability measurements* showed, as can be expected, that neither source nor container water were suitable for human consumption during the no service eras. After the upgrades the quality of water from the BS source points for all upgrade communities was very good in terms of the health-related microbial quality. It complied with the SANS benchmark. However, none of the container water data sets complied with the SANS or

WHO codes as these waters all became excessively contaminated with indicator bacteria after sourcing by whatever means.

4.3 Technical assessment of the basic water supply systems

The purpose of doing the technical assessment presented here (on the basic water supply systems only) was because this is the sentinel system that the water service roll-out programme of the South African government provides for all areas where no water service exists or a rudimentary water supply service is being upgraded. It also formed the technical assessment backbone of the monitoring toolkit.

The typical rural small-community water supply systems assessed in this work were basic water supply systems. They draw source water from rivers, springs or drill-wells, supplying water to an elevated clean-water holding tank, from where a simple distribution system is fed. The systems terminated in a series of public standpipes.

A thorough review of the literature revealed a host of different criteria pertaining to small-community water supply systems. In this particular section the focus was on criteria obtained from *Technical guidelines for the development of water and sanitation infrastructure* by the Department of Water Affairs (2004). Many of these criteria rely heavily on detailed hydraulic analyses and are framed in such specific terms as the percentage of time that threshold pressure can be maintained, the number of nodes not reaching specified flows, etc. These criteria obviously do not apply to basic water supply systems with only a few standpipes. In the main, two criteria were found to be relevant, namely *reliability* and *durability* for a small community water system. These two criteria also form the backbone for the service function of “*availability*” discussed in Section 3.1 and thus provided data for the assessment of this service function.

Reliability of a basic small community water supply system generally encompasses the availability and distribution of water supplied, water usage restriction and pressure in the water main, as well as system failure in providing these services. A common measure of reliability is the probability of system failure, which could result from failure at source, failure during distribution, insufficient pressure, or failure of outlet hardware. Reliability as a single criterion was found to be too broad for the assessment of rural water supply systems. In these cases, it is important to also determine where along the supply chain the failure occurred, and how the reliability could be improved. It was necessary to split the broader concept of reliability into three more narrowly defined criteria, namely *availability*, *capacity* and *continuity*.

The concept of durability was captured as the better defined criterion of *condition*.

This technical assessment thus hinged on four criteria:

- Availability of a water source in terms of source water quality as well as source water quantity. Availability in the context of this particular assessment work was an adaptation of the availability in that it would refer to the system’s ability to deliver the required quantity and quality of water and not the Q & Q required protecting human health – which is the focus of the availability. Hence this will be referred to as system availability.
- Capacity – refers to the system’s capacity to deliver the water from the source to the consumer;
- Continuity – refers to the system’s reliability to consistently deliver water over time;
- Condition – refers to diligent maintenance and repair of the system.

4.4 Summarising the function changes in water supply service interventions

It is evident from the results that, while adherence to technical design standards appear to be adequate, much more attention must be directed to improve maintenance and operation by the service providers. Unless better resources, training, discipline and accountability are provided, the current investment in rural water supply systems will only provide temporary relief, as the systems will remain unsustainable.

4.4.1 Access

An important change brought about by changing (improving) access was the *distance* (in metres) from the house to the source point (point on river bank, handpump or tap). , substantial reductions were achieved in distances to water sourcing points where communities received a basic service followed by (for some) an upgrade to a rudimentary service and then an upgraded service (the study intervention) sometime later.

The communities that initially received rudimentary services were brought substantial relief of the distances they had to traverse to collect their water. The final upgrade to the basic service brought more relief for those on

rudimentary services and even greater relief to those were still on the open sources. The second major criterion for access was *source point density*. Here the intervention towards the basic service contributed to the numbers of households per source point being reduced substantially as well as the numbers of points per km² increased.

4.4.2 Availability

Availability in the context of function means a continual water supply at the source. The combined results are shown here in Table ES5. The results show that all the sources had the capacity to provide water for their respective communities regardless of the level of the service. All the systems were operated on a community level arrangement of pumping hours to lessen the pressure on the operator and the system. These self-arranged interruptions meant that water was not available for 24/7 as is the intention in the guidelines. The daily availability was calculated at 10 hours per day deemed as good as 24 hours per day.

The combination of reduced distance to as well as sustainable capacity, increased flow rate and constant availability of the water at the source point created the expectation that households would increase their per capita daily water demand. This turned out to be not the case as will be shown when the effects on the family household water demand are discussed in the next section.

4.4.3 Potability

Potability in the context of this work refers mainly to two major aspects of the quality of water that humans may drink. First there was the health-related microbial quality (based on *E. coli* indicator organisms) of the water available at the source and the extent to which these might impact on the health, social and economic condition of the recipient community. How the changes in this particular water quality type affected the users are discussed in the next section.

The quality parameters used to assess the sanitary and hygiene condition as well as the aesthetic quality of the water delivered from the three source point components of the basic system (pH, conductivity and turbidity), were about 90% compliant to the South African National Standards for Drinking Water Quality (SABS, 2006). However, the hygienic quality of the water delivered by the systems and measured by the occurrence of total coliforms, was substantially non-compliant at 90% for the rudimentary upgraded systems and 100% for the open sources.

It is clear that, except of pH and electrical conductivity, the water collected at the open source points did not comply to the benchmarks adopted for this work, with the worst quality measured at the unprotected source points. The quality of the water taken from closed (groundwater and tanked) sources complied with the guidelines and standards at the source but the use of containers led to recontamination causing increased numbers of indicator bacteria. Even though the supply waters of the basic services was significantly less contaminated, the health-related quality, as based on numbers of *E. coli* in the water in containers, did not comply by a wide margin.

5 THE EFFECTS OF CHANGES IN THE WATER SUPPLY SERVICES

The previous Section 3 has shown that households benefitted from improved access because of shorter distances to increased numbers of efficient source points (taps) in their area. Improved availability also offered benefit in that it reduced waiting times at the source points as well as made water more available over planned period of time. All these improvements should essentially free up more time for the family to use more productively as well as lessen the toil and injury risk that is associated with the carrying of heavy water filled containers from source point to home. This section summarises the finding of research into these anticipated effects and its implications for impact on the health, sociology and economy (HSE) of the household (summarised in Section 5).

To provide a measure of this risk that makes economic sense, the effect of the improved services (including a potential reduction in the risk of infection) on the incidence of diarrhoea in the study communities is also will also be summarised here.

The aim of this section was to study and describe changes brought about by the water service interventions in terms of selected effects. Specific objectives were to describe the effect of changes in access and availability on water collection time, quantities of water collected per person per day, i.e. the individual water demand, the risk of musculo-skeletal disability due to the carrying containers filled with water and finally changes in potability on the risk of microbial infection per person.

5.1 Methods

The following are summaries of the methods used to measure the various effects either on their own or drawing from the function assessment data summarised in Section 3.

5.1.1 Time

Time was first measured for an individual and then calculated at household level following certain assumptions. Calculations of time were based on a standard container volume of 20 litres, as that is the common capacity of containers used for water collection in the area, and is also in keeping with international literature. This time was the time it took for one person to collect one 20-litre container of water per trip (collection time). This was calculated by adding total walk time (trip time to source and back), to filling time and extra (undefined) time. For this study, the ideal time for collecting water was assumed to be achieved if the tap was on site, reducing time to the minimum say two minutes to walk to the tap, fill and walk back.

5.1.2 Water quantities per person per day

To calculate the *per capita daily water collection* that was achieved in the various communities it was first necessary to calculate the household water collection per day (ℓhwd) and then, using 20-ℓ as a container measure, divide the total household collection to determine the water quantities collected per person per day (ℓcd). Benchmarks were set for water quantities collected per person per day (ℓcd). Per capita water collection was considered to be a minimum level of compliance.

5.1.3 Risk of musculo-skeletal disability

MSD was measured according to three approaches. Firstly, a review of the literature was conducted to investigate whether any risk assessment or health measurement tools currently exist to measure the impact of DWC. Secondly, an exploratory study using mixed methods was conducted to determine the domains of health potentially affected by DWC and which are important to people who do the DWC. Finally, a further review of literature was conducted, to compare the findings of this exploratory study to research into the relationship between physical work and health conducted in other settings. The results of these approaches were synthesised to identify the outcomes and potential risk factors for those outcomes which should be investigated to determine the health impact of domestic water carry (DWC).

5.1.4 Measuring infection risk

This was conducted according a quantitative microbial risk assessment (QMRA) process with the probability of infection by water sampled from household drinking water containers the main focus. Molecular detection of *E. coli* pathogens was performed on the container waters of all the selected households in the study communities. The data were collected on all the variables, while assumptions were made about the dose-responses as well the pathogen fractions in the samples testing positive for indicator *E. coli*. The benchmark for acceptable risk was set at the best performance in reducing risk achieved by a basic supply service in any of the study communities.

5.2 Summarising the *effects* of water supply functions changes

The interventions did not have any effects that could be described as good or compliant. These effects in the end were not as much caused by the inherent quality of the system both in design as well as the quality of the water it provided, but was caused by poor maintenance and operation.

Time was indeed saved by reducing the total individual collection time from what was spent collecting water during the no-service period to what is being spent using the basic water supply service. Most water carriers were still spending “non-compliant” or “unacceptable” amounts of time to collect water for their household needs because of excessive extra time;

Daily water quantities were also not collected to the extent as was expected. Despite the water source points being significantly closer, and the quantities collected were significantly more using the basic water supply service, households seem to bring in the quantities according to their own specific needs, with no indication whether the much vaunted minimum of 25 ℓcd would be achieved;

Despite the method for assessing the risk of MSD still being robust at this stage of this work, it still gave a good indication of the toll that water carriers are clearly subjected to excessive risk of MSD;

While there was some relief for some of the communities in terms of the risk of infection, the container situation still continued to pose a risk.

6 ASSESSING THE IMPACT OF WATER SUPPLY FUNCTION CHANGES

The results summarised in Section 3 showed that there were significant and seemingly beneficial function changes brought about by the water supply interventions – incrementally (from no service to rudimentary service to basic service) as well as direct intervention (no service to basic service). These did not appear to translate into any beneficial effects for the households in terms of the *effect* indicators used in this study (Summarised in Section 4). This is in all probability because of the use of containers to collect from the improved source points and store water at home while using it, as well as poor maintenance and operation of the water supply systems.

This does not however, mean that the service improvements failed.

The consequential impacts were also considered the measured (actual) impacts of the interventions on the health, sociology and economics (HSE) of the recipient communities. These are now summarised in terms of benefit, detriment, or simply no measureable impact. It could very well be, as were pointed out in the previous section summaries, that the actual impact that was already achieved at this point is beneficial and with a few marginal changes in policy, forward thinking and improved service delivery, the effect values as proposed for future indicators (Section 4) could well be achieved.

The *aim* of this part of the study was to measure the function changes in terms of benefit, no measureable impact or detriment. Specific objectives were to describe the health, social and economic impact brought about by changes in water supply services.

6.1 Methods

Health impact was measured by using the relative risk of contracting diarrhoea as an indicator of this impact. The levels of satisfaction related to the water supply services of small communities were used to measure to determine *social impact*. The economic impact was determined by using a social cost-benefit analysis (SCBA).

6.2 Outcome of impact assessment

As the basic services were the primary level of service targeted for assessment in this project, the outcomes of the impact research clearly show the impacts were mostly beneficial for the basic services.

In the context of health, the beneficial impact was based on an arbitrary figure of what constitutes an acceptable level of *diarrhoea* in a community. This figure could change as the concept is further explored in future research. If it is made more conservative in the South African context, then the impact might change from beneficial to no impact or even show the original detriment to remain.

Using only *satisfaction* as the social parameter is too conservative. While relatively high satisfaction levels within the receptor communities were sustained even throughout the times that the systems were not well maintained, more detailed factoring in of the receptivity results (shown in the report attached as Appendix C) would have shown that disappointment with the system failures could offset the positive findings that only the satisfaction indicator produced. However, for the receptivity approach (Theory of Planned Behaviour) to provide feasible results, more real-time before and after studies were required than the study could provide. This is a point that should be researched further.

By far the most influential economic impact indicator was the *social cost benefit* analyses (SCBA). Many areas of social life not often thought of, showed where an improved basic water supply service adds value to the daily lives of people beyond the classical indicators of disease risk reduction, people behaviour change and indeed cost-effectiveness. The reader is referred to the more comprehensive work on SCBA that is referred to under Cameron et al., 2011.

7 CONCLUSION

It follows therefore that the main body of research findings reported on in this document was focussed on the primary aim of the project namely to assess the changes in the functions, effects and impacts brought about by

supplying basic water services a specific set of small and rural communities in the Limpopo province in South Africa.

7.1 What was the impact?

The impact was beneficial overall. However, coming to this finding has conditions and also raised several questions – which will be discussed below as well as in the next sections.

The beneficial impact should come as no surprise, as substantial international literature on this issue shows that the impacts would be more beneficial than detrimental at a point in the time almost immediately following the implementation of a new, or an upgrade to, basic water supply service (BS).

Clearly not all of the functions and effects were attributes to the beneficial impact. Effects such as the bacterial risk of infection as well as the risk of musculo-skeletal disorder were indicative of things not going well, but were in turn strongly associated with the use of containers. The real benefits of having a yard tap or an in-house connection and its relationship to the use of containers have not been assessed.

How is it that the *effect* categories performed so poorly and yet the *impacts* of especially the final upgrades were still beneficial? Clearly, the lower relative risk of contracting diarrhoea should be ascribed to a whole system effect as was so effectively demonstrated by the ❶ benefits of working systems versus the ❷ no impact of struggling systems and the ❸ detriment of non-systems (Majuru et al., 2010).

Relationships between risk assessments such as the QMRA and the epidemiology-based relative risk are precarious exercises and with the limited data sets used in this study, the actual findings of the epidemiological study done for impact assessment should be the more plausible impact rather than predicting the risk as the QMRA is often used for.

Another significant finding is the fact that people do not bring in more water into their daily water use pattern despite the fact that water sourcing is closer and more convenient and regardless of the fact that they appear to be quite satisfied with the fact that they could bring in more water if they felt they needed it. Yet the risk of a household member to contract diarrhoea is less. More study will be required to unravel this phenomenon.

Although there were substantial savings in treatment cost, the predominant factor that made for a sound economic benefit is the savings in time and less disruption of social life, in terms of increased school attendance that bolstered the beneficence.

The main question that arose from this research (and also subsequently answered) was whether this benefit was sustainable.

7.2 Was the beneficial impact sustainable?

Two major conditions dominated the answering of this question. Its outcomes clearly indicated that the BS, as delivered to the study communities, were NOT sustainable, and the benefits initially achievable by such a service, substantially negated.

7.2.1 Communal taps and containers

The first condition was the primary condition by which the BS was provided namely communal tap endpoints. As long as the general first tier service aspect of the BS was based on delivering clean water at communal taps, it keeps the use of domestic water containers with all its detrimental side effects (negative impact on microbial water quality and musculo-skeletal impact on the water carriers who were mostly women and children), within the service. Enabling private connections was not a viable option in the study communities as the households clearly felt that in-house water provision should have been the endpoint and not communal taps.

Three sub-conditions need to be attached to this though:

- As long as people are provided clean water consistently at taps, the seeding of pathogenic bacteria into containers and subsequent increased risk of infection will be limited. However, people do need to be made aware of keeping containers clean;
- If the expectation of increasing people's daily household water use to support health and hygiene is to be realised, people need closer access to water in more amicable conditions;

- While the evidence of potential musculoskeletal impacts of water carry were effectively ruled out of consideration for this study because of the size of the study group, the study did indicate the potential for this situation to be one that can cause a serious chronic disease burden. If these findings were indeed to be universally true, then it is a plausible theory that the cost of treating musculo-skeletal injury might be an economic burden that can render the impact of improved basic water service delivery as detrimental instead of beneficial. More research is urgently required to assess this impact.

7.2.2 System management

The second aspect was the management of the systems. The results clearly showed that where the systems of basic supply services were properly managed (Reference community as well as Upgrade communities 1 and 2), the impact was consistently beneficial for the study period with no reason to believe that it would be otherwise over a longer time provided the conditions do not change.

The findings were clear on the inefficiency of the operations and maintenance of the systems in the area and how these consistently threaten the immediate benefits that are achieved with the implementation of a basic water supply service. No doubt this will be receiving serious attention as the government is putting measures in place to improve this.

What is a greater point of concern was the urban growth that was observed during the study. In especially the Reference Community and Upgrade community 1, the strain on the systems was already evident with evidence on enlarging the system showing it to be some time still before this would happen. Meanwhile the communities will continue to be at risk of failing systems.

7.3 In conclusion

This report does not provide definitive answers on the impacts on a country or global scale. While the results are by no means presented here as an accurate and total assessment of situations elsewhere in the country, it nevertheless should be a plausible reflection of what can be expected from similar situations elsewhere. It was also not intended to be the ultimate research on the topic. The use of large domestic water containers (the likes as is being described in this document) *has to be eliminated* by providing private connections and not communal taps. Taps need to be put as close to homes as possible, at least one tap per living unit, if not in-house, than directly adjacent. The Water Research Commission should consider soliciting research into the social cost-benefits of providing in-house water versus communal taps. It will not be surprising if such findings would show it cost-beneficial for houses to have on-premises water instead of communal taps.

On-premises taps will rule out heavy container carry and enable people to use smaller containers (more economical in term of acquisition cost) with larger openings to enable cleaning. However, if people were to continue using containers because of the model of basic water service delivery to communal taps remain unchanged, the communities should at least be made acutely aware – even trained – as to optimal hygiene maintenance of containers as well as the ergonomically correct way to carry these.

Furthermore, if people were to continue using containers, more consideration should be given to improving dedicated container technology (for transport and hygiene) as well as to subsidy for households to acquire these.

This was not happening at the time of this research, and there was also no evidence that this was on any engineering, social or health service agenda at any level of government. It demands urgent attention.

In terms of finally developing the monitoring tool as a product of this study, the focus was far more on using variables from what the actual basic water supply service was designed to deliver – with some limited variables from the effects and impacts. While the container situation needs to be addressed at a different forum, it could not be left out of the monitoring tool and was factored in for variables where it had the most demonstrated effect namely access to and potability of water.

7.4 A few last words

The author is very happy to say that the district council in the research area is in the process of constructing a regional water scheme that would provide a substantial supply of piped and treated surface water to the many small communities in the area, including the communities that participated in this study. One can only congratulate the service provider and the communities for making this happen. However, on the other hand one can only hope that the treatment storage and supply of water would be managed proportionate to the investment

and better. In the final analysis this means that the villages and towns will always have access to available and potable water. Anything less would be a sad reflection on service delivery.

This study has shown that substantial health, social and economic benefits can be achieved with a proper water supply service based on a proper delivery system. A sustainable water supply service will improve and accrue these benefits.

Which after all is what our society is aiming for when investing billions in water supply interventions for small and rural communities in South Africa.

Acknowledgements

Like with any project with this diversity of topics and the scale of operations, it took more than one research and funding entity to make it happen. The following institutions and persons are gratefully acknowledged for the roles they played:

- The South African Water Research Commission was the primary funder of this project. Other organisations that had input into the funding, directly and indirectly, were the World Health Organisation and the National Research Foundation (South Africa);
- South African Universities played the major role in providing the research support. These were the University of Johannesburg (UJ), where the project started, and the Tshwane University of Technology (TUT) where the project was completed;
 - o From the UJ were involved the Water and Health Research Centre, and the departments of Civil Engineering Science, Sociology as well as Economics and Econometrics;
 - o From the TUT was involved the department of Environmental Health;
- International universities involved were the Technological University of Delft (TUD) (NL), University of East Anglia (UEA) (UK) and University of New South Wales (UNSW) (Aus);
- Primary participating research fellows and students were Dr TG Barnard (UJ), Mike Mokoena (UJ/TUT), Batsirai Majuru (TUT/UEA), Rachelle Koekemoer (UJ/TUT), Jo-Anne Geere (UEA), Elvis Fosso Kankeu (UJ), Kousar Omar (UJ), and Eli Lai (UJ/UNSW);
- Colleagues that collaborated closely were Professors Johannes Haarhoff (UJ), Luuk Rietveld (TUD), Jock Cameron (UEA), Paul Hunter (UEA), Celia Van Zyl-Schalenkamp (UJ) and Nic Ashbolt (UNSW);
- All field workers and community activists whose names do not specifically appear;
- And finally but definitively the most important, the participating communities from the Vhembe District especially those in Folovhodwe, Gumela, Tshitanzhe, Musunda, Guyuni, Helula, Madimbo, Mashangwadvha, Muswodi-Dipeni, Muswodi-Tshisimani, Thondoni, Tsaanda, Tshaluwi, Tshapinda, Tshikwarakwara and Tshitandani;
- All steering committee members and reviewers of this work.

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Chapter 1

Introduction

Socioeconomic development, in particular protection and improvement of public health, is linked to safe drinking-water, yet the majority of the world's population lacks this (Cameron et al., 2011). Much evidence exists to show that, where communities use poor quality water, improving water supply services such as access, availability and potability (Jagals, 2006) generally leads to a significant reduction in morbidity as well as premature mortality from water-related infectious disease (Cameron et al., 2011). Jallow and Barrow (2005) reported that water supply interventions had been beneficial to communities in rural areas particularly to their social sectors such as education and health as well as agricultural projects. Health benefits are however, not the only gains from improving water supply services. Other important benefits, loosely phrased here as economic and social benefits also apply. The purpose of this work was to develop an understanding of the socioeconomic value of improving water supply services and ultimately produce a framework from which to develop a tool for assessing and monitoring the extent of these benefits. The focus was especially on small community water systems serving people who would otherwise be difficult to reach and therefore often left outside of large-scale schemes.

The water service sector in South Africa, and in particular the government, has over the last 15 years implemented its programme of making water accessible to all, spending billions of Rands to establish new water supply services. In doing so, it strived to meet backlogs as well as implement new, as well as upgrade existing water supply services in smaller communities in rural areas as well as for those in fringe-areas of established larger urban settlements. While substantial progress was evidently being made with interventions to improve access to safe drinking water in terms of the hardware (water distribution systems and taps), very little work was being undertaken to date to periodically assess or continually monitor the subsequent impact that these improved water supply services would have on recipient communities throughout the country. The full extent of their impact (beneficial or detrimental) is therefore not known.

A major reason for not doing assessments or monitoring is an ostensible lack of suitable instruments to measure these impacts – quite possibly because of the overwhelming complexity of what needs to be measured. Close scrutiny of local and international literature as well as the activities of the World Health Organisation -network for small-community water supply systems suggests that such instruments do not readily exist, especially not a comprehensive type of impact assessment instrument for developing country settings. At an international level, the WHO and World Bank have attempted over time to provide generic methodologies to quantify the benefits of water improvement interventions. These are useful instruments but are usually based on wide ranges of assumptions that might or might not have been tested at developed and/or developing country level – for one, and certainly have, except for one recent WHO-brokered activity that is reported on later on in this work, not been tested in South Africa.

The original question that spurred this work was whether small community water supply interventions in South Africa were beneficial to their recipients and to what extent?

The South African Water Research Commission solicited and funded this research with the terms of reference requiring an assessment of the sociological, economic, technical, and health impacts and benefits of 10 years of water supply and sanitation interventions in South Africa (Project WRC Project K5/1700 named “*A toolkit to measure sociological, economic, technical and health, impacts and benefits of 10 years of water supply interventions in South Africa*”). The purpose of the research was two-fold – ❶ to develop a methodology to ❷ measure impacts of small-community water supply service interventions. This report presents the method and the research to develop and apply it.

The majority of small-community water supply service interventions before as well as during the time of the research were aimed at providing at least a basic water supply for communities who previously had none, as well as upgrade rudimentary supply services in other communities. This guided the decision to develop the method on a case study basis within a selected suite of small rural community settings. Water supply service interventions in these communities were varied in implementation and also diverse in technology, offering the optimal environment for developing and applying such a method and at the same time providing the preliminary evidence of the impacts of these interventions.

By establishing new water supply systems in rural small communities in developing-country settings, a water service provider usually aims for improving whatever water supply or undeveloped water source a community might have used. This could be untreated (and often contaminated) surface water, or upgrading an already (technically) improved but nevertheless still rudimentary water supply. The improvement would usually consist of

providing an appropriate technology (a water supply system) supported by a set of service functions. With such a system (and supporting functions), the water service provider hopes to see optimal and sustainable use of the system (technology) to the benefit of the community. Since no two communities respond in a similar way to the intervention, a system might work in one area but not in another. This makes for a complex impact measurement approach as the following sections will illustrate.

1 THE IMPACTS OF SMALL-COMMUNITY WATER SUPPLY INTERVENTIONS

A beneficial impact from water supply interventions is most often defined as improved health, which is a popular benefit targeted by researchers, decision makers and service providers. For instance, the Water Research Commission states: *“The primary goal of providing water (and sanitation) services is to improve health; therefore, it is important to undertake periodic assessment of the impact of water (and sanitation) infrastructure on the improvement of health”* (Water Research Commission [WRC], 2005). Using enough clean water more regularly undoubtedly enhances health protection by reducing exposure to disease agents and hopefully, as a direct or even indirect consequence, reducing disease (i.e. health benefit) (Prüss-Üstün et al., 2008). It is conceivable that water service interventions will have more rather comprehensive and beneficial impacts.

An example is the following: limited access to safe water is a major reason for an estimated three million incidences of diarrhoeal illness annually in South Africa (Department of Environmental Affairs and Tourism, S.A). At an approximate cost of R1,000 for the medical treatment alone, this amounts to a considerable R3Bn per annum (Cameron and Jagals, 2011). Reducing diarrhoea incidence (improving health) can therefore also be described as an economic benefit in terms of saving treatment cost. Less disease as well as less time spent on fetching water in a community might also lead to higher levels of community satisfaction. Savings on time spent collecting water from remote sources before the intervention is another important benefit from an improved water supply service (Makoni et al., 2004). Constant availability of water and shorter distance to source is expected to encourage households to use more water per person per day, primarily seen as a hygiene-enhancing attribute (Cairncross and Valdmanis, 2006) and would lead to greater client satisfaction (both are social benefits). More economic benefits are derived from saving water-fetching (access) time as well as saving on health treatment cost (Hutton et al., 2007).

The expectation for benefits therefore has moved beyond just health benefits (Cameron et al., 2011), with comprehensive benefits most often achieved within the health, economic and social circumstances of households (Prüss-Üstün et al., 2008). The impacts categories for this project were therefore selected to reflect health, sociologic and economic (HSE) benefits for the community that receive the new or upgraded water supply service.

2 THE EFFECTS OF SMALL-COMMUNITY WATER SUPPLY INTERVENTIONS

A water supply service must bring a shift away from (impact on) resident (possibly detrimental) circumstances (such as drinking faecally-polluted water) to bring about sustainable health, social and economic benefits for the household and the community. An impact is caused by an effect. Before the HSE impacts can be measured therefore, suitable effect indicators had to be defined. For this study a suite of effects were selected that would most likely be induced by a change of water system and its service. These included effects such as saving time, increasing the family's daily water quantity for domestic use, reducing the risks of infection and disability as well as reducing disease as measured by the incidence of diarrhoea in the recipient communities.

At a first glance, these effect indicators do not appear to be complex to measure – especially not from a research perspective. However, a generic assessment tool is not intended for doing extensive research as it cannot be expected from potential users to undergo the rigours of a true research endeavour. Moreover, effects might not be directly linked to an intervention. What was required was first measuring changes brought about in the water service functions by the change in water supply. This was an even more complex process as will be demonstrated in the next section.

3 COMPLEXITIES OF MEASURING CHANGES AFFECTED BY WATER SUPPLY INTERVENTIONS

The water supply intervention and its associated service functions have to be in harmony meaning that the supply system had to be appropriate in design with the functions ensuring optimal implementation, operation and maintenance. A water supply service is a rather complex interaction between its *system*, which is the technology base providing the water, and the *functions* which support the system to effectively deliver water. The functions are based on three primary properties described in South African water governance and other related literature. A

system should provide access to an available and potable source of water. Simply put, impacts on the recipient community are determined by the sustainable functions of the water supply service once operational

An important premise for this study was then that changes in a water supply service can be indicated by the changes in its service functions. These changes were first measured and described before their effects could be determined and described. Once the effects are clearly understood, the related HSE impacts can be determined. Finally, when these impacts became clearly understood – even on a limited and manageable but plausible scale – could a generic and simple monitoring tool be developed for application on a wider scale.

Identifying communities where changes in the functions, the effects of these changes and their impacts could be assessed proved a substantial challenge. These measurements had to be conducted within a dynamic matrix consisting of at least six identifiable dimensions. These complex dimensions are encountered not only in South Africa but also elsewhere in the developing world:

Impacts are multivariable: At its very foundation, impact of a basic community water supply service intervention will be multivariable, as it will affect the health, social and economic (HSE) domains of household/community life. While an assessment methodology could quite possibly be established to measure effects within each of these three domains, a next level of variability needs to be considered namely measuring the impact in communities that already had their systems established even before the study started – as would be the case for most areas where this method was to be applied in future;

Measurement over time: Understanding the extent of the HSE impact requires assessment of the situation in a community before the intervention, so that it could then be compared to the situation as assessed after the intervention. These types of data are not readily available in areas where small community water supply services were already established for any period of time before the study commenced. It was also in these communities where the preliminary study surveys encountered a myriad of different water supply services, especially in the context of the technology;

Types of water supply services: These varied quite substantially across many rural and peripheral communities in different areas of South Africa, each one with its own challenges to the HSE domains – especially in those communities where the services were upgraded in parts of communities and not in the adjacent ones;

Incremental interventions (upgrades): In some areas, communities with no previous water service were being provided directly with new water supply services. In other areas communities previously had rudimentary water supply services (already an improvement over a no-service situation) that were being upgraded to a next, more complex but still basic level of service – often in communities in close proximity of each other. These situations had potential to cause substantial shifts in effects and needed to be accommodated in a generic monitoring tool;

Inadequate operation and maintenance: Many of the established services are/ were in various states of disrepair and dysfunction because of inadequate management, mainly in operation and maintenance. It was therefore not a simple case of once-of measurement. The tool has eventually to be capable of being a continuous monitoring instrument through these circumstances;

Communal water supply: Finally, a common feature of much of the design and configuration of the basic community water supply systems in especially the rural areas was based on the extensive use of communal source points (e.g. taps) rather than these taps being on-site where a household dwells. This perpetuated the practice of households water carriers using portable containers to fetch water over distance from source points and store it in the household while being used – literally a case of a secondary distribution system where humans and their containers literally fulfil the function of a pipe bringing water to a home. This situation has often been reported to negate benefits initially thought to be achieved by improvements in the water service.

This provided another challenge for this project as it was not easy to find, in one package, communities whose circumstances were sufficiently generic and representative not necessarily of other communities in South Africa but rather of the different water supply dimensions.

4 PROJECT PURPOSE, AIM AND OBJECTIVES

The main purpose of the project was to produce a tool (WRC Supplementary Report 1700/2/12) sufficiently generic to be used for assessing the impact of improving small community water supply services. The tool needed to be applicable by potential users in the community water supply service and consumer sectors. The assumption was that the potential users from these sectors would not be in a position to measure all potential variables such as were researched for this project. It would simply be too elaborate. This means that the tool had to provide a realistic measure of impact without the requirement of gathering large volumes and types of data. This also

initially meant that research had to be done and assumptions made for the variables to be used in the tool, and that these variables had to be tried and tested against real-time research data before inclusion in the tool.

While the selection of variables were being researched at the project onset, small communities were identified where it was possible to assess, over time, concurrent HSE scenarios of *before* and *after* the participating communities received water supply service interventions. The target communities also had to receive a variety of water supply systems which would offer research into situations where communities were being provided with a new service from no-service as well as being upgraded from rudimentary service situations. System management and container distribution were assumed as default confounders (See Section 5 below) that would be encountered in any basic small-community water supply service.

After reviewing conditions and services for several community clusters in the provinces of KwaZulu-Natal, Eastern Cape, Free State and Northern Cape, a range of small rural study communities were eventually identified in and selected from a limited geographical area of the Nwanedi River basin in the Vhembe District Municipality of the Limpopo Province (Section 5 below). Ongoing research in the selected communities by the project research group (since 2004) formed an excellent basis for this project as it already provided access to the study communities. It also provided data that supplemented the research data generated by this project over a period of more than three years (2006-2009). These communities numbered from 6 to 14 village-level communities with populations varying from 200 to more than 5,000 people with a total of approximately 10,000 people being affected by the various levels of water supply services addressed in this study. While the results are therefore by no means presented here as an accurate and total assessment of situations elsewhere in the country, it nevertheless should be a plausible reflection of what can be expected from similar situations elsewhere.

This report does not provide definitive answers on the impacts on a country or global scale nor is it intended to be the ultimate research done on the topic. It is hoped that researchers elsewhere will do more work with especially the methods that were used during the research to refine them and increase the resolution of the results.

The toolset that was developed as a single and much simplified monitoring-level instrument based on suites of more elaborate impact assessment tools that were developed and used for the research. The research results provided the basic input for the development of the tool. By using the tool, service providers can determine for themselves whether the small-community water supply services they provide are in some way beneficial (or not) for the health, social and economic circumstances of people in their respective constituencies without requiring the extent of research data that were produced for this study.

4.1 Overall project aims

The project had a two-fold aim. The primary aim was to research and document the changes in the functions, effects and impacts brought about by basic water supply interventions in small and rural communities in a selected area in rural South Africa. Then the tool was developed based on the findings from this research.

4.2 Overall project objectives

The following objectives were achieved to meet the project aims:

- An intensive literature search provided the research framework of the various function-, effect- and impact-criteria, their indicators and associated parameters.
- A range of rural villages were to be selected based on:
 - The possibility to assess situations before and after water supply interventions;
 - The types of systems and services that the study villages were to receive – these had to be typical of systems providing basic water supply in peri-urban and rural areas.
- A suite of instruments were developed and then used to measure the changes brought about by various types of water service system and function interventions as well as the management of the systems considering the human-driven container-water supply link between the system endpoints (e.g. communal taps) and the households.
- The effects of these changes were quantified and described in terms of a suite of measurable effects.
- These water supply system changes and their effects were then translated into impacts (ranging from detriment to benefit) on the health, social and economic conditions of the households in the study communities.
- A generic assessment tool was finally developed from these assessments.

4.3 The research framework

Figure 1.1 shows how the objectives for the research translated into the research framework. After selecting the study communities based on the status of their water supply, the respective water supply systems, their functions and the effects of changes (before and after the intervention) in these functions and effects were assessed and translated to weighted impact values. Finally the tool was developed, tested and tried using data generated from the study area.

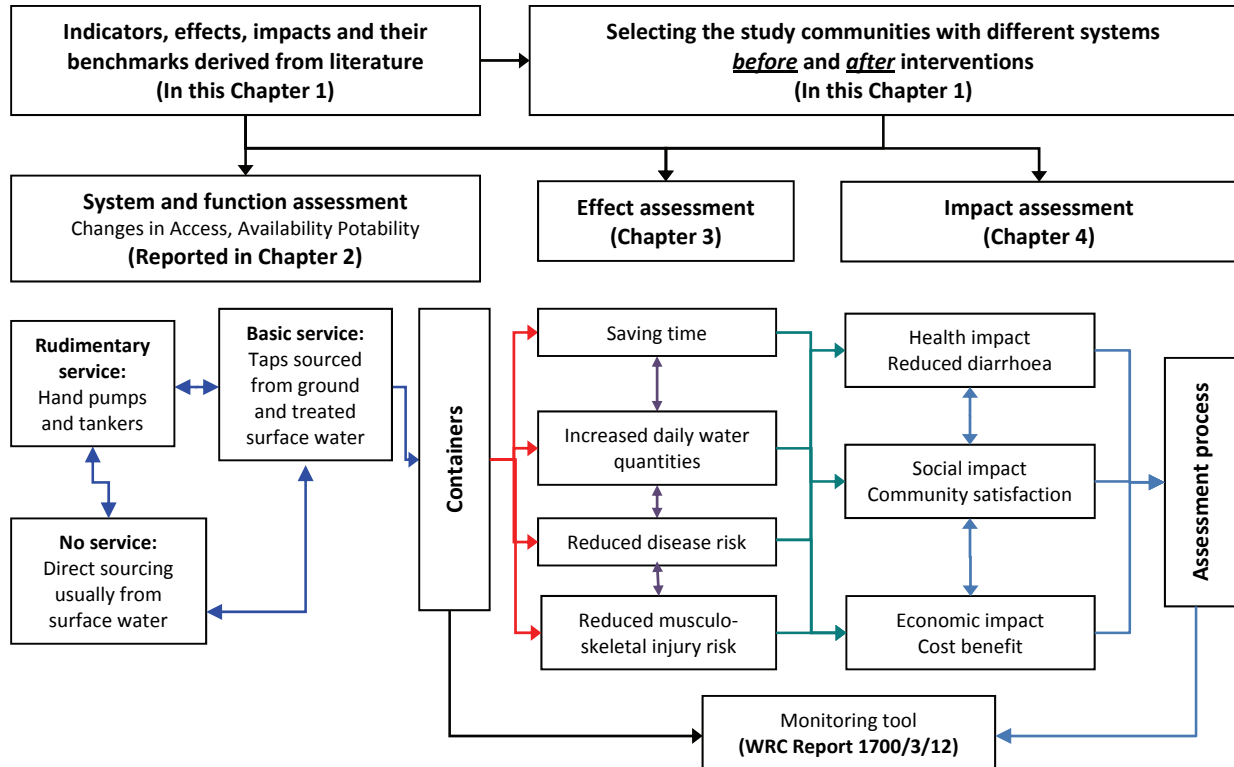


Figure 1.1: The research framework used to assess functions, effects and impacts for development of the monitoring tool

The research framework shows the various services, the effects expected when the service change, as well as the impacts resulting from this process. For each of these indicators were compiled tables of benchmarks from local and international guidelines and other literature. These are summarised in Table 1.1 (next page) and discussed in more detail in the chapters following.

Table 1.1: Criteria and parameters for the functions, effects and impacts of small-community water supply system interventions

Function criteria	System and function assessment		Effect and impact assessment	
	Indicator	Benchmark	Effect	Impact values
Access	Distance to source point	≤200 m from home	Saving trip time through reduced distance	• Social: Extra time for own affairs time • Reduced safety risk • Economic: Extra time for livelihood activity
	Source point density	≥ 15 points per km ² ≥ 1 point per 250 people	Saving extra time because of extra filling point options	• Social: Extra time for own affairs time • Reduced safety risk • Economic: Extra time for livelihood activity
	Source point technology	Condition of tap and/or handpump	Saving filling time by appropriate technology	• Social: Extra time for own affairs time • Economic: Extra time for livelihood activity
	Sourcing conditions	Condition of filling platform	Reduced risk of injury because improved sourcing conditions makes easier container filling and loading	• Social: Extra time for own affairs time • Economic: Extra time for livelihood activity
	System continuity	≥350 days per year available ≤48 hr interruption	Increased water quantities available per person per day	• Social: Extra time for own affairs time • Collection can be after school • Economic: Extra time for livelihood activity
Availability	Daily water needs of households	≥25 litre per person per day (ℓcd) ≥10 ℓ/min flow rate	Saving collecting time Increased ℓcd for personal hygiene Increased hand washing	• Health: Reduced waterborne disease • Social: Improved options for personal hygiene • Increased feeling of well-being • Economic: Reduced disease treatment cost
	Source point health-related microbial water quality (HRMWQ)	Zero <i>E. coli</i> in 100 mℓ water	Low container contamination potential	• Health: Reduced waterborne disease as indicated by acute diarrhoea • Social: Increased satisfaction
Potability	Point of use container HRMWQ	Zero <i>E. coli</i> in 100 mℓ water	Reduced risk of bacterial infection	• Increased feeling of well-being • Reduced disease treatment cost • Reduced care and recovery time • Reduced time lost at work/school

5 CONFOUNDERS

This research required constant and careful consideration and re-routing because of the complexities described earlier on. These complexities were exacerbated by the variety of water supply modes, ranging from absolute “self-help” (taking water from a natural surface water source), to upgraded technology that includes sourcing, treatment (where applicable), small scale bulk clean-water storage and distribution of the water to communal taps in the community.

This research also had to consider certain factors that are not by definition (and policy) part of the water service functions in South Africa. These were ❶ the use of containers to collect water from source points, and ❷ the home storage and possible treatment of the collected water.

5.1 The container effect

The South African approach for water service providers to improve access to a basic water supply is based on communal taps, which are most often quite some distance from dwellings. Households collect water from the taps in assortments of containers and then carry it to and store it at home during use. Many thousands of South African households, especially in small rural communities with or without a basic or upgraded water supply, still fetch water from water points some distance from their homes. The use of containers therefore remains a significant confounding factor in terms of assessing impact regardless of the mode of upgraded water service delivery. It has been shown that the container effect can seriously jeopardise the benefit potential of a small-community water supply intervention and sustainable service.

There is increasing evidence that the way these containers are managed by households have a detrimental effect on several aspects of domestic water supply management by households in small and rural communities. These include ❶ deterioration of the health-related microbial water quality from the good water at the tap to poor water at point of use and ❷ adding extra burden of toil to households including those who receive a basic water supply service (Jagals et al., 2004; Appendix B). While not an official part of a water supply service, the container distribution system (it may well be described as a human pipe system) is an integral part of water distribution in many communities with basic water supply services and plays an important role in considerations of health, social and economic impact. The *container effect* was *de facto* part of all function-, effect- and impact-measurements for this study and is also included in the monitoring tool.

5.2 Home treatment

Households were excluded from the study if households indicated some form of home treatment, i.e. disinfection with household bleach (chlorine). The reasons were that the real exposure situation would be masked and moreover, that a water supply service did not include any facilitation for home treatment. It was nevertheless found that none of the households randomly selected for this study practiced home treatment. While communities appeared to be well aware of what it is, they nevertheless appeared not to practice home treatment at any measureable scale, regardless of the source of water.

6 THE STUDY COMMUNITIES

This work focussed on the impact at rural small community household level. Most data were collected directly from the participating households, with more data collected from community discussion group activities within the villages as well as interviews with service providers.

A waypoint address based on location coordinates was established for each of all the households in the study area using global positioning system (GPS) devices (Garmin 60 Csx®). The mapping software programme OziExplorer® v3.95 was used to download the household addresses from the GPS devices and export them to text files from where these were imported into Microsoft Excel® spread sheets. Each household was allocated a unique identity code in the spread sheet, which was used for randomly selecting sample households as well as identifying all collected data, its capturing and analysis for the particular household throughout the study.

The initial target sample size was ≥10% and more of the total population (Population Survey Minimum Requirements, 2005) in a community group. This number was exceeded to ensure sample sizes of sufficient statistical strength. The number of households corresponding to the percentage of each community was then randomly selected (using the randomising tool in Microsoft Excel®) from the total household number in each community and is shown in Table 1.2.

Table 1.2: Community sample sizes (numbers of households and populations)

	Total household number	Mean family size	Approximate total population	Selected sample households	Approximate sample population	Sample size
Upgrade community 1	650	5.8	3,770	70	406	11%
Upgrade community 2	120	5.5	660	45	248	38%
Upgrade community 3	94	5.7	536	38	217	40%
Reference community 1	128	5.1	653	30	153	23%
Reference community 2	66	5.6	367	31	174	47%
	1,058		5,986	214	1,198	

The study was introduced to the head of the household (the related ethics approvals are discussed in each chapter). The head of household then nominated a respondent, usually a senior matriarch such as the spouse or the mother in the household, or in the absence of such a person, another household member suitably in a position to provide information about the family related to the study.

Regular feedbacks were given at community-level meetings, where especially the discussion group data were substantiated.

Each chapter in this report deals with work done in a set (some or all) of communities within the group of communities in Table 1.2. Figure 1.2 shows the communities that were involved in the project.

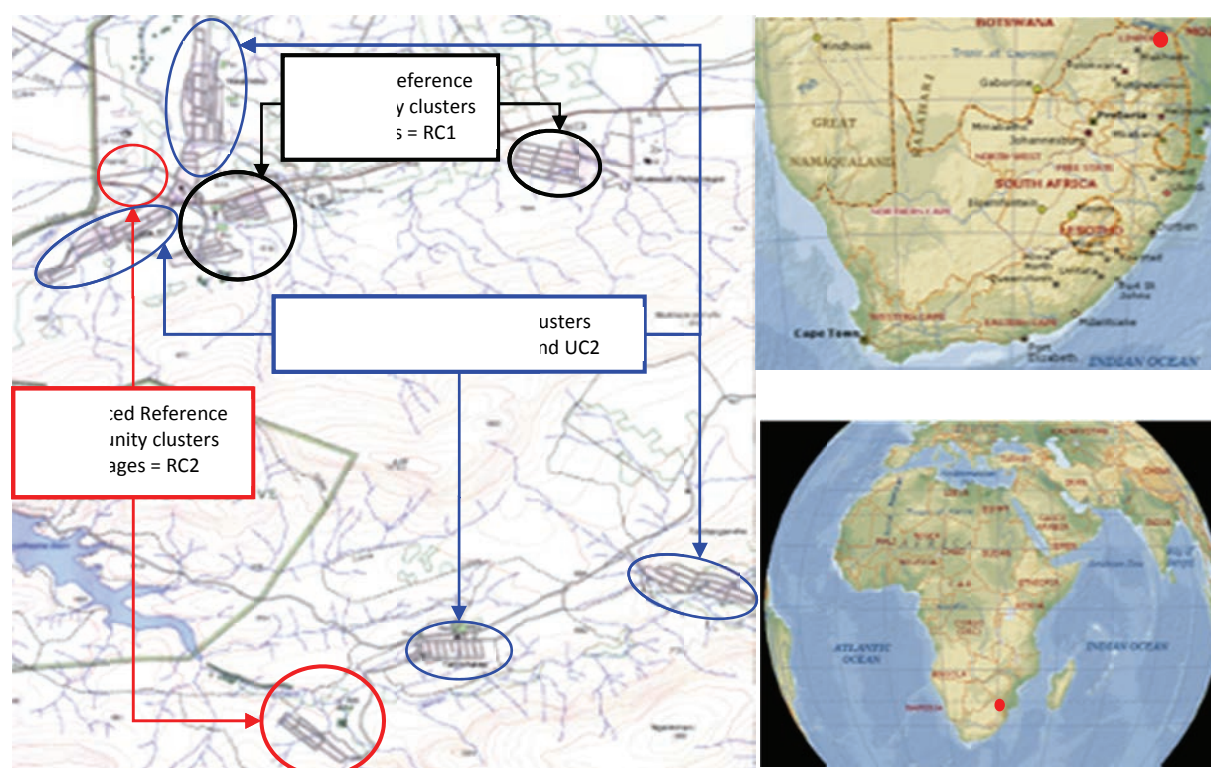


Figure 1.2: Map of the study area. The research was conducted in 8 rural community clusters – consisting of 14 villages in the Nwanedi River basin in the north-eastern parts of the Limpopo Province, South Africa (Figure 2.2).

Each chapter will indicate the group of communities that participated in the research reported on in the particular chapter. Depending on the requirements for the particular study component, the community groups were mostly the same groupings except for some studies where these communities were excluded in order to work with smaller groups of communities to achieve higher resolution. Some of the studies required exact and homogenous community groupings, for instance the work done for the function changes (Chapter 2), for the effects (Chapter 3) and impacts (Chapter 4).

The technical water system assessments reported on in Chapter 2 as well as the water carry study reported in Chapter 3 involved a wider range of communities from the same area. This was done to incorporate a wider range of water supply systems to assess for operational and water carry issues. For the health, sociologic and economic impact work, communities from Chapters 2, 3 and 4 overlapped as some studies were already on-going since 2004 when the first water supply upgrades were implemented.

7 LAYOUT OF THE REPORT

The research findings and its implications are reported in four chapters followed by a conclusion:

- Chapter 1 is this Introduction chapter;
- Chapter 2 reports on research into the water supply services and functions and the water supply systems supported by these services. It deals with assessing changes (or shifts) in the water service functions and systems of the selected rural small community supplies as the services established and/or improved;
- Chapter 3 deals with assessments of the effects of these improved functions on the recipient communities across the health, social and economic domains of everyday life in the researched communities. It is the hope that researchers will find the methodologies for the various research components sufficiently attractive and or challenging to pursue some research of their own. This will provide much needed refining of the methods as well as sharpening the results so that it can continue to inform and improve the knowledge base that we have begun to develop by this research;
- Chapter 4 presents findings of the impact assessment and summarises the effects in the context of the impacts;
- Conclusion.

8 RESEARCH REPORTS AND PUBLISHED LITERATURE

The following documents provide detailed reporting on the methods and findings reported in the various chapters of this research report and can be accessed at the various points as indicated.

8.1 Reports

- Chapter 2: The water supply services assessment
 - Assessing the value of upgrading rural small community water supplies in Limpopo, South Africa – masters dissertation by Majuru B (2010). Available online at: http://libserv5.tut.ac.za:7780/pls/eres/wpg_docload.download_file?p_filename=F324267437/Majuru%20B.pdf
 - Rapid technical assessment of rural water supply systems. Research report by Haarhoff J, February 2012. In *Tools to measure impacts and operations of rural small-community water supplies in rural South Africa*. A supplementary WRC report 1700/2/2012.
- Chapter 3: The effects of changes in the water supply services
 - Improved access to small community drinking water supply systems and its effect on the probability of bacterial infection posed by water in household drinking water containers – masters dissertation by Mokoena MM (2009). Available online at: <http://ujdigispace.uj.ac.za:8080/dspace/bitstream/10210/3162/1/Mokoena.pdf>
 - The potential effect of domestic water carry – research report by Geere J and Jagals P (2010) Appendix B.
- Chapter 4: Impact assessment
 - Majuru B; Hunter PR and Jagals P. 2011. *Health impact of small-community water supply reliability*. International Journal of Hygiene and Environmental Health. 214 (2) 162-166.
 - Community participation in the planning of water service delivery in a rural community in Limpopo Province – masters dissertation by Koekemoer R (2009). <http://ujdigispace.uj.ac.za:8080/dspace/bitstream/10210/3501/1/Koekemoer.pdf>
 - The social receptivity of rural water supply systems – research report by Lai EH, Koekemoer R, and Jagals P (2009) Appendix C;
 - Cameron J and Jagals P. 2011. *Chapter 2: The practice of economic assessment of small-scale drinking water interventions*. In: *Valuing water valuing livelihoods – Guidance on Social Cost-benefit Analysis of Drinking-water Interventions, with Special Reference to Small Community Water Supplies*. IWA Publishing/WHO Water Series. ISBN: 9781843393108. <http://iwapublishing.co.uk/template.cfm?name=isbn9781843393108>
- Tools to measure impacts and operations of rural small-community water supplies in rural South Africa. A supplementary WRC report 1700/2/2012 containing:
 - A tool to assess of small community water supply systems in rural South Africa – Jagals P and Rietveld LC (2012);
 - Rapid technical assessment of rural water supply systems – Haarhoff J, 2012.

8.2 Publications

The following publications partly or completely emanated from, or is in the process of doing so, or can be directly associated with this research. The publications can be obtained from the publishers:

- Majuru B, Jagals P and Hunter PR. Application of benchmarks for assessing rural small community water services in low income countries and the impact of supply reliability – Submitted September 2011 to the Journal for Environmental Science & Technology – *In Press*.
- Cameron J and Jagals P. 2011. *Chapter 2: The practice of economic assessment of small-scale drinking water interventions*. In: Valuing water valuing livelihoods – an approach to the economic assessment of water supply interventions. IWA Publishing/WHO Water Series. ISBN: 9781843393108.
- Jagals P and Rietveld LC. 2011. *Chapter 8: Estimating costs of small scale water supply interventions*. In: Valuing water valuing livelihoods – an approach to the economic assessment of water supply interventions. IWA Publishing/WHO Water Series. ISBN: 9781843393108.
- Majuru B; Hunter PR and Jagals P. 2011. *Health impact of small-community water supply reliability*. International Journal of Hygiene and Environmental Health. 214 (2) 162-166.
- Geere JL, Hunter PR and Jagals P. 2010. Domestic water carrying and its implications for health: a review and mixed methods pilot study in Limpopo Province, South Africa. BMC Environmental Health, 9:52 doi:10.1186/1476-069X-9-52.
- Geere JL, Mokoena MM, Jagals P, Poland F and Hartley S. 2010. How do children perceive health to be affected by domestic water carrying? Qualitative findings from a mixed methods study in rural South Africa. Child: care, health and development. doi:10.1111/j.1365-2214.2010.01098.x.
- Fosso-Kankeu E, Du Preez H and Jagals P. 2010. Health implications of lipopolysaccharide endotoxins in domestic container water used by rural households in South Africa. Journal of Water and Health. 08.4 601-610.
- Haarhoff J and Rietveld LC. 2009. Public standpipe design and maintenance for rural South Africa. J. S. Afr. Inst. Civ. Eng. [online]. 2009, Vol.51, n.1, pp. 6-14.
- Rietveld LC, Haarhoff J and Jagals P. 2009. A tool for technical assessment of rural water supply systems in South Africa. Physics and Chemistry of the Earth. Vol 34, pp 43-49.

8.3 Conference presentations

- Geere J, Hunter PR and Jagals P. 2010. Domestic water carrying and its implications for health in Limpopo Province, South Africa; a mixed methods pilot study. Water Institute of Southern Africa, Biennial Conference and Exhibition. April. ICC Durban.
- Majuru B and Jagals P. 2010. The effect of new small community water supply services on health. Water Institute of Southern Africa, Biennial Conference and Exhibition. April. ICC Durban.
- Mokoena MM and Jagals P. 2010. The effect of water-supply service delivery on the risk of infection posed by water in household containers. Water Institute of Southern Africa, Biennial Conference and Exhibition. April. ICC Durban.
- Fosso-Kankeu E and Jagals P. 2009. Toxic cyanobacteria in container-stored water used by poor and rural households. 15th International Symposium on Health-Related Water Microbiology, IWA. May 31 - June 5, Naxos, Greece;
- Jagals P, Mokoena MM and Barnard TG. 2009. Improved access to small drinking water supply systems and its effect on the probability of bacterial infection posed by water in household drinking water containers. 15th International Symposium on Health-Related Water Microbiology, May 31 - June 5, Naxos, Greece;
- Jagals P and Hunter PR. 2009. Reducing diarrhoeal disease in small rural developing country communities: The value of water supply interventions. 15th International Symposium on Health-Related Water Microbiology, May 31 - June 5, Naxos, Greece;
- Jagals P. 2009. Health and social Impacts of water at community level. Round Table panellist for Water, A Looming Crisis? Presented by the Centre for Development and Enterprise. November 2. Johannesburg.
- Pond K and Jagals P. 2008. Economic assessment of small community drinking water supply interventions. 5th meeting of the International Network for Small Community Water Supply Management (presented by the WHO) – 15-21 November, Kampala, Uganda;

- Haarhoff, J., Rietveld, L.C., and Jagals, P. 2008. Rapid technical assessment and troubleshooting of rural water supply systems. Proceedings of the 10th Annual Water Distribution Systems Analysis Conference WDSA2008, Van Zyl, J.E., Ilemobade, A.A., Jacobs, H.E. (eds.), August 17-20, 2008, Kruger National Park, South Africa.
- Jagals P. 2008. A toolkit for measuring impacts and benefits of water supply interventions on the lives of rural and poor households in developing countries. Water Institute of Southern Africa, Biennial Conference and Exhibition. May. Sun City.
- Jagals P. 2007. Traditional drinking water supply systems and existing technologies: Hardly sufficient for consumer needs and socio-economic issues in Southern Africa. Technology for safe drinking water in Southern Africa, 3rd Regional Technology Platform Nov. Cape Town.
- Khan S and Jagals P. 2007. Some requirements for measuring health impacts related to water quality. 3rd Water Research Showcase – Annual Symposium for the Universities of Johannesburg, Pretoria, Witwatersrand, and Tshwane University of Technology. August 17. Maropeng.
- Omar, KB, Barnard TG and Jagals P. 2007. Molecular bacteriology to assess infectivity potential. 3rd Water Research Showcase – Annual Symposium for the Universities of Johannesburg, Pretoria, Witwatersrand, and Tshwane University of Technology. August 17. Maropeng.

Chapter 2

Assessing the water supply service functions

1 INTRODUCTION

In this part is discussed the changes brought about in the water service functions based on changes made to the water supply systems in the research area.

A sustainable water supply service for a small rural community requires a fully functional and technologically manageable system to support the functions of water service delivery. The system must provide easy and sustainable access to a consistently available, good quality water supply (Jagals, 2006). The system should consist of the best available, affordable and sustainable technology to source, treat, distribute and deliver the water within a community according to (often minimum) design parameters that are defined by country policy (WRC K5/1700/3).

As such the functions required to suit a particular setting (conditions in a community), will determine the scale and calibre of the system. The result of this is that almost no two small systems are, or will be alike and it will therefore be difficult to generalise the findings of this components of the project. The team nevertheless strove to select a suite of small systems that should, in the South African context, be reminiscent of a vast majority of these systems throughout, and the conditions under which they function.

The water supply system and their recipients, the way they are managed and the extent to which the recipients optimise the use of the system, are the main determinants of impact. In terms of establishing and eventually upgrading a small water supply system and its functions in a community, the process in South Africa largely follows a pattern of first establishing a rudimentary service from a non-serviced supply (e.g. hand pump on a borehole in communities that previously had to rely on open sources) and then upgrade the rudimentary service to a basic service with appropriate small system technology. With the advent of the (very) focussed water supply roll-out in South Africa after 1994, many basic services were established directly from the open source, while in other cases, upgrades were done. This caused a rather characteristic effects cycle as shown in Figure 2.1.

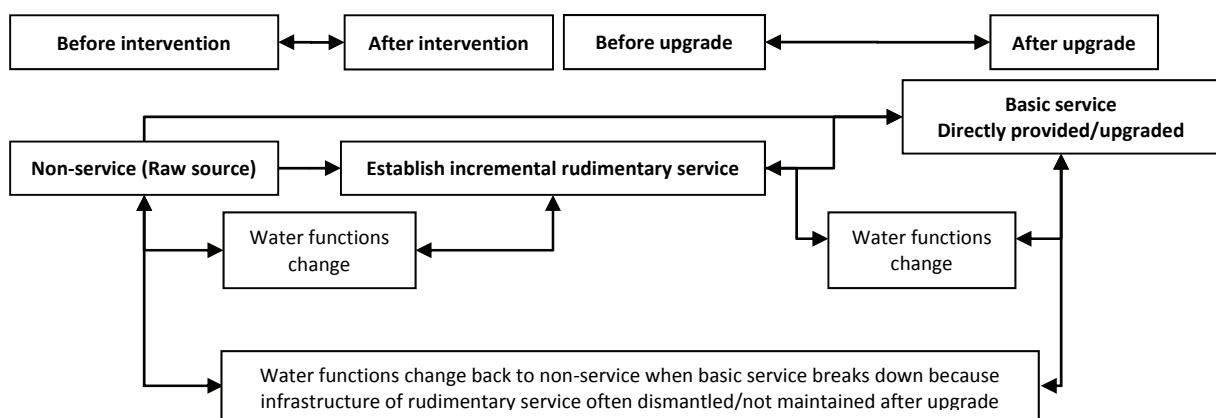


Figure 2.1: The steps from a non-service to a basic service provide an effects cycle of system improvement and breakdown

As this and the next chapter will demonstrate, each of these upgrade steps poses its own unique challenges in terms of the water service functions and the effect that each might hold for the user community. Figure 1.1 in the *Introduction chapter* is a less complex version of Figure 2.1 but both show that even the more advanced “basic supply service” poses a challenge should the basic system be interrupted or fail, especially if alternative support is not immediately given by the service provider, i.e. bring in clean water by tanker vehicle, people have to return to their original open sources to collect water until the service is again operational.

This chapter essentially presents an integration of two research activities that were conducted to measure the indicators shown in Table 1.1 of Chapter 1. The primary research activity focussed on the three primary water service functions (access, availability and potability). The secondary activity focussed on technical assessment of the actual *basic* water supply systems services after the upgrade process as this particular level of service is the flagship of small-community water supply services in South Africa. This secondary activity provided critical data for the function assessment in terms of the capacity, continuity and condition of the water supply systems and also provided a general measure of the current sustainability of these systems.

Methods (tools) were developed and applied for the assessment activities reported in this chapter. The detail descriptions of these subsets of methods and their applications can be found in the detailed research reports on this work which are on the sites as indicated in Section 6 at the end of Chapter 1 (Introduction).

The functions that will ensure beneficial HSE impact from a water supply service are *access* to and *availability* of *potable* water. To achieve maximum benefit, the system must, deliver these functions according to specific and measurable parameters (Table 1.1 Chapter 1). The effects (beneficial or not) that the functions would have if optimally implemented and sustained, are discussed in Chapter 3.

1.1 Aim

The aim of this project component was to determine changes in water service functions brought about by upgrading the water supply services of selected small rural communities in Limpopo province, South Africa, based on the village case studies shown in Chapter 1.

1.1 Objectives

To achieve the aim, the study set out to measure service function changes as a result of the upgrades and what the extent of these changes were. By comparing the different sets of indicator measurements (before and after upgrades), the value gained from the water supply interventions could be determined. The following were the specific objectives:

- A review of the literature was done of all the various components and functions of a small community water supply system;
- A wide range of already existing and newly established small-community water supply systems in the study area were assessed for:
- Changes in the each of the service functions based on changes in the status of their indicators (Table 1.1 Chapter 1) after changes (upgrades and breakdowns) in the service;
- A technical assessment was undertaken of the upgraded/new basic water supply systems to determine the condition of these systems in terms of capability, capacity, maintenance and operation. This was done to support the assessment of the service functions;
- The post-intervention changes in the water supply service functions were summarised to be matched with the effects of the changes described in Chapter 3.

2 LITERATURE REVIEW

Upgrading rural small-community water supply systems will have some effect on recipient communities, as was discussed in Section 1. This section reviews small community supply systems as they are internationally as well as in the rural South African context. This is followed by a review of the water supply service functions and their indicators, including the ways in which the functions can be measured.

2.1 Water supply services to small communities

Small-community water supplies (SCWS) are water supplies to small numbers of people and are found in developing and developed countries alike (Davison et al., 2005). Definitions vary, the basis ranging from the size of the population served by the system, quantity of water provided or the type of supply technology used (World Health Organisation [WHO], 2004). For instance, in a report on SCWS in Europe, SCWS were defined as supplies serving more than 50 but less than 5,000 people, or providing more than 10 but less than 1,000 cubic metres per day (Davison et al., 2005).

Although SCWS can be used to supply commercial and public facilities, household supply is more common (Hulsmann, 2005). A general characteristic of a SCWS is that it is abstracted, treated and stored in close vicinity to, and distributed within the recipient community (Momba et al., 2008). Where possible water might be supplied untreated, especially if drawn from underground sources, or undergo a limited treatment process so as to save on costs (Australian Water and Wastewater Association, 1996). This approach is commonly encountered in rural communities in developing countries in particular because of the small populations often located in isolated and remote areas (Rush et al., 2000). According to Bartram and Gordon (2008), 10% of the rural population in developed countries is dependent on SCWS, while the majority of rural areas in the developing world rely on SCWS (Mahmud et al., 2007).

Whether in developed or developing countries, a common threat to SCWS is the problems with operation and maintenance. This is often due to untrained community members being involved in the operation and maintenance of such systems (Hunter et al., 2009b).

2.2 Water supply services for small communities in South Africa

Water supply services in South Africa are generally more developed in urban than in rural areas (Dungumaro, 2007). It is mostly in these rural areas where water services are still non-existent or (rudimentary), that SCWS are being established, or upgraded to basic water supply services (Tissington et al., 2008).

At the inception of South Africa's new democratic government in 1994, approximately 33% of the population had no access to safe water (Muller, 2008). Of these, 61% were black and lived in rural areas (Rush et al., 2000). Where water supply services were established in rural areas, the majority were rudimentary. Expectations were high that the new government would make equitable amongst other things, access to basic water supply services (Smith and Green, 2005), with a higher level of basic small-community water supply service than rudimentary water supply services or no services.

The Reconstruction and Development Programme (RDP) of the current government (ANC, 1994) was formulated as a framework for development to redress the many inequalities that existed up to 1994, including access to safe water. From this framework ensued the White Paper on Water Supply and Sanitation Policy (Republic of South Africa [RSA], 1994), on which are based the benchmarks for basic water supply services prescribed in the Water Services Act (RSA, 1997). Despite the policies and legislation on the supply of water services, many households were still without basic water supply services, partly because they could not afford the services (Muller, 2008). The Free Basic Water Policy (Department of Water Affairs [DWA], 2001) was instituted as a means to make water economically accessible for all. Stipulations from the policy are implemented and funded in various ways, but essentially it means that 6,000 litres are provided at no cost to all households in the country every month. This is calculated to 25 litres per person (capita) per day (l/cd) for a household of eight people. Municipalities, through the Municipal Infrastructure Grant process, have access to resources to shoulder their responsibility of providing the basic water supply services (Tissington et al., 2008).

According to the Department of Water Affairs' 2008/2009 annual report (DWA, 2009), 88% of South Africa's total population now receives free basic water (which implies access to a basic and higher water supply service) with 79% of the people in rural areas being supplied in this fashion (Department of Environmental Affairs and Tourism, S.A.). The remainder is divided between areas that have no water supply infrastructure at all and are still to be served, the 'no service' areas in the context of this report, and areas where rudimentary infrastructure exist but do not meet the requirements of a basic water supply service. These three levels of service are reviewed in the following sections.

2.2.1 No water supply – the “non-service” scenarios in this project

The Water Services Act (RSA, 1997) defines water supply services as “the abstraction, conveyance, treatment and distribution of potable water...” by a water services provider. Based on this definition, where no such action is undertaken for a specific community under the jurisdiction of a water service provider, a service does not exist, and for the purposes of this study, reflected conditions of “no service”.

Up to quite recently, an estimated 5% of the total South Africa population still have no water supply services at all (DWA, 2009), of which the majority would be rural people. Water source points under these conditions are often quite distant, with the water at the source point often not available and mostly contaminated when it is available. Households from such communities collect water from open sources such as rivers and streams, and carry it in containers back to their homes. Hemson (2007) reported distances to and from these open sources of up to 3.7 kilometres, and over two hours are spent by an individual collecting water in some villages in Limpopo. Water is collected mainly by immersing containers in open surface water sources where the depth is sufficient, or by scooping water from shallow sources into the containers using smaller vessels (Magrath, 2006).

In some areas these open sources are not perennial, and frequently run dry during winter or other dry periods. During these periods, hand-dug wells along dry river beds are used as alternative source points of water (Mazvimavi and Mmopelwa, 2006). Jagals (2006) reported mean per capita daily water collection of 18 l from rivers and canals in rural villages in Limpopo. Water samples from some rivers in Limpopo have been reported to contain bacteria such as *Escherichia coli*, *Vibrio cholerae* and *Campylobacter* as well as high faecal enterococci numbers (Obi et al., 2003).

2.2.2 Rudimentary water supply service

Approximately 7% of the South African population (mainly rural), has rudimentary water services (DWA, 2009), which are yet to be upgraded to basic services. A definition of rudimentary water services is given in the Water Supply Service Levels guideline (DWA, 2000), which also provides benchmarks for the functions of each level of service. In the guideline, a water supply service that does not meet all the criteria of basic water supply services was defined as rudimentary. Water points that fall under the rudimentary level of service were described as typically located between 200 and 500 metres from households, with elementary technology such as handpumps and windmills and some elementary management activities such as source protection. The guideline also provide for home treatment of water as a requirement as the risk of contamination was high. Containers are still required to collect water, and quantities collected vary between 5 to 15 ℓcd.

For this project, rudimentary water supply services were defined as limited services being supplied where there is some kind of elementary technology to either protect the water point or to at least abstract the water, as in the case of a handpump. This service is also, by its very nature, provided to small rural communities (Rural Water Supply Network, 2009). The equipment for this level of service is often problematic. Musonda (2004) found that in one village in Zambia, the handpump that had been installed was difficult to operate, and women in particular struggled to draw water because the pump was too stiff. Another common problem with rudimentary technology such as handpumps is inadequate maintenance (Lenton et al., 2005), mainly because communities and/or service providers most often struggle to find spare parts (Jabu, 2005).

While the guideline makes no mention of community tank services, there are several rural South African communities, such as the ones in this research, where water supplies are brought in by vehicle tanker and transferred to stationary tanks in the serviced community. Although these services are classified amongst “unimproved sources” in some literature (UNEP, 2003; Bartlett, 2005), these services were for the purposes of the project, regarded as rudimentary because of the technology involved and proximity of the tanks to the households. Moreover, Hutton and Haller (2004) state that these services are problematic not because of the quality of the water that they supply, but because of the unnecessarily high cost involved in supplying the service. In South Africa the DWA estimated that trucking in 25 ℓcd is about 30 times more expensive than supplying water through pipes (Bond, 2002). This may have implications not only on frequency with which the water is supplied, but consequently availability of the supply and thus the volume of water that can be collected (Lenton, 2005), which is contrary to the concept of a basic water supply service. These are additional reasons why community tank services were regarded as rudimentary services for this project.

2.2.3 Basic water supply service

The Strategic Framework for Water Services (DWA, 2003) defines basic water supply service as “*The provision of a basic water supply facility, the sustainable operation of the facility (available for at least 350 days per year and not interrupted for more than 48 consecutive hours per incident) and the communication of good water-use, hygiene and related practices*”. Further, the Framework defines a basic water supply system as “*The infrastructure necessary to supply 25 litres of potable water per person per day supplied within 200 metres of a household and with a minimum flow of 10 litres per minute (in the case of communal water points).....*”. In rural areas these types of services will invariably be a small-community water supply service (DWA, 2002).

As in South Africa, the maximum distance to communal standpipes in Swaziland is specified as 200 m (Mwendera, 2006), whereas Botswana specifies a maximum distance of 400 m to communal water source points (Mazvimavi and Mmopelwa, 2006). In a study in rural communities previously using open sources that had just been provided with basic water supply services, Jagals (2006) reported that although the distance from household to source had on average been reduced to within the 200 m, 15% of the newly serviced study population still had to walk distances of over 200 m to the communal taps to collect water.

In the same study by Jagals, per capita water collection did not change significantly after the intervention, with the mean daily collection remaining around 18 ℓcd despite the new basic water supply services. Results of work by Rietveld et al. (2009) in this project (Section 2.2) suggested that availability of the basic water supply was also not as it should be. They reported some villages in Limpopo that had water supplies interrupted for seven days of every month. In the same study, when the water was actually available, flow rates were well above the 10 ℓ/min specified, averaging 31.8 ℓ/min – literally a case of bad and good in the same service.

In a survey of 55 SCWS in the Eastern Cape by Momba et al. (2006), only 28% of their treatment systems were found to deliver treated water that was within the recommended microbial water quality limits of not more 10 total coliform colony forming units (cfu) per 100 mℓ of water sample and 0 faecal coliform cfu per 100 mℓ at the point of distribution. Moabi (2006) reported no detectable *E. coli* in water sampled from communal taps sourcing

water from groundwater in Limpopo. However, when this tap water was compared to the water stored in the containers of the households that source the water from these taps, the water stored in the containers had significantly more total coliforms and *Escherichia coli*.

This then comes to emphasize the common issue in the three levels of service discussed so far, i.e. the use of small vessel/domestic containers to move water from source to home. The more advanced services may supply water of good quality but water source points are still off-site (not in the home). This required the water to be collected in containers, carried home and stored in the containers while being used. These activities re-contaminate the stored supply. The problems associated with this situation are reviewed in more detail in later on, but it essentially means that the quality of water delivered at the tap is much better than the quality as at the point use. The guideline (DWA, 2000) describes the quality of water delivered under the basic service as “moderate...contamination can occur during transport...” – which implies that the container issue is recognised in guideline documents but, as will become evident through a lack of further guidelines and comments, does not elaborate nor provide guidance on its potential health, social and economic implications.

Despite the progress made in providing water through the basic water service, social acceptability of the services appears low, as most communities aspire to a higher level of service (DWA, 2000). Koekemoer (2009) reported that while most of the study communities appeared to be satisfied with the improved water quality provided by the basic service, there was still a substantial dissatisfaction with the off-site location of communal taps and the problems with maintenance which resulted in supplies being interrupted during the time of the study. Regarding location, the major contention is that many households prefer on-site taps, but are unwilling to – or cannot afford to – pay the costs of installing them (DWA, 2000).

These issues of distance from household to water source point (access), availability of supply and water quality (potability) are reviewed in more detail in the next section.

2.3 Functions of a water supply service

The concept of safe water is defined as water that is potable, easily accessible and is constantly available in sufficient quantities. This will be a critical concept in the context of this report. These three principles were, for the purposes of this project, considered the functions of a water supply service and are reviewed below.

2.3.1 Access

Although there is a variety of literature on access to water, consensus lacks in defining what is meant by ‘access’ (Agi and Umenai, 2003). For instance, the UNICEF/WHO Joint Monitoring Program (JMP) defines access in terms of the water source; whether it is ‘improved’ or ‘unimproved’ (Devi and Bostoen, 2009). Roy et al. (2005) reported on access to water for rural women in Kenya in terms of the time spent collecting water and the quantity collected.

Jimenez and Perez-Foguet (2008) discussed access in two parts namely physical and socio-economic access. The authors stated that physical access is defined in national policies that set out maximum distances to water sources and the number of people served by a water source/point. Socio-economic access entails factors that influence access, such as the affordability of the service, as shown in the Free Basic Water Policy (Chapter 1) for instance. Agi and Umenai (2003) reported that the most frequently-used definition is that of the United Nations Development Programme (UNDP), which states that those with access comprise “The proportion of the population using any piped water, public tap, borehole with a pump, protected well, and springs or rainwater”. This differs from the World Bank definitions, which are based on the type of residential area being assessed. In these definitions, access in urban areas means water sources such as public fountains or standpipes located not more than 200 meters away, and in rural areas access implies that members of the household do not have to spend a disproportionate part of the day fetching water. In the case of the latter, such a definition is vague, as no global consensus is given as to what constitutes ‘a disproportionate part of the day’. According to the authors, some governments modify these World Bank and UNDP definitions to apply to their population, with the most common factors in definitions being distance, time and water quantity.

Agi and Umenai (2003) argued that without a standardised definition of access, discussion and comparison of access to safe water becomes haphazard. Given the myriad of factors upon which the various definitions of access are based, the current definitions are at best indicators (Jimenez and Perez-Foguet, 2008), which should be standardised. In the context of this study, the function of access to water for rural SCWS in South Africa is based on two factors described by Jagals (2006) namely the distance walked to get to a water point, and once there, the technology (means) by which the water is actually obtained or sourced.

The literature as well as practical experiences on the ground essentially sees four conditions that have to be explored and contextualised to become clear indicators of “access”. These are distance, sourcing technology (i.e. a tap), source point density and sourcing conditions – all of which are reviewed next.

2.3.1.1 Distance as an indicator of access

According to Muller (2008), where the Free Basic Water Policy (DWA, 2001) has been implemented in the rural areas, the major determinant of water consumption has been the distance over which it is carried from source to home. The basic level of water supply service requires that water source points be located not more than 200 metres from the household (DWA, 2003).

In a study on water use in Benin, Hadjer et al. (2005) reported results similar to the access conditions classified by Howard and Bartram (2003) – where the volume water increased as the distance over which it was carried decreased. This classification by Howard and Bartram also includes collection time, as it is tied to distance. In their report, Howard and Bartram specified a maximum distance of 1,000 metres, beyond which the service level was classified as ‘no access’.

2.3.1.2 Sourcing technology as an indicator of access

Sourcing technology can be defined as the means by which water is abstracted from the source point by the consumer. The technologies used in SCWS vary from more sophisticated water treatment plants (sometimes of a compact ‘package’ design) that can serve customers with in-house connections, to single-point sources such as a borehole fitted with a handpump, and a communal tap somewhere in the community environment (Davison et al., 2005). In developing countries single-point sources are the most common, the major determinant of these supply technologies being the cost involved (Gadgil, 1998) as well as the design to suit comfortable water collection at the source point (Haarhoff and Rietveld, 2009).

Ntshingila (2006) noted that sourcing technology influences the daily quantity of water collected by a household. Koekemoer (2009) reported the ability to collect more water as one of the things that community members were satisfied with in a village where basic services had been established (satisfied with using the taps that replaced handpumps as the sourcing technology or the river’s edge as the access point).

The reliability of a sourcing technology also plays a large part in the reliability of a water supply service. It is estimated that 50% of handpumps in rural Africa are disused (Rural Water Supply Network, 2009), mainly because of problems with maintenance and operation. In such circumstances, households often revert to untreated sources in their vicinity (Jabu, 2005).

Bartlett (2001) reported that improvements in source technology can have also have other unprecedented effects, as in The Gambia where the installation of a handpump meant that because it was safer to use than traditional sources such as wells and rivers, the primary responsibility of water collection shifted to children, some as young as seven. Similarly, in the repeat study of the Drawers of Water, Thompson et al. (2000) reported a three-fold increase in the total time spent collecting water partly because of queuing at the taps.

2.3.1.3 Source point density as an indicator of access

The number of water sourcing points (e.g. hand pumps, communal taps, spots on river banks where people can reach the water) in a community is not clearly defined in literature. The number of accessible points is one aspect that can be of great value for instance in bringing about reduced distance as well as the related time savings in terms of collecting water. The bits of available literature also focus primarily on the numbers of communal taps. The Sphere Project (2005) recommends 250 people per tap provided there is a flow of at least 7 litres of water per minute at each tap. A South African guideline recommends water point densities of 15-25 taps per km² (CSIR, 2001). However, in both these guidelines as well the DWA (2004) guideline of water points within 200 metres, the aspects of reduced distance and saving time were not the main drivers.

The work reported in Section 3 below (Technical assessment of the water supply systems) explains further approaches to calculating water point density.

2.3.1.4 Sourcing conditions

The environmental surrounds and structural conditions of the source points play a significant role in how water is sourced. Haarhoff (WRC, 2012a) have shown that poor standpipe and tap conditions create difficult circumstances for people to source water at taps (as part of basic water supply systems). Geere et al. (2010a) have shown how water carriers, especially children, struggle in poor sourcing conditions.

2.3.2 Availability

Three indicators of availability are reviewed here. In the guidelines for basic water supply services (DWA, 2003), availability is defined by the physical presence of water contained in the pipe behind a tap and the flow rate when the tap is opened. The quantity of water that is available for collection is also an indicator of availability (Jagals 2006).

Three conditions have to be met before water can be described as “available”. These are availability at source both in terms of being there as well as sufficient quantity, and then flow rate.

2.3.2.1 Continuity – availability at source

The availability of water in a basic water supply service in South Africa is benchmarked as operability of the system for 350 days a year, and interruptions not exceeding 48 consecutive hours (RSA, 1997). The guideline (DWA, 2000) refers to this as availability of water at a source point for at least 98% of the year. The water supply should also have the capacity to deliver at least 20 litres per person per day consistently (WHO, 2004). Ineffective operation and maintenance have a major influence on the reliability of water supply, and hence the quantity of water that households can collect (Howard and Bartram, 2003). The subsequent breakdowns result in the supply being interrupted for weeks on end. A major reason for such prolonged interruptions is that spare parts and sometimes the human resources to repair the infrastructure are not available. According to Zwane and Kremer (2007), these problems in the maintenance (and hence reliability) of the supply make it difficult to quantify benefits that could have ensued from the water supply intervention.

To cope with unreliability of supply, communities often use what was their original “no service” supply as alternative sources (Khanna and Khanna, 2006). The problem however, is that these alternatives are more often than not, untreated sources such as rivers, negating whatever health benefits that might have initially been derived by the upgrade to a basic service (Hunter et al., 2009b).

Often communities agree amongst themselves to interrupt the supply for a specific period during the day, or over weekends, for various reasons, such as allowing the operator to rest, or allowing the reservoir to fill up again. These cannot necessarily be seen as interruptions as such an arrangement can often lead to the consistent availability of water to which people have organised and reliable access (Koekemoer, 2009).

2.3.2.2 Flow rate

A water supply system must at least have water available every day for the basic water needs of a household (Majuru, 2010). This means that it must be provided at a quantity per person per day at a decent yield of flow rate. This way people will have enough water and it is readily available when they need to access it.

A study by Gleitsman et al. (2007) showed that community members were not willing to pay for the use of handpumps because the flow rate of water from the handpumps was too low and it therefore took too long to collect water from the pumps. Such an example illustrates the influence that flow rate can have on the time it takes to collect water. This flow rate and consequently the time it takes to fill a container can also have a bearing on the quantity of water collected. For instance, municipalities in South Africa have been known to use ‘the drip’ which restricts the flow rate of water to prevent the use of water over and above the Free Basic Water amount for households that have not paid for overdue accounts (Peters and Oldfield, 2005).

Unauthorised connections, for instance connecting a hosepipe to a communal tap, are becoming an increasingly common sight in SCWS in South Africa. Seshoka et al. (2004) reported on one village where 1,700 illegal connections were counted, the majority of which were being used to irrigate garden plots. The result of this will be that while the ‘connectors’ have more than their share of water, the water pressure is lowered to such an extent that communal taps furthest from the reservoir run dry (Koekemoer, 2009).

2.3.3 Potability

As water-related infectious diseases continue to be of concern particularly in the developing world, a major focus remains on providing water supplies that are microbiologically safe, although potability also refers to other parameters such as the chemical safety of water. This study focussed on the health-related microbiological quality as it is deemed of greater concern in water supply quality in developing countries (Jagals, 2006). It also focused on using the presence of *E. coli* bacteria as a measure of infection risk posed by the water that the people in the study area would drink.

2.3.3.1 Significance of micro-organisms in water supplies

Exposure to enteric pathogens can lead to waterborne disease (Craun et al., 2006). However, not all pathogens found in water are of equal public health significance, as some pose a serious risk of disease and are given high priority for health significance such as *Vibrio cholera*.

While it would be more accurate and precise to test water for the presence of the specific pathogens, it is hardly possible for a small community supply service to test for each of the pathogens that could be in the water, as the respective pathogen test methods are often expensive conduct (Low, 2002). Indicator organisms are tested for instead. Among these are faecal coliforms, whose presence in drinking water indicates faecal pollution which indicate a risk of pathogen infection for consumers (Crampton, 2005; WRC, 1998; DWA, 1996).

A commonly used indicator of the faecal coliform group is *E. coli*. Most guidelines and standards specify that faecal coliforms such as *E. coli* should not be detectable in any 100-mL sample of drinking water (Hoque et al., 2006). However, where water is provided through off-site source points such as communal taps, simply providing water that is free of *E. coli* at the tap does not necessarily mean that it will not be of risk to public health, as containers are still used to collect and store water, an activity that lead to microbial contamination of the water consumed from the container (Nala et al., 2003).

2.3.3.2 Potential for infection

Part of the management of health-related drinking water quality is predicting the risk of infection likely to arise from ingesting the water (Howard et al., 2006). Quantitative microbial risk assessment (QMRA) is one tool that is commonly used to predict the risk of infection. However, because of the data requirements of the tool (microbial pathogens and dose-response criteria), it often needs to be simplified before being applied in areas such as the developing world where data may not be available or resources scarce to do comprehensive analyses. An alternative approach is to derive risk of infection from literature – scaling the risk in relation to the number of faecal coliforms as was done by Mahmud et al. (2007) and Steyn et al. (2004). Unlike QMRA, this method only requires data on the number of indicator organisms, which is fairly simpler but still remains rather qualitative as it provides risk outcomes with high levels of uncertainty.

The South African Water Guidelines (DWA, 1996) provide qualitative statements on the risk of infection based on levels of faecal coliform numbers in drinking water. In another guideline, the South African Water Research Commission (WRC, 1998) also provides a simple reference for infection associated with faecal coliform numbers in drinking water. However, the latter does not refer to *infection risk* but merely provides statements on the likelihood of whether infection would occur as a result of consuming water containing numbers of faecal coliforms within specific ranges. This presents a problem in terms of the terminology to be used when referring to both these guidelines.

Steyn et al. (2004) differentiated between the *possible* risk of infection based on what is evidently a No Observed Adverse Effect Level approach of the South African guidelines, and the *probability* of infection that would be the basic approach for a QMRA. The distinction between possible and probable infection was that the former referred to risk of infection from an indicator organism (*E. coli*) and the latter (probability) referred to risk of infection from a specific pathogen. There is no evidence in both guidelines by DWA (1996) and WRC (1998) to suggest that the statements on the effect of exposure by humans to faecal coliforms were based on QMRA. Thus, a prudent term in the case where the specific pathogen was not tested for, would be *possibility of infection*, which was the approach used for this component of the project. Results of a QMRA done with the pathogenic fractions of the indicator *E. coli* used in this part are presented and discussed in Chapter 3.

A further problem with the use of the guidelines by DWA (1996) and WRC (1998) is that the possibilities of infection are based on faecal coliforms (the indicator group) instead of *E. coli* (an indicator micro-organism within the faecal coliform group), which means that these guidelines cannot be used directly in the case where *E. coli* was the indicator tested for in water quality assessment. While there is ample literature suggesting that in highly polluted water such as sewage water the faecal coliform/ *E. coli* ratio can be as high as 1:1 (DWA, 1996), a report by Jagals et al. (2001) suggested that these ratios vary widely depending on the contamination levels in water, with the *E. coli* fraction in the faecal coliform numbers decreasing as the water becomes less contaminated, e.g. ranging from sewage to container water. Thus, a simple 1:1 ratio would not apply in the case where, for instance, treated water is stored in container. A possible approach could be to multiply the fraction of *E. coli* found in faecal coliforms by the number of faecal coliforms to adapt the scale used by the WRC (1998) and DWA (1996) to numbers of *E. coli* proportionately to the faecal coliforms levels in the guidelines. Jagals et al. (2001) compared different microbial water quality testing methods on waters with different levels of faecal coliform contamination. For container-stored water the percentage of true *E. coli* yielded from faecal coliform colony-forming units ranged from an average 10% to average 35%, but these differences were not statistically significant. Because there was

no significant difference in the percentage yields reported, it can be reasonably assumed that either one of the fractions can be used, although in the light of the many uncertainties surrounding this approach, 35% would be more conservative in erring to the margin of safety and was therefore assumed a reasonable fraction to use to benchmark the *E. coli* exposure levels.

3 THE RESEARCH: ASSESSING THE WATER SERVICE FUNCTIONS

The research on this particular part of the project was conducted by measuring and comparing the three water supply service functions of access, availability and potability (Table 1.1; Chapter 1) for each of the three service levels discussed in Section 2.2. This section presents these results and their analyses to demonstrate whether changes did indeed occur in the functions when the services were upgraded. For instance, did the household water fetchers travel significantly shorter distances to source points after the upgrades? Was the water of a better health-related microbial quality? And was the water consistently available at the new source point after upgrading to the basic level of service?

3.1 Assessing for changes in the service functions

3.1.1 Study areas, population, study design and the supply systems

The research was conducted in six rural community clusters – ultimately consisting of 15 villages in the Nwanedi River basin in the north-eastern parts of the Limpopo Province, South Africa (Figure 1.2 Chapter 1). Several small-community water supply services were being established in the area at the time, offering the opportunity for this work.

3.1.1.1 The study communities (Table 1.2, Chapter 1)

The study communities are summarised in Table 1.2, Chapter 1), including the “upgrade communities”. These were communities that initially had no service, as well communities that used a variety of rudimentary services. These services were upgraded during the study period into three basic water supply systems. Of these three communities, one was a “large” rural community with approximately 650 households (<500 houses) and more approximately 5,000 inhabitants, while the other two were “small” rural communities with between 100 and 500 households. Also included were two “reference” communities in the same vicinity as the upgrade communities; one that was fully serviced with a basic water supply system since before 1994 as well as a cluster of several small villages but that no service throughout the study period.

As Figure 1.2 shows, the study communities were within close proximity to each other, and were similar in terms of topography and natural resources such as water and bush (wood as main source of energy). An important next step in the study was to demonstrate whether the communities were also sufficiently homogeneous, demographically as well as and socio-economically, in order to compare the respective data sets (from each community).

3.1.1.2 Demonstrating homogeneity

To compare the data collected from the study communities, these communities had to be sufficiently homogenous (no statistically significant differences) in terms of the parameters of demography and socio-economic status. If this was demonstrated, the rest of the data pertaining to the functions for each could be compared and differences detected from these would not be attributed merely to these underlying community variables but could be attributed to, or associated with, the water supply upgrades within the three upgrade communities – one upgrade just prior to (the large community) and two during the study period (the smaller communities).

3.1.1.3 Ethics

This study formed part of a more comprehensive study conducted in a total of 14 village communities in the Nwanedi River Basin. This particular study was part of project K5/1700 funded by the South African Water Research Commission titled “*A toolkit to measure sociological, economic, technical and health impacts and benefits of 10 years of water supply and sanitation interventions in South Africa*”. The indicators selected for this study and their related collection methods included questionnaires, observation sheets, water sampling protocols, and also the topics discussed with community discussion groups. It also included informed consent by households to participate. Where required, the relevant methods were considered and approved by the relevant research ethics committees of the University of Johannesburg as well as the Tshwane University of Technology.

For the work in the respective communities, verbal consent was also obtained from the traditional leaders in the study area. At the household level, informed consent to participate was obtained from the household head after presenting the content of the informed consent form in the local TshiVenda language. If the head of the household consented, he or she signed two copies of the informed consent form and assigned a family representative as respondent to continue the participation.

3.1.2 The study duration

The overall period of study in this particular area of the Nwanedi River basin was from 2004 to 2009, with this particular project commencing in 2006. During this time several pilot community discussion group and household survey activities were conducted to prepare and construct the questionnaires, observation sheets, water sampling protocols, and finally also provided the basis for community group discussions conducted throughout this particular study. All the studies spanned all four seasons of the year. Reference Community 1 (RC1) had a small water supply system since before 1994 and Reference Community 2 (RC2) had no system nor did they receive any upgrade – the data for RC2 was collected at the same time as that of Upgrade Communities 1 (UC1), 2 (UC2) and 3 (UC3).

3.1.2.1 The surveys (collecting data)

The communities participated, on several occasions, in a total of seven sampling and six groups of survey activities.

- Early on cross-sectional surveys collected demographic and socio-economic data. This was done once at the beginning of the study of each participating community, i.e. the baseline;
- The second round of survey activities saw periodical cross-sectional surveys conducted of the function indicators. These cross-sectional surveys covered the baseline and post-upgrade periods;
- The third of activities were group discussions in the communities during which times feedback from the function indicator surveys were given and problem issues clarified. The sampling activities were for collecting water samples from the containers at the household as well as from the various sources.
- The same data collection tools were used throughout for each of the survey activities and the same protocol for water sampling and testing. The interview-based survey tools were first constructed in English then translated into the local language of TshiVenda and then back-translated to English to ensure clarity and accuracy of the questions. The data collection tools, including the contents of questionnaires and data capture sheets, as well as the capture of data are described later on under the sections about the respective indicators.

3.1.2.2 The assessment team

Trained fieldworkers whose mother tongue is the local TshiVenda language and who were also fluent in English, collected the data on questionnaires in structured interviews as well as doing observations. All data were recorded on paper sheets. These fieldworkers were overseen by graduate fieldwork supervisors, who did the periodical cross-sectional data collection such as distances, times and as well as water sampling. The supervisors also did the quality checking on the data from the baseline demographic and socio-economic interview phase. The data were again quality checked, collated and analysed by the principle researchers involved in this study.

3.1.2.3 Data analyses

The methods of data analyses are discussed in the sections below. Data were analysed with SPSS v17 and Statistika v9. Graphs were plotted with SigmaPlot v11.

3.1.3 The water supply services

The water supply services for the study communities as they were during the baseline period as well as after the upgrade are outlined in Table 2.1. The “upgrade” in the context of this study was the change from ① no service to a full basic by water supply service with communal taps on standpipes and ② upgrading from no service to handpumps and communal tanks (rudimentary water supply service) and then to communal taps (basic water supply service).

The alternative sources were the original sources that the upgrade communities would revert to whenever the rudimentary or basic water supplies were interrupted. Technology refers to the means by which water was accessed from the source, such as a hand-pump on a borehole and or communal tap on a standpipe connected to a piped water supply network. It also refers to the containers and their peripheral devices (scooping vessels) used when collecting water from the open sources during “non-service” circumstances.

Table 2.1: Pre- and post-upgrade water source points

	No service	Rudimentary service		Basic service	
	Primary source and technology	Primary source and technology	Alternative source	Primary source and technology	Alternative source
UC1	Open water – river water sourced with containers			Groundwater pumped untreated into a system ending in communal taps	River and springs source with containers
UC2	River water sourced with containers	Groundwater accessed by boreholes fitted with hand pumps	River and springs	Groundwater pumped untreated into a system ending in communal taps	River and springs (Original hand pumps not maintained)
UC3	River water sourced with containers	Treated water from remote large town brought in by tanker-lorry and stored in village-level tanks	River	Treated surface water pumped into a system ending in communal taps	River (Original tanks removed and tanker service ceased)
RC1				Groundwater pumped untreated into a system to communal taps	Original springs source and nearby river with containers
RC2	Open water – river water sourced with containers	No upgrade- households continued to use untreated surface water throughout study period			

UC1 = Upgrade community with direct upgrade from open water to basic system; UC2 = Upgrade community with handpumps; UC3 = Upgrade community with water tanks; RC1 = Reference Community with basic supply service; RC2 = Reference Community with no supply service

3.1.3.1 Issues on containers and home treatment

3.1.3.1.1 The container effect

Access to a basic water supply in South Africa is primarily based on providing communal taps throughout the receiving communities. Households then collect water from the taps in assortments of containers and carry it to, as well as store it at home during use (Figures 2.2a and b).

**Figure 2.2a:** Container carrying from open source**Figure 2.2b:** Container storage in the households

There is substantial evidence that the way these containers are managed by households have a detrimental effect on several aspects of domestic water supply by households in small and rural communities. These include deterioration of the health-related microbial water quality from the good water at the tap to the point of use and adding extra burden of toil to households through carrying containers including those who receive a basic water supply service. Because containers are also used under conditions of no-service and rudimentary service, all water sampling was done from the container waters as part of all function and effect measurements for this study.

3.1.3.1.2 Home treatment

Households were excluded from the study if they indicated some form of home treatment, i.e. disinfection with chlorine. The reasons were that the real exposure situation would be masked and moreover, that a water supply service did not include any facilitation of home treatment especially in the container collection situation.

It was nevertheless found that none of the randomly selected households practiced home treatment of water, an activity that, while the communities were well aware of what it is, appeared not to be practiced at any measureable scale, regardless of the source of water.

3.1.3.2 The “non-service” reference communities

Non-service, in the context of this study, meant that there was no process or infrastructure by which water supplies were provided to a community by a service provider. The Upgrade community 1 (UC1) did not have any incremental upgrade before the study commenced and was directly upgraded from a river source to a basic supply

service. Reference Community 2 (RC2) in particular did not have, nor did they receive, any upgrade before or throughout the study period. Households continued to collect and store water in, as well as use water from containers after sourcing the container water from the open sources such as the same small rivers and springs (Figures 2.3a-2.3c) that all two upgrade communities also used before they were provided with their own respective rudimentary and then basic services.

The reference communities (RC) were included in the study for the following reasons:

- To verify that the outcomes of the three upgrade communities were not due to seasonality or chance;
- Because two of the upgrade communities already had rudimentary water supply services from times before the study started, RC2 in particular provided the evidence of what typical conditions would be in a 'no-service' scenario;

Finally the rudimentary water supply systems were reported to often break down before the study period and also did so (as did the basic water supply systems) during the study period, all during which times households would revert to their original open sources (typical no-service scenarios).



Figure 2.3a: Collecting water from a spring **Figure 2.3b:** Collecting water from a river **Figure 2.3c:** Carrying water home

The assumption was that these breakdowns would continue given the current state of water supply service management by the local authorities in the area and also in South Africa as a whole. The RC therefore also provided a continual reference point for what typical conditions would be like during these breakdowns.

3.1.3.3 The rudimentary water supply services of the upgrade communities

Upgrade Community 2 (UC2) consisted of several adjacent villages which used a similar rudimentary water supply service with groundwater as its source. This source was accessed by several handpump-fitted drilled wells at locations throughout the villages. Households collected water from the handpumps in containers (Figure 2.4a) and stored it in their homes.

It was established that these handpumps broke down often, which implied that the ground water was accessible for only a certain proportion of the community's total time. There were several pumps in the community, which implied that although the breakdowns appeared to be frequent, it was unlikely that all pumps would break down at the same time. However, total breakdowns did occur intermittently during the study period.

All these various times of service and no service were measured and are reported on later in this part. The communities, during discussion group activities, indicated that when the pump nearest to a household broke down, the particular household would revert to their most convenient (often the closest) open source to collect water for their other domestic needs but still endeavoured to get water for drinking and cooking purposes from the closest operable handpump even if it was in the neighbouring village.

When all pumps were broken, the households then reverted to their open (alternative) sources (Table 2.1) for all their water needs (including untreated water to be used for drinking) until the handpumps were repaired. For the purposes of this study, it was assumed that a total reversion to no-service only happened when all pumps had broken down at the same time.

Upgrade Community 3 (UC3) was one large village with a totally different type of rudimentary service to UC2. The community was supplied once a month with treated water delivered by a local municipality tanker. The tanker drew this water from the supply of a large town some 30 kilometres away on a given day and, during several trips, filled the eight 5-kilolitre plastic storage tanks situated evenly spread throughout the village. While the tanker

filled the community tanks, households also collected water (as much as they had containers for) directly from the tanker during that time (Figure 2.4b), and stored it in their households.



Figure 2.4a: Collecting water from a handpump



Figure 2.4b: Filling containers at the tanker vehicle



Figure 2.4c: Communal water storage tank

The community had organised itself that their small container water was used first before the households started to use the water in the large storage tanks. In order for the water in the community storage tanks to last for as long as possible, the community restricted themselves to collecting one container of water from the storage tanks per household per day for as long as the water lasted in the tanks (Figure 2.4c).

This one (usually 20-ℓ) container of water was mainly used for drinking and food preparation, which made for a complicated calculation on the volume collected per person per day. The households collected the rest of the water that they needed from their open (alternative) sources which was quite far away, costing them a considerable amount of time to collect. When the tank-water ran out completely, the households' alternative was to collect all the water for their needs from nearby river, which implied exposure again to poorer quality of water for a proportion of the time, treated tanks water being available for the rest of the time.

3.1.3.4 The basic water supply services for the upgrade communities

The upgrade to basic water supply services in UC1 and UC2 was done by removing existing pumps from an existing borehole and installing a pump powered by an electric motor (UC1) and diesel motor (UC2), and pumping the untreated groundwater into elevated clean-water holding/pressure tanks, from where the water was distributed under gravity through networks of pipes to communal taps on standpipes throughout all the villages in the community (Figures 2.5a-c).

Interruptions in supply during the study period were mainly due to the pump breaking down or electricity/diesel running out, during which periods households used the open sources. In UC2 the handpumps remaining after the upgrade soon became redundant as a result of non-maintenance. Effectively, the only alternative sources during breakdowns were the open untreated surface water. The upgrade in UC3 consisted of a small-scale treatment facility (package plant), which drew untreated surface water from a nearby small river.



Figure 2.5a: Motorised pump on borehole



Figure 2.5b: Clean-water holding tank



Figure 2.5c: Communal tap

The water was pumped through the system consisting of the conventional processes of flocculation, sedimentation, filtration and chlorination, before being pumped to an elevated clean water reservoir in the community, from where it was then distributed under gravity to communal taps through a network of pipes (Figures 2.6a-c). After the upgrade, the storage tanks in the community were decommissioned and removed by the service provider to be set up elsewhere. This left the community with open sources as only alternative during breakdowns or other interruptions in supply.

Despite these upgrades, households in both communities still had to collect water by container from the communal taps and store it at home as the supply was not piped into the households' dwellings or lots.



Figure 2.6a: Small-scale treatment



Figure 2.6b: Clean-water holding tank



Figure 2.6c: Communal tap

3.1.4 Benchmarking the functions and their indicators

This section describes the methods used to measure the indicators of the functions of access, availability and potability. The same methods were used across the three communities and all the levels of service.

3.1.4.1 Access

Measuring changes in access required ① data about the distances walked by the water carrier from the household to the water sourcing point at each of the various levels of service as well ② describing the technology used to abstract the water from the sources as well as the conditions at the water source points.

3.1.4.1.1 Distance

The actual distances between households and water points were physically measured by walking with the study participants to the water source points while recording the distance (in metres) with the odometer function (accuracy ± 10 m) of the Garmin 60Csx GPS devices and noting these distances on the data sheets.

3.1.4.1.2 Source point density

Source point density was simply calculated by dividing the number of taps into the number of people, households or into the square kilometre area covered by the village. Using the point per area was more appropriate for the monitoring tool while for effect and impact, it was also important to know how many households were using to a single source point in a community.

Detailed numbers would be measured using the numbers of people per point but for the number of taps per household, the assumption was 6 persons per household as this was close to the 90th percentile of the household sizes in the area.

3.1.4.1.3 Sourcing technology

Sourcing technology referred to the means by which water was abstracted from a faucet like a tap or tank spigot a water source point. The open sources had none of these but the actual point of access was considered for consistency. While sourcing technology was an important indicator in terms of *accessibility*, it was not a measureable in itself in terms of access but played an important part in measuring the time it required to fill a 20-l container during measurements of the function of *availability*.

In the case of the no service community, this was done using 'self-service' technology, i.e. using the containers and some other filling devices to collect water from open sources (Figures 2.7a-c). Where the water at the source point was of sufficient depth, such as rivers and streams, the water collector immersed the container into the water to fill (Figure 2.7a). In cases where the source was not deep enough, a smaller vessel would be used to scoop water and pour into the container (Figure 2.7b). In some cases where an unprotected spring was the source, water flow was manipulated to spout through a pipe and the container would be placed or held under the water flow to fill (Figure 2.7c).



Figure 2.7a: Immersing container in river



Figure 2.7b: Scoop-filling container at stream



Figure 2.7c: Spout-filling at spring

The sourcing technology at rudimentary service water points were handpumps and tank spigots (Figures 2.7d and 2.7e). The rates of filling a 20-ℓ container at these points would be determined by the delivery condition of the pump and in case of the tanks, the level of water in the tank. This meant that containers filled faster the fuller the tank was because of the higher pressure.



Figure 2.7d: Collecting water from a handpump



Figure 2.7e: Tanker filling containers, before filling storage tanks (Note the storage tank spigot front left)



Figure 2.7f: Collecting water from a communal tap

Normal household faucets/ taps were generally used as communal tap technology to source water in the basic service (Figure 2.7f). The rate at which a container filled under a tap would also be determined by the capacity and condition of the system (Refer to section on System Assessment below).

Observation sheets were used to collect data from which were described the sourcing technology at the water source points. These observations were then combined with results from activities to measure the fill and flow rates where applicable to ultimately provide the results for the filling times.

3.1.4.1.4 Sourcing conditions

The sourcing conditions were measured for the basic water supply service only (Section 3.2 below) since it was not possible to empirically measure the conditions at river banks and hand pumps. The latter was qualitatively assessed (getting the community perspective) and are described in Chapter 3 later on.

3.1.4.1.5 Benchmarks for compliance of the access function

Benchmarks for distance and sourcing technology were compiled for this study. The benchmarks for distance shown in Table 2.2 below were derived from literature and existing RSA guidelines. The compliance level was set at the 90th percentile, in other words a service would be seen as compliant if 90% of the measurements (in this case the distances) were within the set guideline value or standard in Table 2.2.

Table 2.2: Benchmarks for *access* in terms of distance (metres) source and point density

Indicator	Service level	Benchmark	Benchmark origin	Source
Distance	No service	Recommended 1,000 m maximum	WHO guideline	Howard and Bartram (2003)
	Rudimentary	Recommended range of 200 to 500 m	Existing RSA guideline	DWA (2000)
	Basic	Compliance level 200 m maximum	Existing RSA guideline	DWA (2003)
Source point density	All services	15 points per km ² or 1 point per 40 households assuming 6 persons per household or 1 point per 250 people	Literature	Sphere Project (2004); CSIR (2001)

In the case of non-service, no clear benchmarks could be identified. For this study a maximum distance of 1,000 metres, as recommended by WHO (Howard and Bartram, 2003), was used. Since sourcing technology was not a measurable indicator in this study, no quantitative benchmarks were developed for it.

However, as sourcing technology had an influence on filling time, which was in turn influenced by availability, the following qualitative benchmarks were used:

- At the no service level, availability at source should be such that the water is accessible (suitable spots on the river banks where people can stand and fill containers, the flow is perennial and allows for collection of sufficient quantities;
- Sourcing technology for the rudimentary water service, such as handpumps, should be easily operable and not require much labour. Such technology should also be easy to maintain, i.e. easy to repair and spare parts readily obtainable;
- Basic water source technology such as taps should require minimum effort to operate, and be durable enough to close off the flow if the faucet is closed. Taps should also be easy to maintain, i.e. easy to repair and spare parts readily obtainable.

3.1.4.2 Availability

The function of availability consisted of three measurable indicators, namely the temporal and physical presence of water at a water point (availability at source), and the flow or filling rate of water into the container (depending on the sourcing technology). Changes in the parameters for these indicators, as well as changes in the distances and sourcing technology, were suggested to bring about changes in the third indicator – which was also an effect value indicator, namely the per capita daily quantity in litres of water (ℓcd) collected from the water point.

3.1.4.2.1 Availability at source

Availability at source meant the days during the study period that the water was available at the source points measured against the days that the water was unavailable.

For the basic service, this was measured by the number of days during the study period when there was no water supply was at the taps. For the rudimentary service using handpumps, it was the days that all the pumps were inoperable. For the rudimentary service using tanks, it was the number of days that the tanks were completely empty. For the no-service, it was the number of days that the open source was dry and water could not be collected from it, which did not happen during the period of study and according to the households, never happens otherwise.

The fieldwork supervisors kept a record of the days when the water supply systems were operational. In addition, households were asked weekly which water sources they had been using, and breakdowns in the system as well as which alternative source they used if they were indeed collecting water. In the case of UC3, the non-availability of the water before the upgrade was not due to breakdowns but due to the fact that the water in the tanks only lasted for some time in a month as the local municipality did not increase the frequency of filling at all during the time of the study.

3.1.4.2.2 Flow and fill rate

Flow rates at the taps were calculated from the time it took to fill a 20-litre container at the water points.

3.1.4.2.3 Benchmarks for compliance of the availability function

Benchmarks were set for the two indicators of availability, namely availability at source and flow rates. For availability at source these were the percentages of time that water was available at a source point (Table 2.3).

Table 2.3: Benchmarks for *availability* of water at the source point, flow and fill rate and per capita collection

Indicator	Service level	Benchmark	Benchmark origin	Source
Availability at source	No service			
	Rudimentary	70% of the time	Literature	Bartlett (2005)
	Basic	96% of the time with breakdowns repaired within 48 hours	Existing guideline	DWA (2003)
Flow and fill rate	No service			
	Rudimentary	17 ℓ/min	Literature	Sphere (2005)
	Basic	Compliance level 10 ℓ/min	Existing guideline	DWA (2003)

For no service conditions, water was deemed always available at the source. No official guideline could be found for the minimum availability at source points for a rudimentary service and a benchmark was derived from

literature, even though this particular report (Bartlett, 2005) referred only to handpumps. For the basic level of service, the Strategic Framework for Water Supply Services (DWA, 2003) recommended availability of water a minimum of 350 days per annum, translating to a minimum availability of 96% per annum. Furthermore, the guideline stipulates that interruptions in supply must not exceed 48 hours. Thus for availability at source for the basic level of service, there were two benchmarks of compliance, namely repair of breakdowns within a maximum of 48 hours and availability of supply for at least 96% of the time.

The 96% availability was based on water being available at taps for at dawn to dusk least daylight time (evened out at 12 hours). The reasons for this were that most communities do not collect water after dark for safety reasons. This also offers the opportunity for the local operator to pump water during the night to get the reservoir filled and save costs – arrangements that are often made by the amongst the communities itself.

For flow rates compliance was considered to be at the 90th percentile except for non-service, where flow-rate was not benchmarked.

3.1.4.3 Potability

The potability of water – as defined by its health-related microbial quality of water (HRMWQ) – was assessed using indicator *Escherichia coli* (*E. coli*). The HRMWQ was tested for the sources as well as for containers. The source results were to demonstrate water quality changes brought about at source by the upgrade. Results of the container samples would reflect the exposure posed to the households at the point where they use the water, especially for drinking after starting to use the upgraded system. Container water quality was then assumed to reflect the effect of the changes in the source water, i.e. the less contaminated the source water, the less contaminated the container water would be.

3.1.4.3.1 Water sampling

Water samples were collected from the water source points at several occasions to represent the quality in summer and in winter. Water was sampled from the containers of the selected households at the same time. At this time the respondents in the households were asked which source the water had been collected from. One-litre samples were collected in sterile containers and preserved below 10°C before analysis – within 2 hours – in the nearby field laboratory of the research group.

3.1.4.3.2 Water testing

The IDEXX Colilert-18™ Quanti-Tray testing kit was used to detect indicator *E. coli*. The most probable number (MPN) of *E. coli* per 100 mL of water was then determined tables provided with the Quanti-Tray™ kit.

3.1.4.3.3 Benchmark of Potability compliance

This component of the study was not meant to quantify or characterise the microbial risk posed to the consumer as in doing a quantitative risk assessment. This aspect is discussed in Chapter 3. This part of the work was to demonstrate compliance of the water to set quality standards/guidelines that use *E. coli* as an indicator of infection or health risk posed by the water if consumed. For this study, the compliances were benchmarked for the water quality at the source point as well as at the point of use (containers). This current section addresses compliance while reducing the possibility of infection as an effect value is made in Chapter 3.

The South African National Standard (SABS, 2006) deals with the quality of water delivered by a water supply system at controlled end-points, i.e. the quality of the water at the tap or at the delivery point of a handpump or community storage tank. It does not deal with the quality of water at the “no service” source point (e.g. river), nor of that at the point of use which was, in the case of this project, the container water quality. This standard was therefore used (Table 2.4) to benchmark the water for compliance of potability at the source point at the 95th percentile.

Table 2.4: Benchmarks for potability of source and container water

Function indicator	Service level	Benchmark	Benchmark origin	Source
Container water quality	All	Zero (0) <i>E. coli</i> per 100 mL	Existing guideline	WHO guideline (WHO, 2006)
Source water quality	No service (not to be treated)		Existing guideline	WHO guideline (WHO, 2006)
Source water quality	Rudimentary and basic		Existing standard	SANS (SABS, 2006)

Compliance levels: SANS (SABS, 2006) = 95th percentile; WHO (WHO, 2006) = 90th percentile

The WHO Drinking Water Quality Guidelines (WHO, 2006) state that water intended for drinking should not contain any *E. coli*. These guidelines, although essentially using similar criteria as does the SANS (2006), were used as the benchmark for microbial quality of water sampled at the point of use as well as the no service source points,

and although the WHO had not set compliance levels in their guidelines, a compliance level for this project was set at a less conservative 90th percentile to compensate for the re-contamination of water in containers and the untreated source water.

3.1.5 Assessing changes in the functions related to upgrades

While measurements of the functions for this study were based on an individual going to fill a 20-ℓ container of water and bringing it back home, the measurements also reflected the changes brought about by the upgrade as well as the reverse when the systems break down. The tools for conducting this step of the project were explained in the previous section and the results are presented in tables and plots (results section) later on. The change assessment approach and methods are described in detail in the research report referred to at the beginning of this chapter. The assessment framework is shown in Figure 2.9.

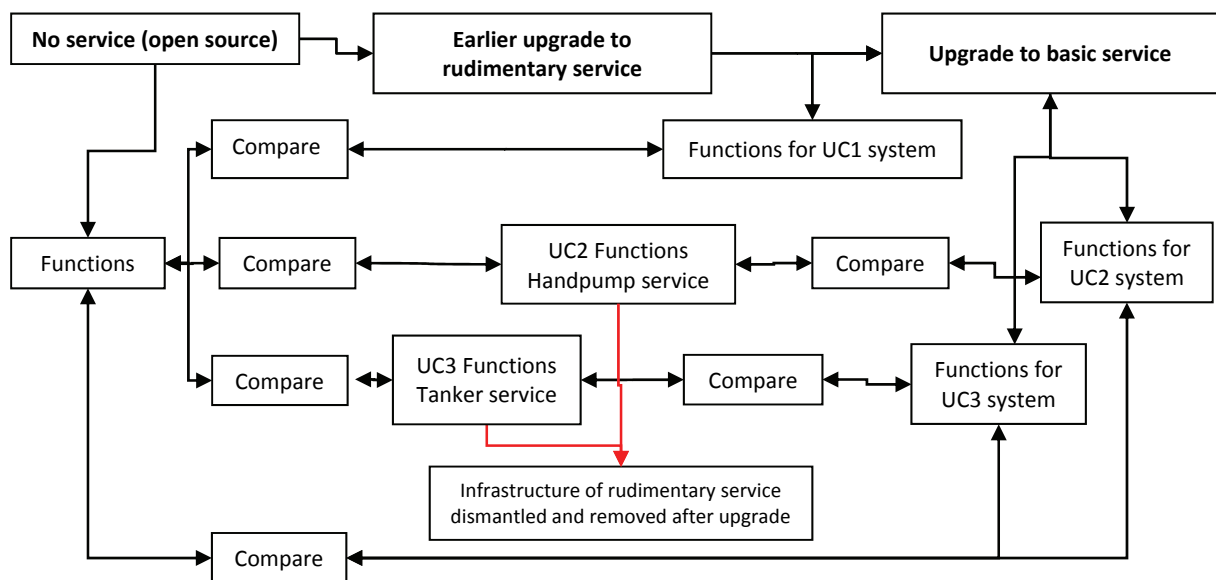


Figure 2.8: Framework for assessing the function changes

3.1.5.1 Describing the data

The data were described for each function indicator for each of the levels of service using descriptive statistics such as the mean, median, the maximum and minimum as well as quantiles. Except for compliance of the microbial water quality from supply systems, the level of compliance for the other function indicators (for instance whether a service complied with the 200 metres maximum distance) was set at the 90th percentile, which would be less conservative than the conventional 95th percentile and more realistic reflection of developing-country settings.

Where compliance benchmarks specified a minimum value, the 10th percentile was used. In the case of the microbial water quality data, the log values of the natural figures were used to stabilise the expected wide variations in the data (Helsel and Hirsch, 2002). The compliance level for this component was the 95th percentile as prescribed by the South African National Standards for Drinking Water Quality (SABS, 2006), although where possible, the 90th percentiles were also shown in the results for container-stored waters since the SANS (SABS, 2006) provides for drinking water from a serviced end-point such as a tap at 95th, a more conservative level of compliance.

3.1.5.2 Measuring changes

Analyses of variance (ANOVA) were used to measure and compare changes in the quantitative data for the three levels of services. It was expected that the data for the indicators of distances, water quantities, and the time components, would be normally distributed and of equal variance. For these datasets parametric ANOVA was used. The microbial data were expected to be mostly not equally distributed around the mean and would require non-parametric ANOVA. As it turned out, analyses of the data for normality and equal variance showed that most of the data sets often were non-parametric – even the supposedly more stable distance, time and water quantity data.

It was therefore decided to use non-parametric ANOVA throughout the study as these were, for the purposes of the study, suitably robust and reliable to detect differences in data sets regardless of whether data were parametric or not (Helsel and Hirsch, 2002).

For each indicator, the data for all the levels of service were tested for variance using the non-parametric Kruskal-Wallis Analysis of Variance on Ranks test. This test is used when comparison of more than two data sets is required. For this study there were four data sets to be compared, namely the 'no service', rudimentary service using tanks, rudimentary service using handpumps and the basic service (communal taps). Where data sets differed from each other, Multiple Comparison Tests (MCT) were used to identify which of the data sets differed and to what extent. Where the results of the MCT were not specific about testing for differences (did not test), the non-parametric Mann-Whitney Rank Sum test was used to verify differences (or not) between any two of the data sets.

3.1.5.3 General approach to hypothesis setting

The null (or zero) hypothesis (H_0) in this step of assessing changes in the functions as the upgrades were effected, was that there would be no significant differences between the function indicators at the ❶ no service, ❷ the rudimentary service using tanks, ❸ the rudimentary service using handpumps and ❹ the basic service. Accepting this hypothesis meant that the functions did not differ at the various levels of service, which would have certain implications as explained in the sections below and discussed in the Results section later on. The same would apply to rejecting the H_0 , which would imply that the functions did differ between the levels service. Such differences are also reported on and the reasons for the differences discussed.

3.1.6 Results and discussions

3.1.6.1 Homogeneity of the study population

The section discusses the homogeneity of the study communities. The results of comparing demographic and socio-economic data of the three study communities are shown in tables below.

Table 2.5 shows that there were no significant differences in gender amongst the study communities ($p = 0.427$ overall). The average age in the study communities also did not differ significantly ($p = 0.465$ overall) as did household size, with $p = 0.214$.

Ultimately there were no significant demographic differences between the villages and none for energy source. While the socio-economic differences in education and income as discussed above could have resulted from the differences within the 0-14 age group, the overall analysis of age data showed no difference. For the purposes of this project, the study communities were considered sufficiently homogenous.

Table 2.5: Demographic homogeneity of study communities based on gender and age

Variable	Reference Community 1	Upgrade Community 1	Upgrade Community 2	Upgrade Community 3	Reference Community 2
Male (% of study sample)	46.3	48.2	46.8	42.4	40.4
Female (% of study sample)	53.7	51.8	53.2	57.6	59.6
Age (mean)	26.1	25.7	26.0	25.3	23.2
Household size (mean)	5.3	5.8	5.4	4.5	4.5

Three socio-economic determinants were also compared, namely education, income and energy source (Table 2.6). There were no significant differences in gender amongst the study communities ($p = 0.427$ overall). The only significant differences in education were those between RC2 and UC2.

There were significantly more people with primary education (up to Grade Seven) in RC2 than there were in UC2 ($p=0.000$). RC2 also had significantly more people receiving an income than UC2 ($p = 0.000$), as well as UC3 ($p = 0.013$). However, there were no significant differences in the energy source used amongst the communities, as almost all of the households in the three communities used wood as the energy source ($p = 0.543$ overall).

Table 2.6: Socio-economic homogeneity of study communities (%) based on education, income and energy source

Variable	Reference Community 1	Upgrade Community 1	Upgrade Community 2	Upgrade Community 3	Reference Community 1
Education (% primary education or less)	60.1	58.7	59.2	66.7	72.0
Income (% of study sample)	39.3	32.1	34.3	39.9	54.7
Energy source (% of sample using wood)	90	92.2	97.7	100	100

The differences in the education and income could be explained by that although overall there were no statistically significant differences between the villages in the ages of the study population, the percentages of 0-14 year olds differed somewhat (36.6%, 42.2%, 47.6% for UC1, UC2 and RC respectively). This suggests that because the RC had a high percentage of 0-14 year olds, the majority of them could have been in primary school, and so could have resulted in the high percentage of people with primary education or less. This could have also had an effect on the number of people receiving an income, because the parents/caregivers of the 0-14 year olds in the RC could have been receiving child support grants and would report this as income for the family. Child support grants are given up to the age of 15 in South Africa, and, according to Van den Berg et al. (2005), the uptake of child support grants in rural South Africa has been expanding rapidly. These differences were therefore not considered sufficient to confound the findings of other comparisons between the various study communities.

3.1.6.2 Measurement of functions across the levels of service

The data presented here are in box plots with the summary tables in the detailed research report referred to in Section 8 in Chapter 1. Some of the data sets for several of the functions in this section will appear to be different. This will be pointed out and the differences discussed later on in terms of their significance.

3.1.6.2.1 Access

Access was defined by three determinants or variables, namely distance, source point densities and source technology. These variables distinguished between the domestic water management processes of getting to a water source point (distance) and, once at the water source point, tapping into the source of the water (collecting) in containers and then conveying the water to a storage point at the home where it could be used from the container until a refill is required.

3.1.6.2.1.1 Distances to water points

Figure 2.9 shows the distances, in metres, from the households to water source points for each service level. The whiskers at the upper ends of the boxes (for Figure 2.9 and the other figures to follow) are the 90th percentiles and the lower whiskers the 10th percentiles.

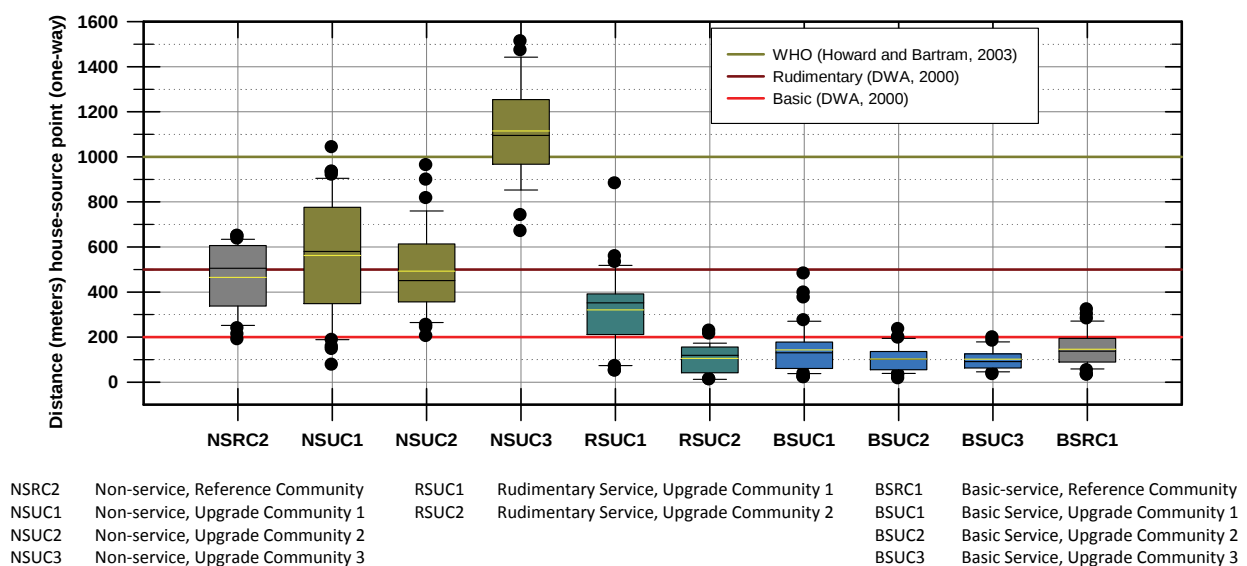


Figure 2.9: Distances (in metres) from households to water points across the levels of service

The black dots beyond the ends of the boxplot whiskers are outliers beyond the 95th percentile, up to and including the maximum and minimum values in the data set demonstrating the extent of data range. The yellow horizontal lines are the mean values.

The maximum distances to river source points under the non-service (NS) of up to 1,500 metres in UC3 were farther than the benchmark maximum distances of 1,000 metres. Distances to water source points in both the RC2 as well as NS conditions for UC1 and UC2 were below the 1,000-m benchmark, which meant that they complied with the benchmark value. The upgrade of UC2 to handpumps closer to home during the RS era significantly reduced ($p \leq 0.001$) the distance previously travelled to the open sources – and even more so for the community-level storage tanks in UC3. For UC2, the distances to RS hand-pumps at the 90th percentile were just above 500 metres (the benchmark value), which meant that, although there were some outliers beyond

500 metres, the service complied with this function parameter. For the RS in UC3, the distances were so significantly and substantially reduced ($p \leq 0.001$) that they already complied with the BS benchmark of 200 metres during the RS period.

The distance of just below 200 metres (at the 90th percentile) measured for the basic level of service (BS) in UC2 and UC3 respectively complied with the maximum distance specification of 200 metres between household and tap for a BS. However, the distance of 280 metres at BS for UC1 did not comply. Upgrading from RS to BS also brought significant relief of trip distance for the UC2 handpump village as the taps were significantly ($p \leq 0.001$) closer than even the handpumps. However, for the tank-served village (UC3) the upgrade to BS did not bring any significant relief as the taps were at similar distances as the tanks. The overall effect of moving NS to BS was that the water source points were moved closer from as far as 742 and 1,380 metres afield (to the open sources) to between 171 and 280 metres (at the taps) – significant relief in terms of carrying water from the source to home.

3.1.6.2.1.2 Source point density

Perhaps more important than the sourcing technology, is source point density. Table 2.7 shows the densities in the study communities.

Table 2.7: Source point densities in the study communities

	Indicator	No service (open sources)	Rudimentary (handpumps)	Rudimentary (tanks)	Basic (taps)
Upgrade Community 1	Points per km ²	4			15
	Households per point	68			19
	Capita per point	406			114
Upgrade Community 2	Points per km ²	8	8		33
	Households per point	30	30		8
	Capita per point	165	165		41
Upgrade Community 3	Points per km ²	9		24	45
	Households per point	32		12	6
	Capita per point	143		53	29
Reference Community 1	Points per km ²				35
	Households per point				13
	Capita per point				75
Reference Community 2	Points per km ²	4			
	Households per point	15			
	Capita per point	68			

The more source points there are in a community, the more access the community would have to the water source and therefore it will also reduce the time spent at the source (e.g. queuing). As was seen from the literature review, source point density descriptions are not well defined and also vary substantially. The non-service source points, were the points where the community would access the open sources as stream and river banks, were not homogenous in topography and people would choose points where they can safely get to and from the water. The other source points were the number of devices accessible to source water, i.e. pumps, tanks and taps.

Upgrading to basic services did improve the source point density substantially with the smaller communities being significantly advantaged with the number of taps they eventually could use to source water (compare UC1 to RC1 and the other UC's).

3.1.6.2.1.3 Sourcing technology

Sourcing technology was defined earlier as the means by which water was abstracted from a water source point. This refers to the devices and the way they are configured or used at the source. In the case of an upgraded system, a tap at the end of a distribution system is the sourcing technology. In the case of a community without any form of service – usually those communities that collect their water directly from an open source such as a river – there would not be any form of technology application other than using a container and/or scooping vessel to extract the water from the source. Table 2.8 shows the sourcing technology as it was observed for at each service level.

Table 2.8: Sourcing technology at source points across the levels of service

	No service (open sources)	Rudimentary (handpumps)	Rudimentary (tanks)	Basic (taps)
Sourcing technology	'Self-service'; containers immersed in or scoop-filled from rivers and streams	Boreholes with handpumps	Storage tanks filled by mobile tanker	Communal taps

For the NS, when the rivers and stream in the area were in normal to low flow, containers were immersed into the water where it was deep enough to do so – this resulted in a short filling time. It required little effort to get the

water into the container and generally no queuing time as the river sourcing areas were sufficiently wide to allow several fillers in at the same time.

However, in some areas where the river or stream was shallow, it took longer to fill a container as water had to be scooped with a smaller vessel and decanted into the container until it was full. The open sources in the study communities were generally perennial, and thus complied with the sourcing technology benchmark.

As for the RS, the handpump technology used by UC2 often broke down and remained inoperable for weeks on end as spare parts were not readily available, meaning that such technology did not comply with the benchmark namely that it should be easily repairable and its spare parts easily obtainable. The hand-pumps also required effort to pump the water up, which resulted in required longer filling-times than at the NS. The tanks of UC3 had spigots which could easily be opened, as well as maintained – these taps were not worked hard by the water collectors as for half the time the tanks were empty and not used. Although collecting water from the RS tanks by households in UC3 merely meant placing a container under a spigot, the filling time was longer due to low flow rates.

For the BS, the sourcing technology was the taps on standpipes. While they required little effort to be operated when functional, the taps worked much harder than for instance the tank spigots, and wore out rapidly, with maintenance and operation very late in arriving. When they did function the container was placed under the open tap until full. Despite the fact that the taps were often inoperable, they did comply with the benchmark values. The sourcing technology had a bearing on the time it took to fill containers as well as the flow rate of the water and is discussed later on in this context. The greatest improvement brought about by sourcing technology was from the BS taps, as little effort was required and the filling times were short. Although these changes were not quantitatively described, the changes were qualified as significant by the community focus groups.

For both container and or tap, the technology plays an important role in how long it takes the fetcher to fill the container from the source. In the case of water leaving a spout, (hand pump or a tap), the container must fit underneath the spout, and the flow-rate of the water determines how quickly the container fills. For those who accessed an open source (river, stream or spring), the condition at the access point determined how the container is filled which in turn affected the filling time. In the case of an open source with sufficient depth, containers were submersed in the water and filled rapidly. In cases where the water was too shallow to do this, the fetcher filled the container with a scooping vessel of some kind, which took much longer.

Table 2.9 shows the various times it took members of the study communities to fill a 20-ℓ container at the various sources. Included in all these measurements is a fixed value of 1 minute getting the container ready for filling at the source point and lifting (for carry) the container after filling. In this case of filling the upper and lower limits of the 95% confidence interval of the minutes it took to fill a 20-ℓ container, was used because of the uncertainty around the measured values (a mix of measured as well as qualitative data were used).

Table 2.9: Shifts in fill times (minutes) for a 20-ℓ container as various *sourcing technologies* changed with improved *access*

Source point	Filling method	Average time	UL95%Ci
Open surface water	Dunking container in source or scoop-filling	3 min	5 min 13 sec
Rudimentary service devices, e.g. hand pump	Place under pump spout or tank spigot	4 min 30 sec	5 min 25 sec
Taps on system	Place under tap	1 min 40 sec	2 min

UL95%Ci = Upper limit of the 95% confidence interval

The improved sourcing technology did significantly reduce the filling time at the source point because of increased flow-rates at the taps. The effect this would have in the total collection time will be discussed in Chapter 3. However, this is when the water was available. The next section will show that water was not always available at the source point which in some way negated the improved access. This effect is also discussed in Chapter 3.

3.1.6.2.1.4 Source point condition

This is discussed in Section 3.2 on Technical Assessment below.

3.1.6.3 Availability

Availability referred to the temporal and physical presence of water at the water source point (availability at source), the flow or filling rate of water at the water point (depending on the sourcing technology) and also the quantity of water that could be collected from that water point. Results of the quantity of water collected are presented as litres per capita per day (ℓcd).

3.1.6.3.1 Availability at source

Availability at source was reported as the percentage of the number of days during the study period when the water supply service was operable or, in the case of rivers, the number of days in the study period when the river was not dry and water could be collected from it. Table 2.10 shows the availability of water across the various levels of service.

Water was constantly available during the NS era because the rivers were perennial (did not run dry). In this context the NS source points rather ironically complied with the benchmark.

Table 2.10: Percentage availability of water per annum at source points considering self-arranged shut-offs for basic system users

	No service (open sources)	Rudimentary (handpumps)	Rudimentary (tanks)	Basic (taps)
Upgrade Community 1	100%			85%
Upgrade Community 2	100%	83%		89%
Upgrade Community 3	100%		50%	58%
Reference Community 1				80%
Reference Community 2	100%	No upgrade- households used open sources throughout study period		

During the RS era, the water supply from the tanks in UC3 lasted for approximately two weeks of the month after being filled, and so for 50% of the time UC3 households reverted to open sources when the tanks ran dry. This did not comply with the benchmark of 70% availability suggested as the benchmark. While the groundwater accessed by the handpumps in UC2 was always available, the handpumps were all totally inoperable for approximately two weeks in every three months, because of breakdowns. This meant that the groundwater could not be accessed because the borehole diameter was too small to lower down any form of collection vessel. However, the service complied with the availability criterion for a rudimentary supply service because of the 83% availability of water at the handpumps in UC2 was more than the 70% minimum availability suggested as the benchmark.

During the BS period of the study, the water supply system in UC3 broke down frequently, with the result that tap water was available only 58% of the time as opposed to 89% in UC2. This meant that the availability of water at the taps for both small upgrade communities was substantially below the minimum benchmark level of 96% availability because of breakdowns as well as other operational disruptions such as running out of diesel or treatment chemicals. For the larger UC1, despite the community arrangement of shutting the tap system off for 12 hours per day, the availability was still just 75% because of long interruptions. For RC1 the interruptions amounted to 20% of the year the community did not have water. . In terms of the consecutive number of days of breakdown, the benchmark of not more than 2 consecutive days (48 hours) of inoperability was not complied with by the BS in both upgrade communities. UC1 and UC2 experienced several breakdowns, lasting between 1 and 7 weeks.

Non-availability at the rudimentary and basic water source points meant that the conditions reverted to NS conditions as the open sources under this service level was the only alternative. In essence, the availabilities summarised in Table 2.8 above imply that for instance, communities using the tanks (UC3 during the RS era) were exposed to the functions and the consequent effects of 'no service' for 50% of the time that they had the rudimentary tank service and 42% of the time they had the more advanced basic water supply service.

Availability at source was a pivotal element in this study, as the other indicators were to a large extent affected by the shifts in availability. The irony of these findings was that water was far more available to the study communities during the time when they had no service. The trade-off having closer and cleaner water less available will be discussed in Chapter 3. While these services did not comply with the benchmark values, using the reliable borehole to feed the system in UC1 and UC2 brought them greater continuity at least for the post-intervention period of the project. On the other hand, the option of providing a surface water treatment package plant for UC3 appears to have had, at least for the post intervention period, not brought any relief in terms of availability and people had to resort to their original sources.

3.1.6.3.2 Flow and filling rate

Flow rates affect the quantity of water that would be collected, mostly because of the time it takes to fill containers, which would see the water collector only take what can be loaded in the time available to collect water. In the case of water source points at rivers and streams, it was the filling rate being reported on, as opposed to the flow rate. Both terms actually represented basically the same measurement, which was the speed with which water poured into a 20-litre container.

The difference being that flow rate applied to water source points such as the pipe on a handpump, the spigot on a tank or the tap on a communal tap, where water could *flow* out because it was channelled, whereas filling rate

applied to open sources where the water was not channelled, but either simply *filled* the container (e.g. by immersing a container in a sufficiently deep part of a river) or had to be decanted into the container with another smaller vessel, as in the case of shallow rivers, streams and open springs. From here on both will be referred to as the filling rate. Table 2.11 summarises the filling rates measured at the water source points.

Table 2.11: Minimum filling rates in litres per minute (at the 10th percentile) across the levels of service

	No service (open sources)	Rudimentary (handpumps)	Rudimentary (tanks)	Basic (taps)
Upgrade Community 1	7			24
Upgrade Community 2	7	4		24
Upgrade Community 3	7		3	12
Reference Community 1	7			25
Reference Community 2	7			

The filling rates were the same for the NS condition of the three communities. The filling rate at the NS open sources was higher than the filling rate at the RS water source points. This could be explained by the fact that at the open sources, containers were mostly immersed in deeper parts of the open water at the source point.

The handpumps produced a low filling rate of approximately 4 litres per minute, because the handpump technology required manual effort (pumping) from the user. The lowest filling rate however, was at the tanks, because the rate decreased with the decrease in the volume of water in tanks and consequently decreased pressure as the tanks became empty. Both these fill rates were well below the proposed 17 litres per minute (ℓ/min) benchmark. The highest filling rate was at the taps (BS), where for UC1 UC2 UC3 and the RC1 it was between 12 and 25 ℓ/min respectively at the 10th percentile. This was over the minimum of 10 ℓ/min benchmark and therefore complied with the guidelines. Thus, the upgrade to BS and the consequent improvement in sourcing technology increased the filling rates to almost twice and sometimes more than that of NS and RS.

3.1.6.4 Potability

Results of potability measurements were presented as the log numbers of *E. coli* in a 100-mℓ sample of water measured against benchmarks of compliance. These samples were collected from the containers in which water was stored as well as the water source points from where the water was collected. Figure 2.10 shows the results of both source as well as container water analyses. The container water quality results are plotted next to each source from where the container was filled.

During the non-serviced era, the source waters were untreated rivers and streams. Figure 2.10 shows that no clear pattern could be identified with some container water improving somewhat in quality, others deteriorated even further and some remained similar to the source water. The most important point here was that neither source nor container water were suitable for human consumption on average and especially not at the 90th percentile.

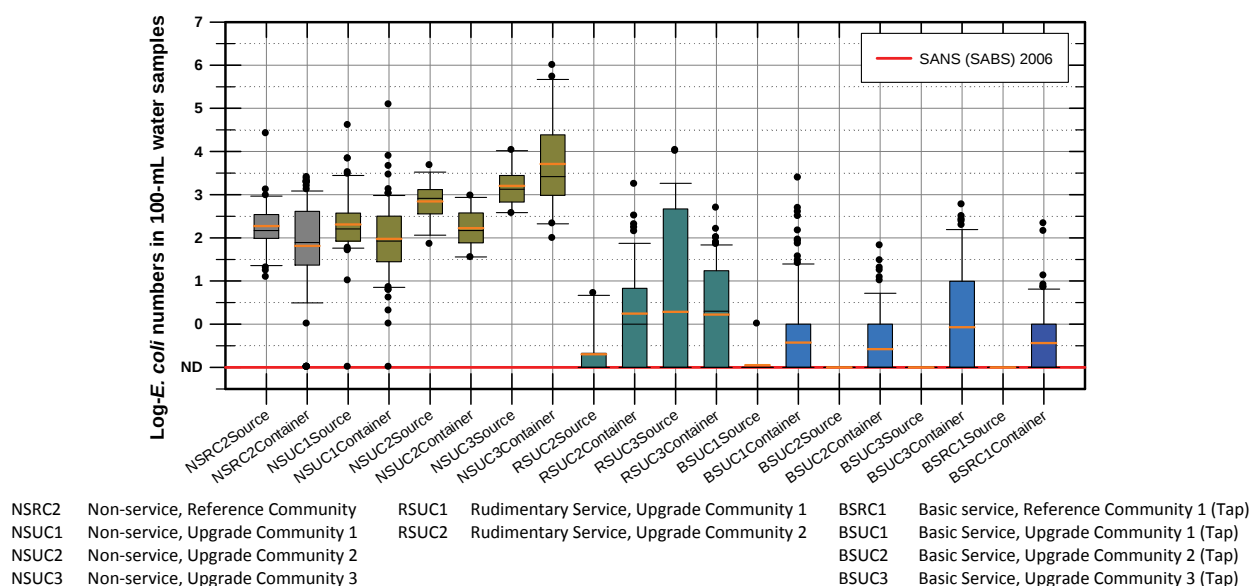


Figure 2.10: Health-related microbial quality of water sampled at the sources as well as from the related containers

The two communities that were provided a rudimentary service experienced a significant improvement in the source water of UC2 because of the groundwater access through handpump. However this access was only 83% of

the time (Table 2.8). The rest of the time the community sources water from the nearby river like they would do during the NS time, hence the failure of the source water to fully comply during the period of the study. For UC3 the source water result remained poor because of the 50:50 tanker water (good quality) and then river water (poor quality). In both cases the container water, although much improved from the quality in containers during the NS time, were still non-compliant because of the intermittent filling of the same containers with clean and contaminated water, thus “seeding” the container again with microbes that may grow in the container as was shown by Fosso et al. (2008; 2010).

The quality of water from the BS source points for all upgrade communities as well as Reference Community 1 was very good in terms of the health-related microbial quality. It complied with the SANS benchmark, as no *E. coli* were detected at the 95th percentile except for one data point in the source water for UC1 that had 1 *E. coli* per 100 mL in a set of 15 samples.

Figure 2.10 further shows the effect of the containers on the microbial quality of good quality source water. None of the container water data sets complied with the SANS or WHO codes as these waters all became excessively contaminated with indicator bacteria after sourcing by whatever means. UC3 was especially poor because of containers becoming contaminated when the households have to source contaminated river water for 42% of a year during the time of the study period.

The effects of these persistently higher levels of organisms are discussed in Chapter 3 in terms of the health risk it presented.

3.2 Technical assessment of the water supply systems

The purpose of doing the technical assessment presented here (on the basic water supply systems only) was because this is the sentinel system that the water service roll-out programme of the South African government provides for all areas where no water service exists or a rudimentary water supply service is being upgraded. It also formed the technical assessment backbone of the monitoring toolkit.

In the context of this report, the research was undertaken to provide data on the condition of the basic water supply services to support the overall water supply service assessment reported on in this chapter. The research also provided a handy tool that can be used by water service providers to do rapid assessments of the performances of small water supply systems in their domain.

The research was conducted on a variety of rural water supply systems in 14 rural community clusters (including the communities reported on in Section 3.1 of this chapter) in the Nwanedi River basin in the north-eastern parts of the Limpopo Province, South Africa. The research was conducted between July 2006 and October 2008. The detailed research reports, which include examples of how apply the various calculations can be found in the research reports referred to in Section 8 at the end of Chapter 1.

The typical rural small-community water supply systems assessed in this work were basic water supply systems as per the definition in Section 3.1 above. They draw source water from rivers, springs or drill-wells, supplying water to an elevated clean-water holding tank, from where a simple distribution system is fed. The systems terminated in a series of public standpipes.

3.2.1 Study areas

This particular part of the project was conducted in several rural community clusters in the Nwanedi River basin (Figure 1.2; Chapter 1). These supplies were assessed and reported on as part of the water service function assessment reported on in Section 3.2 of this chapter (above) and in particular, provided information on the availability function.

The study communities all had basic (piped) water supply systems, most of them built during the past decade. In the past, the Department of Water Affairs and Forestry was responsible for water supply in these parts but this responsibility was recently being transferred (this happened during the assessment period) to the local municipality, assisted by the district municipality. This period of transition, when new institutional structures were taking up new responsibilities, could have influenced the results of the assessment.

3.2.2 General requirements for technical assessment methods

The methods used in this component required three general requirements:

- Consistency and comparability. To make comparable assessments between many different systems scattered throughout a large and diverse country, it is important to eliminate subjectivity of the assessors as far as

possible. All observations, readings and impressions thus have to be quantitative and algorithmic for reduction to a set of comparable numbers.

- **Practicality.** The assessments must only rely on what can be measured on site. In practice, it is notoriously difficult to find, for example, reliable as-built drawings from regional offices, or historical sequences of water quality measurements from some remote central laboratory. Also, there is an almost complete lack of on-line data for flows and pressures.
- **Rapidity.** A field assessment must be done as rapidly as possible, to allow an observer to collect all the required field data in a single site visit.

It is obvious that an assessment will only provide a “snapshot” of the system at the time of the assessment. To assess the frequency and duration of supply failures, however, consumers have to be interviewed as well about the system functioning for the past two weeks. Multiple assessments would therefore have to be carried out if a more comprehensive picture is required of the system performance, say twelve months to represent a full year. There would be no other option but to conduct multiple site visits to capture extreme events such as the dry winter months when groundwater tables are likely to drop, or the summer vacation period when many migrant workers return to their home villages to put the water supply systems under additional strain.

It was therefore assumed that the supply area of a water supply system is homogeneous – if not, it will be necessary to split the supply area into subsections where land use, customer profiles and water point density, for example, are about the same.

The limited scope of the proposed assessment method prohibited detailed assessment in absolute terms. The primary power of the methods used here was in its ability to rank and compare the results from a number of different systems. The outcomes here can be used to guide authorities to those aspects of the systems which are performing poorly (e.g. water quality, or systems where the growth had outstripped the capacity of the system), but does not provide detailed solutions.

3.2.2.1 Selection of assessment criteria

A thorough review of the literature (Section 2 in this chapter) revealed a host of different criteria pertaining to small-community water supply systems. In this particular section the focus was on criteria obtained from *Technical guidelines for the development of water and sanitation infrastructure* by the Department of Water Affairs (2004). Many of these criteria rely heavily on detailed hydraulic analyses and are framed in such specific terms as the percentage of time that threshold pressure can be maintained, the number of nodes not reaching specified flows, etc. These criteria obviously do not apply to basic water supply systems with only a few standpipes. In the main, two criteria were found to be relevant, namely *reliability* and *durability* for a small community water system. These two criteria also form the backbone for the service function of “*availability*” discussed in Section 3.1 and thus provided data for the assessment of this service function.

Reliability of a basic small community water supply system generally encompasses the availability and distribution of water supplied, water usage restriction and pressure in the water main, as well as system failure in providing these services. A common measure of reliability is the probability of system failure, which could result from failure at source, failure during distribution, insufficient pressure, or failure of outlet hardware. Reliability as a single criterion was found to be too broad for the assessment of rural water supply systems. In these cases, it is important to also determine where along the supply chain the failure occurred, and how the reliability could be improved. It was necessary to split the broader concept of reliability into three more narrowly defined criteria, namely *availability*, *capacity* and *continuity*.

The concept of durability was captured as the better defined criterion of *condition*.

This technical assessment thus hinged on four criteria:

- **Availability** of a water source in terms of source water quality as well as source water quantity. Availability in the context of this particular assessment work was an adaptation of the *availability* discussed in Section 3.1 in that it would refer to the system’s ability to deliver the required quantity and quality of water and not the Q & Q required to protect human health – which is the focus of the availability discussed in Section 3.1. Hence this will be referred to as *system availability*.
- **Capacity** – refers to the system’s capacity to deliver the water from the source to the consumer;
- **Continuity** – refers to the system’s reliability to consistently deliver water over time;
- **Condition** – refers to diligent maintenance and repair of the system.

3.2.2.2 Selection and weighting of indicators

For each of the criteria, practical indicators were found which are quantifiable during a short site visit, requiring a minimum of prior knowledge. There is more than one indicator for each criterion, which requires weighting to combine them into a single index for each criterion. The ability to adjust the relative weight in this process is a feature which could make this assessment method useful for any other authority who could express their own performance priorities through appropriate weighting.

The indicators for each criterion, and their numerical manipulation, are covered further on when the criteria are discussed in more detail.

3.2.2.3 Water demand

A key parameter underpinning the entire procedure for technical assessment of system availability was the total water demand to be met by the system. It is necessary to identify the main components of water demand in rural context:

- Water losses from the distribution system, between the source and standpipes. This loss is relatively small, as network topologies in small rural systems are simple with little interlinking, pipe lengths are short, pipe diameters are small, and systems are built with robust pipe materials;
- Water lost because of leaks from the standpipe while it is not used;
- Water used at the standpipe. This consists of some direct drinking (a small component) and water used for washing laundry at the tap (a larger component). Many households rather carry the laundry for washing to the standpipe, rather than carrying the wash water to the home;
- Water spilled during the filling of containers due to the narrow opening of the plastic containers now almost in universal use, and spilling of the water while the container is carried or carted to the home;
- Water used from the containers in the home.

It should be noted that metering errors, an important consideration with conventional systems, are not relevant in the typical basic water supply systems established in rural communities as the basic monthly family allocation of 6 kilolitres is free and usually unmetered simply because all the basic rural small-community systems in South Africa start as a system with communal standpipes only. Some individual households may pay an extra fee to be provided with a metered yard tap for their exclusive use but even these would generally not be monitored (meter reading) under the free basic water system.

It is a common feature of many rural small-community water supply systems to supply water intermittently. Storage tanks are filled during the night, with the water supply to the households cut off. (This is to prevent the surreptitious use of water during the night for the watering of gardens, or leakage.) During the day, the water is turned on for a number of hours. Where capacity is adequate, the water is available during daylight hours, but where capacity is limited, the use is further restricted by only turning the water on for a few hours per day. In some cases, where communities have to pay for the diesel required for pumping, the hours are also restricted as a water, and thus diesel saving measure. Different communities have different arrangements. In a case where capacity was severely limiting, water was only turned on every second day, with the alternating day used for filling the storage tanks. Another community may choose not to have any water on Sundays, to allow their pump operator to have a day off.

A reasonable approach for estimating the total water demand is to use the design guidelines quoted above, and to use a single loss factor to account for all the loss components enumerated above. The demand estimate is thus given by:

$$Q_{demand} = \left[(N \cdot D)_{sp} + (N \cdot D)_{yc} + (N \cdot D)_{hc} \right] \cdot \eta$$

(WRC, 2012a; Rietveld et al., 2009)

During this investigation, in-depth effort was not made to obtain reliable estimates for the overall loss factor of all serviced communities in the area as a generic approximation of the loss factor was deemed sufficient. Using the largest community cluster of five villages (total of 900 households) in the area, a volumetric measurement of the daily water demand was made in the storage tank and compared with the measured per capita demand reported on in Section 3.1 above. This suggested a value of approximately 1.25 – a value used throughout this report.

3.2.3 The criteria

3.2.3.1 System availability

The system availability criterion for this technical assessment is used to answer the question: *Does the water supply system have an adequate water source?* System availability therefore pertains to the adequacy of the *source* in terms of *quantity* and *quality* of the water that can be obtained from it. It also refers to the systems' ability to deliver water hygienically clean water (based on system water quality indicators) to the consumer. It is assumed that availability will be reduced when either the required quantity cannot consistently be drawn from the source, or the water quality the system produces drops below the required standard for drinking water supply. The source can be a borehole, a spring or local storage dam, a water treatment facility or a connection to a larger regional network. The availability index is thus made up as a weighted average of quantity and quality sub-indices:

$$I_{av} = \alpha_1 \cdot I_{av,quant} + \alpha_2 \cdot I_{av,qual}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.1.1 System water quantity

The sub-index for water quantity is merely the ratio of the water volume that can be *supplied* to the water volume *demand*, with a maximum value of 1:

$$I_{av, quant} = \frac{V_{month} \cdot 1000}{30 \cdot Q_{demand}} \leq 1$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.1.2 System water quality

Comprehensive water quality assessment in remote rural areas is not possible due to the absence of reliable water quality records. Four readily measurable parameters were therefore selected for the sub-index for system water quality and the water tested at the communal taps to reflect the quality of the water the system is capable to deliver:

- pH to determine chemical stability and aesthetic quality of the water in the system;
- Electrical conductivity (EC) to detect excessive water brackishness (aesthetic quality);
- Turbidity (NTU) to detect hygienic water problems;
- Total coliforms (TC) are microbial indicators used to signal system (water) hygiene problems.

The first three can be rapidly measured on site, while the fourth requires a simple laboratory procedure. Total coliforms were measured with the *Quantitray* procedure (Described in Section 3.1 above).

For system water quality variables, authorities usually recognise two (sometimes three) limits. For our purposes, water quality at or better than the *ideal* limit would score 1. A water quality parameter worse than the "*absolute*" limit scored 0. Water quality between ideal and absolute would require interpolation between 1 and 0. Where an intermediate *suggested* limit is used, an appropriate index value has to be assigned to this limit. In this work intermediate limits were used in all cases and the index values at the intermediate value were assumed to be 0.5 for pH and EC, and 0.8 for TC and turbidity. Table 2.12 shows the values for the water quality variables upon which the sub-indices were based.

Table 2.12: Guidelines for water quality assessment (adapted from Water Research Commission, 1998)

Parameter	pH	Electrical conductivity	Turbidity	Total coliforms
Unit	(-)	(mS/m)	(NTU)	(#/100 ml)
Absolute lower limit	4.0	-	-	-
Suggested lower limit	4.5	-	-	-
Ideal lower limit	5.0	-	-	-
Ideal upper limit	9.5	70	0.1	0
Suggested upper limit	10.0	150	1	10
Absolute upper limit	10.5	370	20	100

The indices are thus calculated according to the following algorithm:

- Variable $\geq$ absolute upper limit: index = 0.0
- Variable $\leq$ ideal upper limit: index = 1.0
- Variable = suggested upper limit: index = 0.5
- Ideal < variable < suggested: interpolate between 1.0 and 0.5

- Suggested < variable < absolute: interpolate between 0.5 and 0.0

For pH, there are two sets of limits, both on the high and the low side. This requires interpolation when the variable pH exceeds either the higher or lower ideal limit.

For pH and electrical conductivity, *linear* interpolation is suggested, with the general form:

$$y = y_1 + \left(\frac{x - x_1}{x_2 - x_1} \right) (y_2 - y_1)$$

For total coliforms and turbidity, the limits follow an approximately exponential trend. In these cases, *logarithmic* interpolation is suggested, with the general form:

$$y = y_1 + \left(\frac{\ln x - \ln x_1}{\ln x_2 - \ln x_1} \right) (y_2 - y_1)$$

Once a sub-index for each water quality variable had been determined, they are weighted to obtain an overall quality sub-index:

$$I_{av,qual} = \varepsilon_1 \cdot I_{pH} + \varepsilon_2 \cdot I_{EC} + \varepsilon_3 \cdot I_{NTU} + \varepsilon_4 \cdot I_{TC}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.2 Capacity

Can enough water be transported from the source to the outlets (taps) and from there to the consumers (portable containers)? Capacity is the adequacy of the *water supply system* (including transport, storage and distribution to taps) to supply water to the community and finally carrying of water from tap to home by households, i.e. a secondary distribution by human water carriers. Inadequate capacity will typically arise when a village grows in size, per capita demand and population to the point where a previously large enough system will begin to fall behind the water demand. The capacity index is therefore based on four sub-indices, each dealing with a part of the water path from water source to the consumers' homes:

- From source to storage (bulk supply capacity);
- From the storage itself (storage capacity);
- From storage to standpipe (distribution capacity);
- From the standpipe to the home (human carrying capacity).

Once these four sub-indices have been quantified, they are combined by weighting to form an overall capacity index:

$$I_{cap} = \beta_1 \cdot I_{pump} + \beta_2 \cdot I_{res} + \beta_3 \cdot I_{wp,func} + \beta_4 \cdot I_{wp,dens}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.2.1 Bulk water supply capacity

Can enough water be transported from the source to the storage tank? This is quantified by comparing the pumping capacity to the average water demand:

$$I_{pump} = \frac{Q_{pump}}{Q_{demand}} \leq 1$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.2.2 Storage capacity

Is there adequate storage to balance differences between demand and pumping capacity, and to provide adequate reserve during interruptions in supply? This is quantified by comparing the actual storage capacity to a generally accepted design standard:

$$I_{res} = \frac{V_{res}}{Q_{demand} \cdot T_{res}} \leq 1$$

(WRC, 2012a; Rietveld et al., 2009)

The usual requirement for T_{res} in South Africa is 1 day (24 hours) for storage reservoirs fed by gravity, and 2 days (48 hours) for tanks supplied by pumping. For the borehole-supplied systems used in most parts of rural South Africa, the requirement for this work was therefore 2 days.

3.2.3.2.3 Distribution capacity

Can enough water be transported from the storage tank to the standpipes? This is quantified as the fraction of the taps on standpipes which meet a generally accepted minimum flow rate:

$$I_{wp, func} = \frac{N_{wp, good}}{N_{wp, total}} \leq 1$$

(WRC, 2012a; Rietveld et al., 2009)

The guideline used in South Africa is a minimum standpipe flow rate of 10 litres/minute (DWA, 2004). This is easily measured at each standpipe by timing the filling of a calibrated container.

3.2.3.2.4 Human carrying capacity

Are the standpipes close enough to the homes to allow sufficient water to be carried from the standpipe? The most exemplary water supply system would be of little benefit if the standpipes are too far away from some homes. The distance of water points from household is indirectly approximated by calculating an average water point density and relating that to what is minimally required:

$$I_{wp, dens} = \frac{\rho_{actual}}{\rho_{min}} \leq 1$$

(WRC, 2012a; Rietveld et al., 2009)

The South African guideline is phrased in terms of the maximum distance between a home and a public standpipe, set at 200 metres (DWA, 2004). The best theoretical coverage is obtained if the standpipes are arranged in a hexagonal pattern. For an infinitely large supply area, the required water point density to limit the maximum distance to 200 metres is 9.6 standpipes/km². For the more usual case where the standpipes are arranged in a square pattern, the theoretically required density is 12.5 standpipes/km². Given that many local constraints and finite village sizes make optimal coverage impossible, a minimum density of 15 standpipes/km² was assumed. To calculate the water point density, the limits of each village are readily delineated from aerial photographs or Google Earth. By approximating the boundaries with straight lines, the area is quickly determined. The numbers of water points are easily counted during the site visit.

3.2.3.3 Continuity

To what extent is the water supply periodically interrupted? Continuity is the consistency whereby water is conveyed from the source to the consumer. System failure can result from short interruptions (measured in hours) to prolonged periods (measured in days or even weeks). Both types lead to different types of undesirable effects. The South African national guidelines implicitly recognise this distinction by stating a limit of 7 days of total interruption per year, with no single interruption exceeding 48 hours (DWA, 2003). An interruption of more than 48 hours is a serious event which will force households to other, less suitable supplies. A short interruption was thus defined as one having a duration of less than 48 hours, while a long duration will exceed 48 hours. The continuity index has to take both short and long interruptions into account:

$$I_{cont} = \gamma_1 \cdot I_{short} + \gamma_2 \cdot I_{long}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.3.1 Short interruptions

Short interruptions typically occur during power outages, pipe bursts or broken taps. When villages have the ability to make own repairs, these problems are reported and often fixed within a few hours. During the site surveys, however, even these relatively small problems were found to drag on for days, weeks and even months due to a lack of spares, or lack of response from remote, centralised maintenance personnel. If the interruptions continue for only a few hours, households could ride out the interruption by using the water they have already stored in the home and no serious effects follow. What should the minimum period of supply be for any given day? This question depends heavily on the local water supply arrangements of each village, of which some examples were earlier noted in the section on “water demand and losses”. One solution is to estimate the number of hours per day with no supply when supply was expected by the households. The sub-index for short interruptions is thus quantified as:

$$I_{short} = \frac{T_{normal} - T_{non-supply}}{T_{normal}} \leq 1$$

(WRC, 2012a; Rietveld et al., 2009)

The required data has to be obtained by randomly interviewing some villagers. When the first three interviewees provide about the same information, it is accepted. If there are serious discrepancies, then more villagers have to be interviewed.

3.2.3.3.2 Long interruptions

Long interruptions of more than 48 hours typically follow from larger infrastructural failures, for example when pipeline crossings through rivers are washed away, boreholes dry up, fuel deliveries are disrupted, or when smaller problems escalate into long interruptions due to inefficient repair and maintenance procedures.

The effects of long interruptions are more serious. Households have to search for alternative water sources mostly questionable in terms of the water quality, or wait on water tankers to provide an intermittent, often unpredictable supply. Because the national guideline (no more than seven days of non-supply per year or 0.58 days/month) is a small number, an exponential relation has to be adopted, where the factor λ depends on the level of performance indication required. For this report, a value of $\lambda = 0.5$ was found to provide realistic values. The longer term interruptions are expressed as:

$$I_{long} = e^{-\lambda \cdot (N_d - N_{d,max})} \leq 1$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.4 Condition

Is the water supply infrastructure still in good shape? Previous work for this criterion included the concept of durability, expressed as the expected remaining lifetime of a system (Ashley et al., 2004). This is not considered to be useful for rural water supply systems, as the expected lifetime of a system is heavily dependent on the degree of use, the level of maintenance and the extent of vandalism. The preferred criterion is thus condition, which is the current status of the system in terms of its serviceability. For a water supply system, all the components (i.e. pipes, pumps, reservoir, standpipes, handpumps) must ideally be assessed to give an overall picture of the system condition.

A detailed examination of all elements of the water supply system would not have been practical. Therefore, the condition of the water outlet points (the taps on a communal standpipe, handpumps or water meters where present) was selected as an indicator for the condition of the system, assuming that a poorly maintained water point will probably indicate the same state of neglect of the other system components.

For rural systems, almost all the water points are taps on standpipes and the condition index has to be extracted from the standpipes only. Following a critical review of standpipe design and maintenance (Haarhoff and Rietveld, 2009), four readily observable indicators were identified:

- Condition of the tap(s) connected to the standpipe;
- Condition of the standpipe platform;
- Condition of the tap support;
- Presence and condition of secondary water connections.

The index for condition is obtained by weighting:

$$I_{cond} = \delta_1 \cdot I_{tap} + \delta_2 \cdot I_{platform} + \delta_3 \cdot I_{sup port} + \delta_4 \cdot I_{sec}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.4.1 Condition of taps

The taps used at public standpipes are subject to a high degree of wear and tear. The field surveys indicated that the average standpipe tap is opened and closed about 62,000 times per year. Given that the SANS (2006) standard specifies a minimum number of 200,000 actions under light torque per year, a tap of good quality will only last about three years. Taps must therefore be replaced much more frequently than the other hardware elements in the system. Moreover, the South African market is currently flooded with cheap, inferior imports which are indiscriminately purchased by ill-advised tender committees. These taps do not meet the required specifications and compound the need for regular and preventative tap replacement. The condition of a tap will be good and

serviceable if it is without excessive leakage, a broken handle or a bent spindle. The sub-index is simply the proportion of serviceable taps:

$$I_{tap} = \frac{N_{tap,good}}{N_{wp,total}}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.4.2 Condition of platforms

A serviceable standpipe platform is one that is large enough, sturdy and properly drained. It requires considerable effort by women and children to manoeuvre water containers of 20 to 25 kg and load them onto heads or a wheelbarrow. The presence of mud, puddles, bricks/stones or drainage upstands introduces the hazard of tripping, slipping or falling. The sub-index for platform condition is the proportion of serviceable platforms:

$$I_{platform} = \frac{N_{platform,good}}{N_{wp,total}}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.4.3 Condition of tap supports

Often taps are supported by flimsy steel spikes, or loosely tied to shrubs or trees. This makes the standpipe more vulnerable to damage, leakage or vandalism. The sub-index for tap supports is thus the proportion of taps with a proper, sturdy support:

$$I_{sup\ port} = \frac{N_{sup\ port,good}}{N_{wp,total}}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.3.4.4 Secondary connections

In almost all villages surveyed, it was prohibited to make hose-connections to the standpipes. The reasons were self-evident – the hoses make access to the standpipes more difficult to others, the connections were flimsy and mostly leaked profusely, and the water demand increased without compensation to the water authority. (A notable exception is to allow home builders to have a temporary hose connection while the home is being built.) Despite the prohibition, it is not uncommon to find some villages with rampant secondary connections. The presence of hose connections is thus considered as an indicator of how frequently and thoroughly the water system is patrolled and maintained. The sub-index for secondary connections measures the proportion of standpipes without illegal or home-made secondary hose connections:

$$I_{sec} = \frac{(1 - N_{sec,connect})}{N_{wp,total}}$$

(WRC, 2012a; Rietveld et al., 2009)

3.2.4 Summary of requirements and interpretation of technical assessment data

To translate the assessments numbers back into categories for easy comparison and interpretation amongst different locations, a three-tier bench-marking scheme (unacceptable, sufficient, good) was applied, for all the study villages, on the averages of each score. The respective 95% confidence intervals were used as an indication of what can generally be expected of these systems under similar conditions elsewhere. The following were the cut-off values: *Critical* ($0.0 < I < 0.5$); *Sufficient* ($0.5 < I < 0.75$); *Good/compliant* ($0.75 < I < 1.0$). Having defined the assessment criteria and having picked appropriate indicators, all the data requirements are now known and summarised in Table 2.13.

Table 2.13: Data requirements for technical assessment

Parameter	Note on measuring
Number of standpipes	Count during field visit
Number of yard connections	Ask water supply authority
Number of house connections	Ask water supply authority
Population served by each	Determine number of persons per household from demographic data. Count households on site or from aerial photographs.
Water loss adjustment factor	Use preliminary 1.25 to account for spillage and washing of laundry
Source capacity	Use pump capacity or treatment capacity for ground- or surface water
Water quality parameters	Measure on site and laboratory
Supply capacity	Check pump rating or do volumetric test
Storage volume	Measure on site
Water point density	Measure town area from maps or photographs
Water flow rate at standpipes	Measure with bucket and stopwatch
Time without supply	Ask consumers
Standpipe condition	Score on site, photograph for later verification

3.2.5 Results and discussions

The detailed assessment of the results and their discussion can be perused in the research report as indicated in Section 8 of the Introduction chapter. Of the 15 villages assessed, 9 were also assessed (overlapped) for all the other criteria in the other concurrent research activities. To ensure uniform reporting on the same villages, results from only these 9 villages are reported

3.2.5.1 System availability

The measurement of the source capacity turned out to be more difficult than anticipated. In almost all cases, there were little or no indication of the installed pumping capacity – the borehole pumps were devoid of the usual industrial labelling indicating their duty points. There was very little installed instrumentation (pressure gauges and flow meters) and where it was found, it was not working. But in all fairness, even if the installed pumping capacity could be determined, it would be impossible to assess the sustained geo-hydrological capacity of the boreholes without geo-hydrological assessment. Such an assessment would be beyond the reach of a rapid assessment as was the requirement for this project. Rather than trying measure the pumping capacity, the field workers only determined whether the pump, if it was working properly, could supply adequate water to the village. If it could, the pump capacity was set equal to the estimated water demand, thus forcing the sub-index for quantity to unity.

Of the 9 communities assessed, all the sources could supply enough water at the time of the assessment.

Overall the water quality was not compliant in 13 of the 14 communities with the index at the “critical” level. For the 9 communities reported here, the situation was the same with the mean index value at 0.46 (0.52 at the upper level of the 95% confidence interval). The components of the sub-index show that this is primarily due to poor microbiological quality (0.07 and 0.18). Microbiological quality can be relatively easily fixed by heavier and more frequent disinfection, i.e. chlorination.

3.2.5.2 Capacity

The systems’ capacity throughout was sufficient to good. The exceptions were one case where storage was inadequate and four cases where the water point density was inadequate. In the latter cases, it was due to growth of the villages beyond the original borders, without a concomitant increase in new standpipes.

3.2.5.3 Continuity

In the cases where the continuity was not good, it was due to interruptions longer than 48 hours, which could have serious health and other social consequences as the households had to use alternative (and hygienically unsafe) sources. From additional evidence collected qualitatively from the households, the problem predominantly appeared to be poorly managed repair and maintenance procedures. Practically all the maintenance and repair is centralised at the local municipality headquarters, with long response times. Even relatively trivial failures, easily fixed locally if the community was empowered to do so, dragged on to become unacceptably long interruptions.

A lack of continuity can generally be ascribed to insufficient maintenance and support systems. Once systems are built, practical procedures should be in place for rapid reporting of interruptions, availability of spare parts and

qualified maintenance personnel, and their rapid deployment to get the problem fixed. Problems with inadequate continuity will therefore require more attention to, and funding for repairs and maintenance.

3.2.5.4 Condition

Overall the condition of the public standpipes was good in only three of the 14 systems, which is disturbing for relatively new systems. Where these systems failed, it was either due to many poor and illegal secondary connections, or missing or damaged platforms. It appeared that the original standpipes of the systems, as they were constructed by a contractor subject to proper supervision and project management, were quite good. Where newer standpipes were installed where older ones failed, or where distribution systems were extended to supply newly developed areas, the standpipes are little more than a piece of pipe tied to a tree or simply sticking out of the ground without a proper support or a platform.

Once again, this points to a lack of discipline, skills, materials and quality control by the municipal authorities.

4 SUMMARY AND CONCLUSION OF THE WATER SUPPLY SERVICE ASSESSMENT

It is evident from the results of this chapter that, while adherence to technical design standards appear to be adequate, much more attention must be directed to improve maintenance and operation by the service providers. Unless better resources, training, discipline and accountability are provided, the current investment in rural water supply systems will only provide temporary relief, as the systems will remain unsustainable.

The research methods used to assess the function changes are extensive and while reflecting the general conditions that might prevail in similar situations elsewhere in the country, will be difficult to be replicated by water service providers. On the other hand, the methodology that was used to assess the technical conditions of the systems proved to be a simple, rapid benchmarking tool for the research teams, and would no doubt be as such for water supply authorities responsible for rural water supply systems. It also provided a major building block for the total toolset developed for this project.

Both assessments (Sections 3.1 and 3.2) generated sufficient data for construction of the final set of benchmarks to be used in the total toolset. These benchmarks are shown in Table 2.14. The next sections summarise all the values and numbers from Table 2.14, reflecting the function changes for the three levels of service (BS, RS and NS) for the five community clusters (UC1, UC2, UC3, RC1 and RC2). These values were used in the effect assessment discussed in Chapter 3, and finally the impact assessment in Chapter 4 and were used in the final design of the total tool (Chapter 5).

To translate the assessment values back into categories for easy comparison and interpretation amongst different locations, a four-tier bench-marking scheme (*good, compliant, non-compliant* and *critical*) was used. Colour coding with the numbering makes it easy to see the status of the function criteria, i.e. Good = 0; Compliant = 1, Non-compliant = 2 and Critical = 3.

The function data as well as the technical water system condition data first had to be aligned before the final results of the indicators measurements could be construed. The four technical assessment criteria are aligned with the three function criteria as shown in Table 2.14. The final data summaries related to the indicators are shown in Appendix A.

The benchmarks in Table 2.14, as well as the data summaries shown in Appendix A are based on categorised (0-1 from the technical assessment) as well as numerical data from the function assessment. The sections following the table provide summaries from the data in Appendix A.

Table 2.14: Benchmarks for the function performances as determined by the research findings in this study

Function	Indicator	Criteria	Performance			
			Good (0)	Compliant (1)	Non-compliant (2)	Critical (3)
Access	Water point density	Distance in metres from home to water source point	≤10	>10≤200	>200	>500
		Points per km ²	>25	≥15	<15≥5	<5
		Households per point (assuming 6 per household)	≤20	≤40	>40≤80	>80
		Capita per water point	≤100	≤250	>250≤500	>500
	Sourcing technology	Tap and platform condition	1	<1≥0.75	<0.75≥0.5	<0.5
Availability	Capacity of system	Meeting water demand	1	<1≥0.75	<0.75≥0.5	<0.5
	Continuity	Long interruptions	1	<1≥0.75	<0.75≥0.5	<0.5
		Short interruptions	1	<1≥0.75	<0.75≥0.5	<0.5
	Flow rate	Flow rate of taps/fill rate of containers in ℓ/min	20	≥10	<10≥7	<7
Potability	Supply hazard	Source point <i>E. coli</i> : Org/100 mL @ n th %tile	ND (100)	ND (95)	≤0 (95)	>0 (95)
		Containers <i>E. coli</i> : Org/100 mL @ n th %tile	ND (100)	ND (95)	≤0 (95)	>0 (95)
	Supply hygiene	Source point Total coliforms: Org/100 mL @ n th %tile	ND (100)	≤10	≤100	>100
		Source point Turbidity NTU/ℓ @ 95 th %tile	1	<1≥0.75	<0.75≥0.5	<0.5
	Supply aesthetic quality	pH scale @ 95 th %tile	1	<1≥0.75	<0.75≥0.5	<0.5
		Conductivity mS/m @ 95 th %tile	1	<1≥0.75	<0.75≥0.5	<0.5

4.1 Access

An important change brought about by changing (improving) access was the *distance* (in metres) from the house to the source point (point on river bank, handpump or tap). The distance had several effects on the function of access, its main effect being on the household's time, which had a beneficial economic impact for the household as will be discussed in Chapters 3 and 4. Another effect was the relief that households had experienced because of the shorter distances meaning less of the toil of water carrying which is discussed in Chapter 3.

Measuring the time:distance continuum provided the rates of travel (metres per second) by a household water collector, and will be used in the monitoring tool (Chapter 5). Distance also provided a measure of policy compliance, since the South African requirement (DWA, 2003) is that a source point (tap) should be no further than 200 metres from a house for a basic water supply service. At its most basic, the distance from house to tap before and after the intervention is a robust measure of "it is closer to the home". Table 2.15 shows the reductions in distance that were effected where communities received a basic service followed by (for some) an upgrade to a rudimentary service and then an upgraded service (the study intervention) sometime later.

The communities that initially received rudimentary services were brought substantial relief of the distances they had to traverse to collect their water. The final upgrade to the basic service brought more relief for those on rudimentary services and even greater relief to those were still on the open sources. How this affected the time that it took to collect water is discussed in Chapter 3.

Table 2.15: Changes brought about by improved *access* to a small community water supply service

Parameter	RC1	UC1		UC2			UC3			RC2
	BS	NS	BS	NS	RS	BS	NS	RS	BS	NS
Distance to source point	1	3	1	2	2	1	3	1	1	2
Water point per km ²	1	3	1	2	2	0	2	1	0	3
Households per water point	0	2	0	1	1	1	1	0	0	0
Capita per water point	0	2	1	1	1	1	1	0	0	0
Tap and platform condition	2	3	2	3	3	1	3	3	1	3

RC1 = Reference Community 1; RC2 = Reference community 2; UC1 = Upgrade Community 1; UC2 = Upgrade Community 2; UC3 = Upgrade Community 3; BS = Basic service; RS = Rudimentary service; NS = Non-service – using open sources

The second major criterion for access was *source point density*. Here the intervention towards the basic service contributed to the numbers of households per source point being reduced substantially as well as the numbers of points per km² increased.

The *source point condition* was only good for the taps and their platforms two of the new systems of UC2 and UC3. The older systems of the RC1 and UC1 were already falling in disrepair but it was still more convenient to source water at these than at the source points during the periods of no service and rudimentary service.

4.2 Availability

Availability in the context of function means a continual water supply at the source. The combined results are shown here in Table 2.16. The results show that all the sources had the capacity to provide water for their respective communities regardless of the level of the service. All the systems were operated on a community level arrangement of pumping hours to lessen the pressure on the operator and the system. These self-arranged interruptions meant that water was not available for 24/7 as is the intention in the guidelines. The daily availability was calculated at 10 hours per day deemed as good as 24 hours per day.

Table 2.16: Changes brought about by improved *availability* of water supplied by a small community water supply service

Parameter	RC1		UC1		UC2		UC3			RC2	
	BS	NS	BS	NS	RS	BS	NS	RS	BS	NS	NS
Capacity of system to meeting demand	0	0	0	0	0	0	0	0	0	0	0
Long interruptions	2	0	2	0	1	2	0	3	3	3	0
Short interruptions	2	0	2	0	1	2	0	3	3	3	0
Flow rate of taps/fill rate of containers in ℓ/min	0	1	0	1	3	0	1	3	0	0	1

RC1 = Reference Community 1; RC2 = Reference community 2; UC1 = Upgrade Community 1; UC2 = Upgrade Community 2; UC3 = Upgrade Community 3; BS = Basic service; RS = Rudimentary service; NS = Non-service – using open sources

Ironically, the continuity of the sources during the no service period scores top marks as these sources did not falter. Once technology and its operations and maintenance was introduced and the water made more accessible, the continuity faltered because of the systems being unreliable often leading to long interruptions. UC3 was particularly disadvantaged because their new basic supply service was as unreliable as their rudimentary service prior to the intervention. A plus was that when the water was available, the pressurised basic system supply would have a good flow rate, which did contribute to reducing total water collection time as well be shown in Chapter 3.

The combination of reduced distance to as well as sustainable capacity, increased flow rate and constant availability of the water at the source point created the expectation that households would increase their per capita daily water demand. This turned out to be not the case as will be shown when the effects on the family household water demand are discussed in Chapter 3.

4.3 Potability

Potability in the context of this work refers mainly to two major aspects of the quality of water that humans may drink. These are shown in Table 2.17. First there was the health-related microbial quality (based on *E. coli* indicator organisms) of the water available at the source and the extent to which these might impact on the health, social and economic condition of the recipient community. How the changes in this particular water quality type affected the users are discussed in Chapter 3. Then there is the quality parameters used to assess the sanitary and hygiene condition of the system and finally the aesthetic quality of the water delivered from the three source point components, which are dealt with in the system assessment work discussed in Section 3.2 above.

The various waters, in terms of pH, conductivity and turbidity, were about 90% compliant to the South African National Standards for Drinking Water Quality (SABS, 2006). However, the hygienic quality of the water delivered by the systems and measured by the occurrence of total coliforms, was substantially non-compliant at 90% for the rudimentary upgraded systems and 100% for the open sources.

Table 2.17: Changes brought about by improved *potability* of water supplied by small community water supply services

Parameter	RC1		UC1		UC2		UC3		RC2	
	BS	NS	BS	NS	RS	BS	NS	RS	BS	NS
Supply hazard condition at source point/tap: <i>E. coli</i> 100 mℓ	0	3	0	3	1	0	3	3	0	3
Container hazard: <i>E. coli</i> 100 mℓ	3	3	3	3	3	3	3	3	3	3
System hygiene condition/at source point/tap: Total coliforms/100 mℓ	3	3	3	3	3	3	3	3	2	3
System hygiene condition at source point tap: Turbidity as NTU/ℓ	0	3	0	3	2	0	2	2	0	3
Aesthetic water quality at source point/tap: pH	0	1	0	0	0	0	0	0	0	0
Aesthetic water quality at source point/tap: Conductivity	0	1	0	0	0	0	0	0	0	0

RC1 = Reference Community 1; RC2 = Reference community 2; UC1 = Upgrade Community 1; UC2 = Upgrade Community 2; UC3 = Upgrade Community 3; BS = Basic service; RS = Rudimentary service; NS = Non-service – using open sources

It is clear that, except of pH and electrical conductivity, the water collected at the open source points did not comply to the benchmarks adopted for this work, with the worst quality measured at the unprotected source points. The quality of the water taken from closed (groundwater and tanked) sources complied with the guidelines and standards at the source but the use of containers led to recontamination causing increased numbers of

indicator bacteria. Even though the supply waters of the basic services was significantly less contaminated, the health-related quality, as based on numbers of *E. coli* in the water in containers, did not comply by a wide margin.

What remains to be answered is whether this had any effect in terms of risk (discussed in Chapter 3) and eventually in reduced detrimental health impact, i.e. reduced diarrhoea (discussed in Chapter 4) in the recipient communities

Chapter 3

The effects of changes in the water supply services

1 INTRODUCTION

Chapter 2 show that households benefitted from improved access because of shorter distances to increased numbers of efficient source points (taps) in their area. Improved availability also offered benefit in that it reduced waiting times at the source points as well as made water more available over planned period of time. All these improvements should essentially free up more time for the family to use more productively (Cameron et al., 2011) as well as lessen the toil and injury risk that is associated with the carrying of heavy water filled containers from source point to home (Geere et al., 2010b). This chapter discusses these anticipated effects and its implications for impact (Chapter 4) on the health, sociology and economy (HSE) of the household.

The effect of improved accessibility and availability of supply water on the quantities of water that households collect is also discussed. More water collected per individual per day in households would be taken as a marker of increased potential of improved hygiene both personal and within the home.

Finally the effect of providing more water that is wholly potable will be discussed. From Chapter 2 it was clear that the microbial quality of water at the source improved significantly with system upgrades and complied with drinking water standards. However, with the use of containers to fetch water from the taps and store it at home while being used, this good quality water becomes contaminated and ends up not complying with health-related water quality standards and guidelines. How this affected the risk of infection that might lead to disease was assessed using a quantitative microbial risk assessment approach, the results of which will also be discussed in this chapter.

To provide a measure of this risk that makes economic sense, the effect of the improved services (including a potential reduction in the risk of infection) on the incidence of diarrhoea in the study communities will also be discussed in Chapter 4.

Methods (tools) were developed and applied for the effect-assessment activities (measuring collection times, individual water quantity, risk of disability as well as risk of infection) reported in this chapter. The detailed descriptions of these subsets of methods and their applications can be found in the detailed research reports on this work which are on the sites as indicated in Section 8: Chapter 1.

1.1 Aim

The changes brought about by the water service interventions were to be described in terms of selected effects, which are then used for assessing the health, sociologic and economic impact as discussed in Chapter 4.

1.2 Objectives

To describe the effect of changes (improvements) of:

- Access and availability on water collection time;
- Access and availability on quantities of water collected per person per day, i.e. the individual water demand;
- Access and availability on the risk of disability due to the carrying containers filled with water;
- Potability on the risk of microbial infection per person.

2 COMPONENT REVIEW

2.1 Water collection time

Although a major drive in providing safe water supply is to improve health (Hunter et al., 2009), it would seem that the benefit to health is often as foremost in the minds of recipient communities as are the savings in time and effort required to collect water (Cairncross and Valdmanis, 2006). This is, considering that households can spend between two and five hours collecting water every day and that the majority of those collecting the water being women and children (Water Supply and Sanitation Collaborative Council, 2006).

Hemson (2007) found that for children in the Limpopo and KwaZulu-Natal provinces in South Africa, of the time per week spent on domestic activities, two thirds of that time were spent on collecting water. Results of the study

showed that those who collected water for longer hours than the average often arrived at school late, had concentration problems in class and had to leave school early to again collect water.

Respondents in a study by Were et al. (2006) said that they used the time saved by improved water supply to work on the farm, clean themselves and the compound, attend women's meetings and trade in the market. For school-going children, girls especially, the time saved can be used for better school attendance (Haller et al., 2007). In some instances, the time saved may not be used for anything economically productive, but simply relieves households from the drudgery from collecting and carrying water, giving more time for leisure (Water Supply and Sanitation Collaborative Council, 2006). The toil of water collection can be extensive; 96% of respondents in a survey on water collection reported sore necks and backs from water carrying (Hemson, 2007).

Cairncross and Valdmanis (2006) state that remarkably little is known about the time spent collecting water by an individual or collectively the household in settings where people do not have on-site water supply. Assessment of the time spent collecting water requires measurement of the various components that make up the total water collection time, such time to walk to the source (trip time), queuing and filling time at the source, and time to walk back to the household under the loaded container.

The various components of water collection time are discussed below.

2.1.1 Trip time

This is the time taken to walk to a water point and is closely related to the distance. The time taken to walk back to the household is also related to the distance, but it is likely that people would walk back slower from the source because of the loaded container that they would be carrying (Howard and Bartram, 2003).

2.1.2 Filling (abstraction time)

Once at the source, the time taken to abstract or fill containers is another important consideration. According to the Sphere Project (2005), filling up a 20-litre container should take a maximum of three minutes. However, this might vary widely according to the circumstances.

2.1.3 Extra time

Assessment of water collection time should also take into account other intermittencies that take time such as waiting/queuing at the source (Devi and Boeston, 2009). Queuing often results from low water point densities (number of water points per square kilometre or per number of people), as well as breakdowns leaving a limited number of water points operational (Jabu, 2005). The study by Jabu found that one in three women in rural Malawi by-passed functional boreholes and went to a river because of congestion at the source and consequently the time required to queue. Thompson et al. (2000) found that in areas where households previously used open sources and later had single point sources such communal taps, the water collection time increased by an hour. This was largely attributed to the time spent queuing at the tap for a turn to fill containers with water.

2.1.4 Total collection time

Theoretically, the water collection time is closely related to the distance to the water point (Thompson et al., 2000). However, water collection itself includes intermittences such as those described above, which must be accounted for in the assessment of total water collection time (Devi and Boeston, 2009). Whilst adding up the various components would give a fair idea of the amount of time spent collecting water, it must also be borne in mind that this is usually reported for a typical trip that an individual water carrier would undertake. Most often several trips to the water points may be required to meet the households' daily water needs.

2.1.5 Measuring water collection time

A number of studies report on interviews with respondents on the time they spend collecting water. In most studies, women or other matriarchs in the households are interviewed as they often bear the responsibility of collecting water (Cairncross and Valdmanis, 2006). Deshpande et al. (2007) based their water collection time data on self-reports by households. However, this method can undermine the reliability of the data in that respondents might not necessarily know exactly how much time they spend collecting water, or might even distort the data (Devi and Bostoen, 2009). Were et al. (2006) reported large over-estimates when respondents were asked about the amount of time they spent on water collection. A possible explanation was that because most rural women did not wear watches, they may not have had a clear sense of time.

An alternative approach is to walk with the household members to the source and back and time the whole water collection period (Hemson, 2007), which was the approach eventually adopted by Were et al. (2006). Whereas timing participants throughout all the trips made to water source point might provide much accuracy, it is not always practical. Participants could be timed once, and the rest of the collect time estimated from the number of containers (and consequently trips) required to meet the household's water demands (La Frenniere, 2009), which was the basic method adapted and used for this study.

2.2 Increased daily water quantities

Several studies reported reductions in exposure to diarrhoeal pathogens and reduced incidence of diarrhoea as some of the benefits of increased water quantity (Montgomery and Elimelech, 2007; Bartlett, 2005). A meta-analysis of studies on water supply and diarrhoea showed that combined water supply interventions reduced diarrhoeal disease by 22% (Fewtrell et al., 2005).

However, Zwane and Kremer (2007) argue that the little evidence that exists of the effectiveness of providing communal rural water infrastructure is methodologically flawed. Reasons were that the studies were conducted in ways that made it difficult to disentangle the impact of water provision from sanitation provision, communities were not randomly assigned, and data were from only a limited number of sites.

Some of the outcomes from increased water quantities used by households were not as tangible or direct as reduction in diarrhoea episodes (Hutton et al., 2007), but are inarguably of health or hygiene significance. For instance, in the study by Were et al. (2006), women reported that they washed their clothes more, bathed more often and washed utensils more. These hygiene related activities can all have a health benefit such as reduced disease incidence.

Another major outcome related to increased quantity of water is the savings in time (reviewed in the section above). The time savings do not result directly from the increased quantity, but from the improved supply which allows for greater quantities to be collected within a shorter length of time.

Makoni et al. (2004), reported that where water points were more accessible, the sourcing more reliable and an excess in the available quantity of water, households are more likely to use water for productive purposes such as gardening and brick-making, as opposed to collecting water merely for survival. These productive activities from water are possible when there is also time available to do so.

2.2.1 Defining domestic water quantities

The definition of "domestic water" varies with the socio-economic-status of the community under consideration, or at least the purpose for which the water supply service is provided. For a typical urban community, household water may include water required for amenities such as gardening and sanitation (Ntshingila, 2006), apart from other needs such as drinking and cooking. This refers to their household water demand. Results from a benchmarking study in the Western Cape, South Africa showed that urban communities required daily per capita averages of up to 201 litres (Du Plessis, 2007).

For rural communities however, a more stringent definition of domestic water exists; defining it as the basic water supply needed for direct consumption, preparation of food and personal hygiene (Republic of South Africa, 1994), in other words, their daily domestic use. This is similar to the WHO definition as quoted by Howard and Bartram (2003) which states that domestic water is "water used for all usual domestic purposes including consumption, bathing and food preparation".

2.2.2 Water quantity for an individual

There are various factors associated with the daily quantity of water that people use. Amongst these, cultural habits, socio-economic status and standard of living, hygiene awareness, productive uses charges for water and the quality of the water as experienced by the user (Keshavarzi et al., 2006).

Results of the repeat of the Drawers of Water study (Thompson et al., 2000), showed that households with piped water used up to three times more water than those without piped water. In that particular study, household size, the level of maintenance of water supply systems and level of education were also associated with water quantities used. Keshavarzi et al. (2006) also reported that higher levels of education were related to increased demand for water for hygiene purposes.

25 ℓcd (litre per capita per day) is specified as the minimum quantity of water to be supplied under the basic level of service to households (DWA, 2003). This posed several questions (answers attempted in the following sections) such as what is meant by domestic household water and how much is basic?

2.2.2.1 What is ‘basic’?

In a study on the patterns of domestic water use in rural Zimbabwe, Makoni et al. (2004) referred to ‘basic’ water as the amount needed for drinking, cooking, personal hygiene and household cleaning. The White Paper on Water Supply and Sanitation Policy (RSA, 1994) defined basic as meant for “...direct consumption, for the preparation of food and for personal hygiene...”

2.2.2.2 Is ‘basic’ enough?

The 25 ℓcd currently provided at the basic level of service in South Africa has been debated, with 50 ℓcd seemingly the more preferred minimum (Bond, 2002; Moriarty and Butterworth, 2003). Tissington et al. (2008) as well as Moriarty and Butterworth (2003) both cited a document by Gleick (1999) in their assertion of 50 ℓcd as an acceptable minimum. The 25 ℓcd versus 50 ℓcd debate is supported by the WHO document by Howard and Bartram (2003) in which an average of 20 ℓcd represented a high level of health concern, whereas an average of 50 ℓcd represented a low level of health concern. Table 3.1 summarises the minimum requirement for water needs as recommended by Gleick (1999).

Table 3.1: Recommended litres per capita per day basic water requirements for human needs (Gleick, 1999)

Purpose	Recommended requirement (ℓcd)
Drinking water	5
Sanitation services	20
Bathing	15
Food preparation	10

It could be argued that the recommended quantities might differ amongst populations. For instance, Mokoena (2009) reported unheated (drinking directly from the supply as is) drinking water quantities of 1.26 ℓcd in this same study area, whereas Table 3.1 suggests 5 litres as the ideal quantity – even halving this 5-ℓ for unheated water will not turn out to be as low.

Makoni et al. (2004) demonstrated that the prioritisation of water use followed a pattern influenced by factors such as access and reliability. Survival and hygiene were the main priorities, as respondents ranked drinking and washing as most important. However, where there was excess and reliability of the water supply the productive use of water became more prominent.

2.3 Risk of musculo-skeletal disorder

It is likely that the health impacts and costs of sub-optimal water supply are frequently underestimated, because effects other than acute diarrhoeal illness are not usually considered (Prüss-Ustun et al., 2008). The health impact of various interventions to improve access to safe water has been extensively reviewed, but primarily focusing on rates of acute infectious diarrhoeal illness to evaluate outcome (Haller et al., 2007; Gundry et al., 2004).

This part of the work is about setting an effect-base for coding and mapping people’s perceptions of the relationship between DWC and health. Not assessing potential chronic health impacts such as those that can be caused by carrying heavy loads of water for domestic use may lead to underestimates of costs and benefits of the investments intended to improve safe water access. Comprehensive understanding of both beneficial and detrimental health impacts of water supply service interventions is crucial for appropriate water resource development and management towards improving access (Bartram et al., 2005).

Domestic water carrying (DWC) is defined in this study as any method of collecting and transporting water, on or by a person over distance for domestic use, from a source outside of the home. The World Health Organisation defines ‘domestic water’ as that ‘used for all usual domestic purposes’, categorized variously as: water use for consumption, hygiene and amenity use (Howard and Bartram, 2003). In African countries water use for domestic activities such as animal watering, construction and gardening should also be considered (Thompson et al., 2000).

The health impacts of DWC appear not to have been researched, neither frequently or intensively. Ferguson (1986) suggested that women are subject to high physical stress when carrying heavy water loads. DWC may also have complex health consequences that may be related to exposure to environmental hazards (Briggs, 2003), the physical effects of manually handling, lifting and carrying loads (Joosab et al., 1994; Jager et al., 1997; Levy, 1968), increased risk of physical abuse (Chan, 2007), loss of time for income generating activities and education (Haller et

al., 2007) or positive engagement with culturally appropriate roles (Leavit, 1999). As the health impacts of DWC may be wide ranging and complex, a broad conceptualisation of 'health', functioning and disability was required to fully appreciate how DWC might impact upon the health of different individuals.

The International Classification of Functioning, Disability and Health (ICF) categorizes functioning in relation to health at the levels of body structure and physiological function, engagement with activities and social participation (ICF, S.A). It incorporates environmental factors and provides a coherent view of different perspectives of functioning and disability in relation to health and a common language through which to communicate ideas. The ICF is legally binding as an information standard and has been ratified by 192 countries worldwide. Coding and mapping people's perceptions of the relationship between DWC and health to ICF categories (as was done in this component of the project) is therefore a potentially useful strategy to clearly identify and communicate the health domains which are potentially affected by DWC.

The communities studied for this report have high levels of poverty in some areas (Hope, 2003) where DWC and suboptimal water supply may have detrimental effects that can impact on health. However, it should not be assumed that the upgrading of water supply systems and the resultant improvement in their functions necessarily translates into sustainable reduction in the physical burden of DWC. For example, in East Africa various factors, such as poor system maintenance and stress on infrastructure due to population growth, affected the outcomes of water interventions over time, such that expected benefits may not be realised (Thompson et al., 2000). Appropriate assessment methods (or measurement tools) were not readily available to evaluate whether the interventions effectively and sufficiently reduced the physical burden of DWC.

The aim of this component of the project was therefore to assess whether improved water service functions had an effect in terms of the risk of disability posed by carrying containers filled with water. Because very little is known about the actual health impacts of DWC, this objective was pursued in four objective steps namely:

- Review local and international literature to establish whether appropriate risk assessment (or health outcome measurement) tools currently exist to measure the effects typically anticipated from domestic water carrying;
- To identify variables that should be measured to investigate the risk and/or health impact of DWC;
- Using the variables, develop and pilot a robust provisional method for assessing the risk/health impact of DWC;
- Judge from the pilot study results, what conclusions could be made from the risk of disability posed by DWC, and if feasible, factor this into the impact assessment discussed in Chapter 4.

2.4 Risk of infection

Momba et al. reported in 2002 that almost 30% of the South African population do not have access to an adequate supply of potable water. Many communities use raw water from surface and groundwater for drinking (Venter, 2001). Contamination of stored water in developing countries, like South Africa, is an issue because of the risk of infection it may pose (Steyn et al., 2004).

Because drinking water was still collected and stored in household containers in many areas where water supply systems have been established, the water quality deteriorates in the household due to extra-supply contamination in household containers that are used to collect water from improved (taps) and non-improved sources. This is because of micro-organisms in biofilms attached on the surfaces of container side-walls (Jagals et al., 2003; Momba et al., 2002). This leads to the health-related microbial quality of water stored in the containers being poor often after being sourced from a good quality supply at the tap.

While the project is about whether an impact is made by improving water service functions, this sections deals with the effect of in-container water quality and the risk it poses, despite clean water being provided at the tap.

2.4.1 Container water quality

Containers in the context of this project refer to water vessels used to collect water from sources and store it in the household. There are varieties of different water containers used for this depending on the area. In the rural areas of South Africa, many households use polyethylene and galvanized steel containers for the storage of drinking water (Momba et al., 2002). Most people in the study area used plastic containers.

In many developing areas, studies have shown that collecting water from communal taps, as well as storing it in and the handling of the containers at home cause quality deterioration (Jagals et al., 1997 and 2004; Jensen et al., 2002; Gundry et al., 2004; Wright et al., 2004; Trevett et al., 2005) and poses potential risks of infection to consumers (Jagals et al., 1999; Medical Research Council, 1999). Pathogenic micro-organisms can be introduced to stored water by handling containers with contaminated hands at home (Joubert et al., 2003).

The research done in this project examines to what extent container drinking water sourced from the various selected supply systems were contaminated up to the point of human consumption. For this a quantitative microbial risk assessment technique has been used to assess this risk posed by the container drinking water to an individual per year *before* (no service) and *after* (basic service) intervention.

2.4.2 Quantitative microbial risk assessment

Quantitative microbial risk assessment (QMRA) is a tool that can be used to assess in an individual or a larger population, the risk of infection by microbes in drinking water (OECD/WHO, 2003). It can therefore also be used to answer questions about shifts in the risk caused by intervention such as establishing basic water supply systems in an area where there previously were none (Howard et al., 2006). The QMRA approach to risk differs from epidemiological approaches in that the latter seek to measure actual levels of disease in the population while the former attempts to calculate the risk that is known or inferred of the concentration of particular microbial pathogens in the water supply as well as the infectivity of those pathogens to humans. Howard et al. (2006) views the QMRA as an appropriate tool to assess the risk posed by selected microorganisms in drinking water. The QMRA process normally consists of four steps namely hazard assessment, exposure assessment, dose response and risk characterisation (Haas et al., 1999). This study used a simplified QMRA model based on the QMRA process proposed by the WHO (2004). It consisted of two steps namely exposure assessment and consequence assessment – the latter included dose-response and characterising the annual risk of infection posed to an individual.

2.4.2.1 Assessing exposure to pathogenic microorganisms in water

The first step in the QMRA approach used for this project was to measure an individual's exposure to a dose of pathogenic microorganisms (Medema, 2002). While the microbial quality of drinking water is often measured by bacterial indicators such as *E. coli* (WHO, 2005), the disease itself is caused by viruses, protozoa and bacteria associated with these indicators. Jagals et al. (2006) stated that 65% of waterborne disease in Southern Africa could be attributed to infections and subsequent illness consistently caused by pathogenic bacteria while the viruses (28%) and protozoa (7%) bring up the rest, most likely in the form of outbreaks rather than resident excessive levels of diarrhoea. This study therefore used exposure to pathogenic bacteria as these are the more prominent microbe pathogen group and are also more directly associated with *Escherichia coli* bacteria. *E. coli* is categorised by two groups of strains namely commensal and pathogenic. The pathogenic strains are predominantly diarrhoeagenic *E. coli* (DEC) and may be used to calculate the risk of infection posed by pathogenic bacteria (Jagals et al., 2006; Howard et al., 2006). It is the numbers of DEC in drinking water that determine the risk of infection – in other words the dose of these bacteria that is ingested with the water. The higher the ingested dose of DEC the greater the possibility of an infection and ultimately illness. Dose therefore describes the intensity of exposure (Teunis et al., 1997) and consists of the volume of water ingested by an individual and the number of infectious agents in the water.

Exposure assessment in this study focussed on the ingestion of doses of pathogenic *E. coli* bacteria. The doses were determined by the quantity of water ingested containing certain numbers of the organism. The requirements of the QMRA were therefore the volume of unheated water (WHO, 2003) that an individual would drink per day and the numbers of diarrhoeagenic *E. coli* in that water.

2.4.2.1.1 Quantity of unheated water ingested by an individual

Unheated drinking water is defined as drinking water used for consumption by individuals every day without any form of treatment. It does not include the water used for cooking food or for boiling to make hot beverages (WHO, 2003). Thoeue et al. (2003) and WHO (2003) suggested that the quantity of water ingested could be estimated at 1 ℓ of unheated total water ingestion per person per day. The studies conducted by Gadgil (1998) and Horman (2005) suggested a daily per capita consumption of 2 ℓ for a person weighing 60 kg. A study by Mons et al. (2005) reported that the average consumption of cold tap water by people (ages ranging from 1 year to elderly) is 0.2-1.55 ℓ per day.

2.4.2.1.2 Numbers of diarrhoeagenic *E. coli* in unheated water intended for ingestion

Escherichia coli are generally used to determine the health-related microbial water quality (Hunter, 2003). Section 2 in Chapter 2 describes how *E. coli* bacteria are used to test whether drinking water complies with standards for microbial quality. *E. coli* bacteria are ubiquitous in the intestinal tracts of humans and other warm blooded animals (Haas et al., 2000). While many strains are harmless commensals (usually described as the indicator group), some are pathogenic such as the DEC group (Hunter, 2003; Nataro and Kaper, 1998). There are at

least five groups of DEc. These are enteropathogenic (EPEC), enterotoxigenic (ETEC), enteroinvasive (EIEC), enteroaggregative (EAEC) and enterohaemorrhagic (EHEC) (Van Nguyen et al., 2004; Hunter, 2003; Nataro and Kaper, 1998).

While the pathogenic types can be detected with molecular detection methods, it is usually qualitative, i.e. presence/absence. Quantifying the pathogens is at this stage a cumbersome and inaccurate process. This means that the fraction of the DEc versus the commensal (indicator) *E. coli* (CEc), in a sample of water measuring positive for indicator *E. coli* is not yet known (Nath et al., 2006). Literature on ratios for DEc and indicator *E. coli* in drinking water containers is therefore vague and scarce. A study conducted in Finland by Keskimäki (2001) reported ratios within the DEc in stool samples while Nishikawa et al. (2002) reported on intra-pathogen ratios for DEc in waste water samples. To provide some plausible measure of bacterial pathogenicity and from there doses of DEc in the source and container water for this particular project required an unusual approach.

2.4.2.2 Consequence assessment

Diarrhoea is one of the health consequences of ingesting contaminated drinking water. Drinking water contaminated with pathogenic bacteria can result in acute diarrhoea if this water is ingested without disinfection treatment. It has been reported that more than one billion episodes of diarrhoea occur every year in children younger than 5 years of age in socio-economically developing countries causing 2 to 2.5 million deaths (WHO, 2003). Rotavirus and diarrhoeagenic *Escherichia coli* are the most common pathogens responsible for acute diarrhoea episodes in children (Hunter, 2003; O’Ryan et al., 2004).

However, conversion of the risk to disease such as diarrhoea was not part of this component of the study. Consequence in the context of this project was rather seen as risk being the consequence rather than disease itself.

Diarrhoea as a disease outcome and therefore a health impact is discussed in Chapter 4 but is not necessarily associated specifically with this risk study as it was considered to be a health impact variable associated with the overall outcomes of the water supply service interventions studied during this project.

Haas and Eisenberg (2001) reported that infection (without apparent illness), can be used as a function of dose-response, i.e. health consequence. For this study therefore the dose referred to the ingestion of numbers of DEc while the response had to be obtained from some morbidity (diarrhoea), which was not available. Some other means for defining response had to be devised.

Quantitative microbiological risk assessments require validated dose-response models to ensure accuracy and assess uncertainty (Strachan et al., 2002). Such validation is ideally performed using data obtained from outbreaks. However, it is very difficult to obtain such data that is suitable, especially in South Africa. For instance, surrogate dose-response models for *E. coli* O157 have been used in QMRA, but have yet to be fully validated with outbreak data (Teunis et al., 1997). Other surrogate models were based on a *Shigella* beta-Poisson model that applied data from feeding studies in humans. Both these approaches fell outside the reach of this project since in-depth human health studies were not within the scope of the project.

2.4.2.2.1 Dose response for DEc

DEc can be divided into two categories namely haemorrhagic *E. coli* (HEc) and non-haemorrhagic *E. coli* (NHEc) (Eklund, 2005). Dose-response parameters do exist for NHEc and HEc if some plausible assumptions could be made. A search of the literature does present us with dose-response parameters that were already developed in other studies elsewhere in the world. Haas et al. (1999) as well as Haas and Eisenberg (2001) proposed dose-response values for NHEc as well as HEc.

2.4.2.2.1.1 Haemorrhagic *E. coli*

HEc is described as a group of highly pathogenic bacteria with a very low infective dose (Eklund, 2005). HEc characteristically causes *Shigella*-like invasive infection because of its virulence gene that produces *Shigella*-like toxins (Canil et al., 1993; Raji et al., 2006). Of the five *E. coli* patho-types the EHEC and EIEC bacteria are haemorrhagic because of their modes of pathogenesis (Kaper et al., 2004; Paton et al., 1998). The infectious dose for the EHEC can be less than 100 organisms (Gilligan, 1999; Cloete et al., 2004). EHEC have been isolated from humans with diarrhoea (Raji et al., 2006). EHEC strains have also been reported to have been found in human, animal and food sources. EIEC characteristically causes *Shigella*-like invasive infection typically leading to bloody diarrhoea (Aranda et al., 2004; Schmid-Hempel et al., 2007). The precise pathogenic mechanisms of enteroinvasive *E. coli* (EIEC) are as yet poorly understood although they are thought to mirror those of *Shigella* spp (Hunter, 2003). The EIEC dose required to cause diarrhoea is reported to be less than 10^3 organisms (Kelly et al.,

2003) with as low as 10 organisms by ingestion (Health Canada, 2001). The toxins produced by *Shigella* are similar to those of *E. coli* O157 (Canil et al., 1993; Haas and Eisenberg, 2001).

Based on the above, for this study dose-response parameters HEc were those for *Shigella* used by Haas and Eisenberg (2001) namely infectious dose ID₅₀ of 1.12×10^3 with α as 0.21.

2.4.2.2.1.2 *Non-haemorrhagic E. coli*

NHEc are the DEc strains that require very high infective doses to cause watery or mucosal diarrhoea in individuals. ETEC, EPEC and EAEC are grouped into non-haemorrhagic *E. coli*. Infective dose of enterotoxigenic *E. coli* (ETEC) for adults has been estimated to be at least 10^8 bacterial cells on ingestion; but vulnerable fractions of the population (the young, the elderly and the immuno-deficient) may be susceptible to lower numbers (Kaper et al., 2004; Todar, 2008). Human volunteer feeding studies estimated the infectious dose of enteropathogenic *E. coli* (EPEC) in healthy adults be 10^6 to 10^{10} organisms (Hunter, 2003; Todar, 2008).

This study used – for NHEc – dose-response values of Haas et al. (1999) as well as Haas and Eisenberg (2001) namely ID₅₀ of 8.60×10^7 and α as 0.1778.

2.4.2.2.2 *Characterising risk*

Risk characterisation is the process that combines the information on exposure and dose-response into an overall estimation of likelihood of an adverse consequence (Haas and Eisenberg, 2001). The water quality throughout the system changes still exposed the consumer to risk of infection by microorganisms. Risk of infection is a diagnosis that is defined as "the state in which an individual is at risk to be invaded by an opportunistic or pathogenic agent (virus, fungus, bacteria, protozoa, or other parasite) from endogenous or exogenous sources".

2.4.2.2.2.1 *Risk of infection per year*

Risk of infection per year is the number of times in a year that an individual is infected by pathogen microorganisms that can cause disease (Haas et al., 1999). This is also a widely accepted expression of risk outcome. However, the acceptable risk of infection by pathogenic *E. coli* in drinking water needs to be determined.

2.4.2.2.2.2 *A benchmark for acceptable risk*

Acceptable risk, defined as the level of infection to an individual, reflects a low chance of illness in an individual (WHO, 1993; Haas and Eisenberg, 2001). WHO (1996) and the U.S. Environmental Protection Agency (1991) use an acceptable risk of microbial infection of 1 person in a 10,000 population. An unacceptable (maximum) risk of infection is when an individual is infected more than once a year in a population of 10,000 (WHO, 1996).

2.4.2.2.2.3 *Changes in risk of infection brought about by the water supply interventions:*

Macler and Regli (1993) used bacterial indicators to measure the annual risk of infection rate from water sourced from small water systems. Using the simplified QMRA technique, changes in risk from container water *before* and *after* the intervention were compared according to the annual risk for an individual.

3 METHODS

The following are summaries of the methods used to measure the various effects either on their own or drawing from the function assessment data described in Chapter 2. From the data as well as international literature were derived benchmarks that will be described at the end of each section and summarised in Table 3.18 in Section 5 at the end of this chapter.

3.1 Measuring time

Time was first measured for an individual and then calculated at household level following certain assumptions. These measurements were not assessed against any benchmark as it were not part of the water service function assessments, but part of the effect indicators. Calculations of time were based on a standard container volume of 20 litres, as that is the common capacity of containers used for water collection in the area, and is also in keeping with international literature. This time was the time it took for one person to collect one 20-litre container of water per trip (collection time). This was calculated by adding total walk time (trip time to source and back), to filling time and extra (undefined) time.

3.1.1 Trip time

Trip time was defined as the time it took an individual to walk from households (with an empty container) to and from (with a loaded container) the water source point. Measurements of time (in minutes) taken to walk to the source were taken simultaneously with the GPS-measurements of actual distance from a household to a water source using a stop watch. It was also necessary to walk back with study participants in order to measure the time taken to carry the loaded containers back to the house. This was under the assumption that pace would differ when carrying a loaded container (more strenuous) as opposed to when carrying an empty container to the water source point.

3.1.2 Filling time

Actual filling times were recorded for a subset of the households for the various filling conditions relating to the no-service and rudimentary service. For the basic service, tap flow rates were obtained from work done by Rietveld et al. (2009) in the area as will be reported in the next section. From there it was calculated how long it would take to fill a 20-ℓ container. The method for measuring filling time on its own came from the assumption that filling times varied according to the sourcing technology and consequently method of abstraction. One standard minute was added to each of the filling time measurements to account for time taken to lift a container and place it onto the head, based on the work done by Geere et al. (2010b). Filling *rates* (no-service and rudimentary service) and filling *time* (basic services), were then calculated using the equations:

- For no-service and rudimentary service the fill rate (ℓ/min) = volume of container (20 ℓ)/time taken to fill the container (min);
- For basic service the fill time (min) = volume of container (20 ℓ)/flow rate (ℓ/min) from the taps.

3.1.3 Extra (undefined) time spent during the collection time

This was an exceptionally difficult time component to measure as the households' water collectors were only accompanied once by a fieldworker to get a broad measure of the trip and filling times.

It became clear through the interaction with the households during this as well as the broader baseline data collection phase, that the selected time measurements might have elements of non-representativeness as the measured collection time generally appeared to be shorter than the time that the communities, during the baseline interviews as well as subsequent community group discussions, reported to use for water collection. Extra time appeared to be time spent at queuing at the source points as well as socialising or resting along the way – especially on the way back with a heavy load. This is discussed in more detail in Majuru et al. (2010) as well as in the dissertation-based research report (Section 8: Chapter 1).

For the purposes of this study, the doing of laundry as well as bathing at the source was excluded from extra time as these were not water collection activities although they were often combined with water collecting chores, especially by those with no service.

Moreover, it turned out that the measurement periods were treated by the persons under observation (household water collectors) of “getting the job done” as they were often quite conscious of the presence of the fieldworker and would not, for instance stop and chat to passers-by as they often would otherwise. The presence of the fieldworker often caused for the collector and community-bystanders to react differently to the situation as they usually would.

Confirmation of the extra time was obtained from the household and community discussion groups and presented at the upper limit of the 95% confidence interval of the focus group time data to represent the worst case scenario. It was added to the trip- and filling-time to make up total collecting time by an individual fetching a 20-ℓ container of water.

3.1.4 Benchmarks for total collection time

The question to be answered here is what were time limits for domestic water collection? Hutton et al. (2007) reports on collection times that last mostly between 30 and 140 minutes. Howard and Bartram (2003) have more conservative rankings stating that 30 minutes are actually at the 'no access' (*no service* in this study) level. Considering a household of average 5 five people, who wishes to collect 25 ℓcd using one standard 20-ℓ container, at least one or more (if it is a shared task) of the members of a household will have to make seven trips daily to collect this quantity of water. If these trips could be limited to 15 minutes total collection time (five minutes

walking there and five carrying back) and five minutes for filling and extra time, it would cost a household a total water collection time of 105 minutes.

For this study, the ideal time for collecting water was assumed to be achieved if the tap was on site, reducing time to the minimum say two minutes to walk to the tap, fill and walk back. If conservatively speaking, another 3 minutes are added for extra time, then a total collection time of five minutes or less can be assumed as “good” (0). But if a water carrier walks and carries at approximately 1 second per meter then a 10 minute walk and carry would require a maximum distance to the water source point of 300 metres. If water points are then, as required by policy, 200 metres or less from homes it would be entirely plausible then to describe any trip lasting up to 15 minutes as “compliant” (1) as it would also then provide leeway for uneven terrain and some extra time on the way. “Non-compliant” (2) was, for the purposes of this project, judged to be up to 10 minutes more than compliant time, i.e. ≤25 minutes. Collection taking longer than 25 minutes was deemed then to be “critical” (3) (Table 3.17 at the end of this section).

3.2 Measuring daily individual water demand

3.2.1 Per capita daily water collection

To calculate the per capita daily collection that was achieved in the various communities it was first necessary to calculate the household water collection per day (ℓhwd) and then, using 20-ℓ as a container measure, divide the total household collection to determine the water quantities collected per person per day (ℓcd). The ℓhwd data were collected on structured observation sheets as well as data from the demographic- and socio-economic measuring phases reported on in Chapter 2. These data were captured in a Microsoft Excel® tool designed to calculate the ℓcd.

3.2.2 Benchmarks for ℓcd compliance

Benchmarks were set for water quantities collected per person per day (ℓcd) (Table 3.2). Per capita water collection was considered to be a minimum level of compliance. This level was set at the 10th percentile as it was considered reasonable that 90% of the data for ℓcd should exceed the recommended volume (e.g. the 25 ℓcd under basic services).

Table 3.2: Benchmarks for daily per capita collection (litres)

Indicator	Service level	Benchmark	Benchmark origin	Source
ℓcd	No service	5 ℓcd minimum	WHO guideline	Howard and Bartram (2003)
	Rudimentary	15 ℓcd minimum	Existing guideline	DWA (2000)
	Basic	25 ℓcd minimum	Existing guideline	DWA (2003)

Thus exceeding 25 ℓcd would be ranked as “compliant” (0). Although DWA (2000) recommended a range of 5-15 ℓcd for a rudimentary service, the benchmark was considered to be a minimum of 15 ℓcd at the 10th percentile deemed as “non-compliant” for survival and daily use, scoring (2). Under conditions of no service, the minimum quantity of water per person per day was benchmarked at 5 ℓcd after Howard and Bartram (2003). Below 5 ℓcd scored a (3) which indicates daily water use that is “critically” low for proper hygiene and health. On the other end of the spectrum, a daily collection of 65 ℓcd was foreseen to be a target for the 21st century (DWA, 1994) for households with an onsite connection. This was clearly not going to be achieved under the circumstances encountered in the village. Therefore a “good” (0) collection was simply considered as >25 ℓcd at the 10th percentile.

3.3 Measuring risk of musculo-skeletal disability

Three approaches were used to address the aim of this study component (Section 2.3 above). Firstly, a review of the literature was conducted to investigate whether any risk assessment or health measurement tools currently exist to measure the impact of DWC. Secondly, an exploratory study using mixed methods was conducted to determine the domains of health potentially affected by DWC and which are important to people who do the DWC. Finally, a further review of literature was conducted, to compare the findings of this exploratory study to research into the relationship between physical work and health conducted in other settings. The results of these approaches were synthesised to identify the outcomes and potential risk factors for those outcomes which should be investigated to determine the health impact of DWC.

3.3.1 A methods review

No articles describing an investigation into the relationship between DWC and risk/health were found. Similarly, no reports were found describing specific tools for evaluation of the physical burden of DWC or adaptation of existing health measurement or risk assessment tools for such purposes. As there appears to have been no research into the effects of DWC on health or more indirectly, a study of the risk of disability caused by DWC, the pilot study was conducted to develop insight into the nature of the task and through observational and qualitative research methods, to develop understanding of the risk or potential health impacts of DWC.

3.3.2 Mixed methods pilot study

A phenomenological methodology was used with collection of both qualitative and quantitative data to explore the phenomena associated with DWC performed by adults and children in the study area. The aim was to identify the health domains likely to be affected by DWC which are relevant to both the target population and service providers and establish the grounding for developing tools to measure the health impact of DWC.

The aim of the *quantitative* aspect of this component was to better understand how DWC is performed, gain insight into the potential health effects of the task and identify potential risk factors related to it. An ergonomic systems approach (Buckle, 2005), to gather information about various factors accepted to pose health or injury risks during physical work in other settings (Adams et al., 2002; Briggs, 2003; Wearing et al., 2006; Bongers et al., 2006; Cote et al., 2008) is likely to be useful for initial appraisal of work related to DWC. An ergonomic systems approach can gather information from observation and verbal report (David et al., 2008), to evaluate individual, task, psychosocial, organisational and environmental factors which may impact on the relationship between health and work (Pheasant, 1986; Grandjean, 1988).

Therefore a descriptive observational approach, informed by ergonomic principles, was used to answer the following quantitative research questions:

- Who collects and carries water for domestic purposes?
- How do people carry water for domestic purposes?
- What factors considered to pose risk of injury (and disease) are people exposed to during DWC?

The aim of the *qualitative aspect* of the study was to develop understanding of the potential health impacts of DWC, particularly from the perspective of people who have experience of performing DWC and therefore specific insight into the relationship between DWC and health. Such knowledge is essential for the development of health impact assessment tools with 'content validity', defined as measures which assess content that the target population perceive as relevant to the construct of interest (Atkinson and Lennox, 2006). Qualitative research methods were used to answer the following research questions:

- Which domains of health do people with experience of DWC perceive to be affected by DWC?
- Do people with experience of DWC perceive that DWC should change?

3.3.3 Sampling strategy and participant recruitment

Data was collected from the study communities described in Chapter 1. These communities were purposively selected for their range of water service situations and environments which might have different physical effects or expose people to different risk factors for injury or disease. Specific water source points (WSP) were chosen to include varying infrastructure (for example types of water outlet pipes, communal tap design or unstable river banks) and terrain which will influence methods and effects of DWC in different ways.

Before commencing the research, permission to work in each community was sought from the relevant tribal authority. Each community was then visited over a period of two to three consecutive days. The researchers waited at water source points to identify through observation people carrying water or clearly intending to carry water. In this way a convenience sample was generated by inviting individuals observed at the time during which the researchers visited WSP to participate in the study. From the convenience sample individuals were purposively chosen and invited to participate, to recruit adults and children of both genders and with a range of ages according to the following inclusion and exclusion criteria. Such factors are likely to influence physical capacity for DWC and therefore might result in different experiences of the health impact of the task.

3.3.4 Specific ethics

Informed voluntary consent was sought from adult participants before recruitment into the study. Information about the study purposes and procedures was provided through verbal and written explanation in the participants

preferred language. Although some children collected water in the company of an adult, in many instances, children collected water without adult supervision. Where children were observed to collect water with an adult, informed voluntary consent for the child to participate was sought from the adult. Agreement was also sought verbally from the child in a non-coercive manner by the RA, who was a local Venda male, sensitive to culturally appropriate ways to interact with the children. Care was taken to monitor from children's behaviour that they were not adversely affected by participating in the study.

When children were observed to collect water unaccompanied by an adult, the study purpose and procedures were first explained to the children by the RA in a manner culturally appropriate to their age and level of understanding. Once voluntary verbal agreement was obtained from the children, measurements of their weight and height and the weight of filled containers they intended to carry were taken. They were then video recorded and observed while filling containers and carrying water from the collection point to their home. On arrival at the house, a parent or adult guardian was advised of the study purpose and procedures, and formal consent for the child's participation sought. This gave an opportunity for the video capture and observational data to be erased in the event of the parent or guardian not consenting to participation of their child – however such a situation did not arise.

Ethics approval for the study was obtained from the International Development Ethics Committee, University of East Anglia, Norwich (UK) and the Higher Degrees and Ethics Committee for the Faculty of Health Sciences, University of Johannesburg as well as from the Research and Ethics Committee of the Tshwane University of Technology (RSA).

3.3.5 Data collection

Quantitative data was gathered through simple measurement (for example measuring height, body weight and the weight of water carried), observation and self-report. Simple measurements were taken after voluntary verbal agreement was obtained from participants. Observation was performed by the PI and RA while children carried water and recorded through video capture, photography and recording of field notes in a structured observation schedule. Information on the usual frequency and quantity of water carried and demographic information was obtained through participants' self-report and for children from their own or their guardian's verbal report. This information was also recorded on the structured observation schedule.

Methods of DWC and the environment in which it occurred were captured through observation with a structured observation schedule, video-recording and photography. Procedures were piloted with an adult woman in the study area and adapted to improve feasibility and ease of use. Data about individual and task related factors were gathered from self-reports as well as simple observations and then immediately entered onto the recruitment form as well as a structured observation form for each participant.

A video recorder (Panasonic Mini-DV digital video camera Model NV-GS320) was used by the RA to capture DWC from the water source to the participant's home. Four observed subtasks of DWC were 1) preparing and filling, 2) lifting, 3) carrying and lowering and 4) placement of containers. Video recordings also captured the times taken for each subtask. Occasionally brief pauses in video recording were necessary between subtasks and some participants were observed not performing all subtasks. A GPS unit (Garmin CSX 60) was used to measure the distance travelled between the WSP and house.

A tape measure was used to measure participants' height, using a flat standing-platform and a clipboard placed horizontally on the head to provide level points for measurement. The weight of participants as well as the water carried was measured in kilograms, both calculated from the average value of three consecutive weighing scores.

Participants were interviewed on the sensation of effort required for DWC immediately on completion of DWC using the modified Rating of Perceived Exertion (RPE) scale also known as the Modified Borg scale. The modified RPE is a 12 point categorical scale which has ratio properties and has been validated for use with healthy adults and children of both genders and in hot environments (Finch et al; 2002). RPE scores have been correlated with heart rate in healthy adults and children during workloads ranging from moderate to heavy intensity ($r = 0.80-0.90$), with oxygen consumption ($r = 0.76-0.97$) and OWAS and Body Part Discomfort scores (Olendorf and Drury, 2001).

Qualitative data were collected through semi-structured interviews and informal natural group meetings (NGM) which were conducted with participants near their homes. The two forms of semi-structured interviews were used as different kinds of information may be disclosed in each. The use of NGM as described by Green and Thorogood (2004), rather than formal focus group meetings, was adopted for efficiency and to minimise disruption to participants by interviewing people already gathered together. NGM can also maximise interaction between participants, as well as between researchers and participants. Interview guides were developed in English,

translated into TshiVenda, back-translated and piloted in the study area. They were modified in response to piloting and discussion with the research assistant (RA), a 29 year old Venda male with tertiary level education, fluent in English and TshiVenda, and with experience of verbal and written translation work for social and scientific research projects.

Interviews and NGM were audio-recorded and conducted with immediate translation between the principal investigator (PI), RA and participants. For all interviews, the English questions and RA's immediate English translation of participant responses were fully transcribed by the PI. Two semi-structured interview recordings were fully translated and transcribed by a second, independent translator. Two interviews with children were excluded from analysis, as meaningful data was not collected on those occasions.

3.3.6 Data analyses

Quantitative observational data was entered into and descriptive statistics generated from SPSS 15.0. Video material, photographs and field notes for each participant were reviewed to identify hazards and risk factors for injury. Video observation was also used to time DWC. The times at which subtasks commenced and finished were identified from the video recordings according to specified criteria. For the purpose of this analysis, the times calculated from observation of video material for each participant on two separate occasions were averaged to estimate the time taken by each participant for each subtask. Descriptive statistics of the time for each subtask were then generated (tabled in the Results section below).

The Ovako Working Posture Analysis System (OWAS) (Karhu et al., 1977; Kee and Karwowski, 2007) was used to analyse video capture of DWC. It was used to classify the type of postures adopted and estimate the frequency in which postures considered to impose physical strain occurred during DWC. The tool was applied to three selected cases, chosen to represent the different methods of DWC observed during the study. Analysis of the entire data set is ongoing at the time of this report and will be eventually be published elsewhere.

Two techniques were used to gain insight into the level or intensity of work which people performed. Firstly, the weight of water carried was measured in kilograms and considered as a percentage of body weight and in Newtons of force (N) for head loading. Secondly, participants reported the sensation of effort or 'rating of perceived exertion' (RPE) required for DWC using the Modified Borg scale (Finch et al., 2002).

For qualitative data, thematic content analysis of transcripts was manually performed using 'framework' analysis (Ritchie and Spencer, 1999). Of eleven interviews with children, and a sample of 7 adult interviews, all transcript data was independently coded into units of meaning by the two researchers, who then compared interpretation of the data and agreed the final coding strategy. Codes from the children's data with similar meanings were then categorised together to generate sub-themes which were considered in light of the original research questions to generate themes. Data from individual interviews were triangulated with that from group interviews. The qualitative data was also mapped to ICF categories as a strategy to promote clear identification and communication about the health domains potentially affected by DWC.

3.3.7 Assessment methodology

The results of the qualitative and quantitative data were synthesised to identify the domains of health which should be measured to capture the health impact of DWC, particularly in a way which has content validity with respect to the population being measured. As both qualitative and quantitative data indicated that musculoskeletal disorders (MSD) are likely to be associated with DWC, a further review of literature was conducted to identify factors which have been identified as risk factors for MSD in other populations and settings. Factors relevant to DWC were incorporated into the tool as specific items.

By drawing on the qualitative and quantitative information gathered in this study and published literature reporting risk factors for MSD, a conceptual method with criteria, indicators and benchmarks is proposed to assess the risk of MSD (as opposed to "disability" as mentioned earlier in this chapter) posed by DWC. Table 3.3 presents the criteria with summarised descriptions of the criteria as well as their benchmarks, scores and weights.

The detailed rationale for each component can be found in the full report (Appendix B). The weights assigned to the various criteria outcomes are absolutely arbitrary and based on the experiences of the researchers in terms of the importance of each factor. They could not be weighed evenly as the study relied heavily on the perception of exertion of the water carrier therefore the RPE carried the highest weight. The other ergonomic-related measures were largely untried and were given approximated with the same weight. Age and gender were assigned the lowest weights.

Table 3.3: Domestic water carrying criteria to measure impact

Criteria	Benchmark	Factor score	Criterion weight
Total daily carrying time (TDCT) in minutes ²	0	0	0.20
	$x \leq 15$	1	
	$15 < x \leq 30$	2	
	$30 < x \leq 45$	3	
	$45 < x \leq 60$	4	
	$x > 60$	5	
CW%BW ³	$0.05 < x \leq 0.25$	1	0.20
	$0.25 < x \leq 0.5$	2	
	$0.5 < x \leq 0.75$	3	
	$0.75 < x \leq 1$	4	
	> 1	5	
Total daily lifting load (TDLL) ⁴	0	0	0.20
	$x \leq 100$	1	
	$100 < x \leq 200$	2	
	$200 < x \leq 400$	3	
	$400 < x \leq 600$	4	
	$x > 600$	5	
Rating of perceived exertion (RPE) ⁵	Nothing at all	0	0.25
	Very, very weak	0.5	
	Very weak	1	
	Weak	2	
	Moderate	3	
	Somewhat strong	4	
	Strong	5	
	6	6	
	Very strong	7	
	8	8	
	9	9	
	Very, very strong	10	
	11	11	
	Maximal	12	
Age	$x \leq 15$	3	0.15
	$15 < x \leq 30$	0	
	$30 < x \leq 45$	1	
	$45 < x \leq 60$	2	
	$x > 60$	4	
Gender	Male	0	0.10
	Female	2	

Although these are important criteria, they were not deemed at the same level as the others. If a very young female carried a very light load over a short distance for short times it is inconceivable that it would have a detrimental effect. It is how the load is lifted and carried that weighs almost as much as the RPE.

The results-reporting below deals with only the head loaders. These had the higher rate of perception of exertion and conceivable would also be the ones that would experience least benefits of the four water transporting categories. Furthermore more than 70% of the people fetching water in the area carried the loads on their heads.

3.3.7.1 Total daily carry time (TDCT) in minutes

This is a measure of the duration of carrying x usual number of carrying episodes per day. Qualitative prompt questions are: *'How long do you estimate it takes you to physically carry your water container(s) from the water source you usually use to your home?'* and *'How many times do you usually go to collect water on the days when you collect water?'* The maximum score was assigned to carrying time that took longer than 60 minutes.

3.3.7.2 Container weight (kg) as percentage of bodyweight (kg) (Cw%Bw)

It is often observed that water carriers have to contend with load up to a large percentage of their body weight. It is easily measureable and is included in the tool is a measure of just how heavy these loads are per individual.

3.3.7.3 Total daily lifting load (TDLL)

This is calculated from the measured mean weight lifted (mean weight of a typical container when full x number of containers handled or lifted per usual DWC trip) times number of occasions of lifting and lowering the load per day (frequency of DWC trips per day x 2).

Prompt questions: 'What is the volume of the containers you usually use to collect water?' (convert litres to kg) and then observe and note what is observed after 'Can you show me the containers you would usually use for collecting water?'. 'How many containers do you usually fill to carry each time you collect water?' 'How many times per day do you usually go and collect water?'

3.3.7.4 Rating of perceived exertion (RPE)

This is the difficulty of carrying water using the Modified Borg Scale (categorical scale (scored out of 12) with ratio properties). The standardised RPE explanation to the respondents: 'Think about how hard you feel the work of carrying water usually is for you. This feeling should reflect your total amount of exertion and fatigue, combining all sensations of physical stress, effort and fatigue. Don't concern yourself with any one factor such as leg pain, shortness of breath or exercise intensity, but try to think about your total inner feeling of exertion. Try not to underestimate or overestimate your feeling of exertion; be as accurate as you can'

3.3.7.5 Age and gender

Women and children are at greater risk of injury than men when lifting heavy or asymmetric loads. Studies suggest that because of their reduced size and strength, women and children are less physically suited than men to lifting and carrying heavy loads such as containers filled with 20-25 litres of water, and particularly vulnerable to physical strain when carrying containers by head loading. Therefore in the DWC physical burden scale both age and gender are included as items. The middle age ranges are given lower scores, with the very young or very old scoring higher.

3.3.8 Assessment of the risk of musculo-skeletal disorder

A "good" (0) level of low risk was assumed 0.1 and lower. A level of compliance was assumed to be the upper margin for "low risk" of a detrimental musculo-skeletal effect at 0.33 (1), non-compliant the upper margin for "risk" (2) which was also the critical baseline level for "high risk" (3) was set at 0.67.

3.4 Measuring infection risk

This component of the work was conducted according to the assessment process shown in Table 3.4. The probability of infection by water sampled from household drinking water containers was the main focus.

Table 3.4: The quantitative microbial risk assessment process adapted from WHO (2004)

Assessment steps with variables	Calculations	
Exposure		
Drinking water quality in containers expressed as indicator <i>E. coli</i> per litre	(C _D)	Analyses of water samples
Consumption of volumes of unheated drinking water expressed in litre	(V)	Interview and observation
Exposure by drinking water – indicator <i>E. coli</i> per litre	(E)	C _D x V
Dose – exposure to % non-haemorrhagic <i>E. coli</i> in container drinking water	(dNHEC)	E x %NHEC
Dose – exposure to % haemorrhagic <i>E. coli</i> in container drinking water	(dHEC)	E x %HEC
Consequence		
Dose-response of non-haemorrhagic <i>E. coli</i>	(P _{i,dNHEC})	$1 - \{1 + [(d/N_{50})(2^{(1/\alpha)} - 1)]\}^{-\alpha}$
Dose-response of haemorrhagic <i>E. coli</i>	(P _{i,dHEC})	$1 - \{1 + [(d/N_{50})(2^{(1/\alpha)} - 1)]\}^{-\alpha}$
Risk of infection per day for an individual	(P _{i,d})	P _{i,dNHEC} + P _{i,dHEC}
Risk of infection per year	(P _{i,y})	P _{i,d} * 365

The adapted QMRA, molecular detection of *E. coli* pathogens, was performed on the container waters of all the selected households in the community clusters described in Chapter 1. The data were collected on all the variables, while assumptions were made about the dose-responses as well as pathogenicity in terms of the pathogen fractions in the samples testing positive for indicator *E. coli*.

3.4.1 Data collection

3.4.1.1 Ethics approval

Access was required to the water stocks of the households as well as to some private household information. University ethics approval was obtained from the Research and Ethics committee of the Faculty of Health Sciences, University of Johannesburg as well as from the Research and Ethics Committee of the Tshwane University of Technology (RSA). The study was then introduced to the household elders and explained in detail. Permission and the voluntary involvement of household members were obtained from each household using the approved letter of consent.

3.4.1.2 Respondent

After introducing the study, heads of households/elders were requested to appoint one household member to respond to interviews on behalf of the family. The respondent was usually a senior matriarch such as the mother or grandmother, otherwise a female family member at least 16 years old.

3.4.1.3 Field workers

Four senior undergraduate from the University of Venda as well as one local field worker with a final year secondary school qualification were used as field workers to conduct the survey in the study area.

3.4.1.4 Data collection sheets

The assessment methodology required for data to be collected on daily water volumes of unheated water (in litres) ingested by individuals in households and data of analyses on the samples taken to measure the health-related microbial quality of the water they ingested. The data was collected from each household using structured questionnaires and observation sheets.

3.4.2 Measurables

- Quantities of unheated water ingested per person per day expressed in litre per capita per day (ℓcd);
- The health-related microbial water quality of samples taken from the containers based on two analyses regimes:
- Culturing of *E. coli* bacteria present in the water;
- Determining the pathogenicity of these bacteria using molecular detection techniques.
- Data for these variables were collected repeatedly over the study period and reported at the upper levels of their respective 95% confidence intervals. All selected household containers' water was collected and measured.

3.4.2.1 Household water use (unheated drinking water)

Knowing the quantity of unheated water ingested by a person daily is a critical part of this type of risk assessment because exposure values were calculated from this. The actual water quantities per day ingested by individuals in the sample of exposed population in the communities were measured on four occasions throughout the study period. Data was collected, based on a one-day recall, about the actual quantity of unheated water ingested by the individuals in the household. This was expressed as (V) (Table 3.3) being the volume of water (litre) ingested by an individual per day (ℓcd) and reported at the upper limit of the 95% confidence interval (95%UCi). The 95%UCi therefore reflected the assumption that any differences in the ingestion volumes of the people across gender and age groups for the various villages in the study would be similar and that the average consumption at the highest upper level of confidence will be sufficient to represent the worst probable risk of infection.

3.4.2.2 Health-related microbial quality of water sampled from containers

The quality of water sampled from randomly selected containers of each participating household was assessed using *E. coli* bacteria as an indicator organism. Water samples were collected once *before* and twice *after* the respective interventions. The water collected from the household container was assumed to represent the water quality to which the individual would continually be exposed. The water samples were analysed and the microbial data expressed as indicator *E. coli* bacteria per 1 litre (C_0).

The samples of water were first analysed for *E. coli* indicator bacteria using the culture-based IDEXX Colilert-18™ Quanti-Tray testing kit. The most probable number (MPN) of *E. coli* per 100 mL of water was then read from the MPN table provided with the Quanti-Tray™ kit.

To determine the specific DEC strains present in the samples, the samples that tested positive for *E. coli* were further analysed for the presence of DEC using polymerase chain reaction (PCR) after Omar et al. (2010). Since no clear literature could be found that gives percentage *E. coli* pathogens (DEC) per presumptive commensal (indicator) *E. coli* (CEC) numbers in the water samples, assumptions had to be made about the pathogen fraction amongst the commensal *E. coli* (reported below).

3.4.3 Assumptions

Because of insufficient literature available on the ratios of pathogens actually indicated by indicator *E. coli*, some studies did provide clues on these. However, these were not deemed sufficient and some assumptions were made based on the experimental work done for this study as well as from the literature. These assumptions were:

- The percentage of diarrhoeagenic *E. coli* (DEc) per indicator *E. coli* (CEc) bacteria count in a sample;
- Risk parameters;
- Benchmarks for acceptable risk.

3.4.3.1 Percentage *E. coli* pathogens per *E. coli* indicator count

DEc generally consists of non-haemorrhagic (NHEc) and haemorrhagic *E. coli* (HEc) – these strains are often found in contaminated drinking water. In this study, these pathogens were also assumed to be proxy pathogens for other harmful bacterial pathogens in drinking water. Because unique dose-response parameters for these two groups exist, the infection risk posed by these two groups was kept separate until immediately before the risk characterising phase end of the consequence assessment.

The assumption was that the percentage of samples found to be positive for pathogenic *E. coli* in this study can be assumed to also be percentages of diarrhoeagenic *E. coli* per indicator number for every positive sample (% NHEc and % HEc). Because the two DEc groups solicit different responses, these pathogen categories were kept separate for calculating the risk of infection. The pathogen presence/absence data was converted (in Microsoft Excel XP® spreadsheets) to percentage occurrence per indicator *E. coli* number detected in water sampled from the containers of households in the various villages.

3.4.3.2 Risk parameters

DEc dose-response parameters used were those reported for drinking water by Haas et al. (1999) for non-haemorrhagic *E. coli* (NHEc). For the haemorrhagic (HEc) *E. coli*, parameters for *Shigella* (Howard et al., 2006; Haas and Eisenberg, 2001) and Haas et al. (1999) were used and are shown in Table 3.5.

Table 3.5: Dose-response parameters to calculate probability of infection

Parameters	<i>E. coli</i> for non-haemorrhagic <i>E. coli</i>	<i>Shigella</i> for haemorrhagic <i>E. coli</i>
α	0.1778	0.21
N_{50}	8.60×10^7	1.12×10^3

3.4.3.3 Assuming an acceptable risk benchmark

To compare the annual probable risk of infection for the conditions in the study area, assumption benchmarks were set since, except for those developed by the USEPA (1991) in a developed country setting, these did not exist in literature for developing countries. For this study two benchmarks were derived from the risk data:

- An upper boundary of acceptable probability of infection per year at the low-risk level;
- A minimum boundary of unacceptable probability of infection at the high-risk level;

The area in between the boundaries of acceptable and unacceptable probable risk of infection would, in the context of this study, remain an area of uncertainty which will be discussed later on.

3.4.3.3.1 Upper boundary of acceptable risk

Data from the community that showed the highest reduction of the risk of infection was used as the acceptable minimum level of infection risk to an individual per year at the upper limit of the 95% confidence interval. The acceptable probability of infection benchmark was taken from the village that showed the lowest number of samples positive for *E. coli* indicators and had the most access to and availability of their new system – which was Upgrade Community 2.

3.4.3.3.2 Lower boundary of unacceptable risk

Conversely, data from the village that showed the lowest reduction (if any) of the risk of infection was used as an unacceptably high risk of infection per year at its lower limit of the 95% confidence interval. The unacceptable probability risk of the infection benchmark was to be taken from the village that showed the highest number of samples that tested positive for *E. coli* indicators and that had access for the least amount of time to a new system or did not have access to a system at all – it turned out to be Reference Community 3.

3.4.4 Assessing exposure and consequence

3.4.4.1 Exposure assessment

In this section the objective was to calculate the dose and exposure of an individual to diarrhoeagenic *E. coli* in water sampled from containers.

3.4.4.1.1 Daily exposure to indicator *E. coli* bacteria

Generally the expression of indicator *E. coli* (iEc) in water is done per 100 mℓ and then converted to 1 litre in step with the WHO (2004) approach: $C_D = iEc \text{ per } 100 \text{ mℓ} \times 10$.

The unheated drinking water ingested per individual was then used to calculate the daily exposure (E) to indicator *E. coli* per litre (C_D) in the volume of unheated used for drinking (V): $E = C_D \times V$.

3.4.4.1.2 Daily exposure to diarrhoeagenic *E. coli*

The daily dose of the DEc was calculated separately for non-haemorrhagic *E. coli* (dNHEc) and haemorrhagic *E. coli* (dHEc) from the exposure to indicator *E. coli* bacteria because of their different percentage occurrences in the water samples. The separation was also required in order to apply the two different dose-response parameters: $dNHEc = E \times \%NHEc$ and $dHEc = E \times \%HEc$. The daily exposure to diarrhoeagenic *E. coli* was the summation of the separate calculations: $dDEc = dNHEc + dHEc$.

3.4.4.2 Consequence assessment

The consequence was calculated as the risk of infection first calculated daily and then annualised.

3.4.4.2.1 Daily risk of infection from diarrhoeagenic *E. coli*

This is the risk of infection posed on an individual who is exposed (per day) to the particular *E. coli* pathogen group (NHEc or HEc). This was calculated (for this study) according to the formulae shown below using the risk parameters N_{50} and α from Table 3.5. The probable risk of infection (P_i) was calculated using the formula of Haas et al. (1999) as well as Haas and Eisenberg (2001) (Table 3.6).

Table 3.6: Daily probable risk of infection (Haas and Eisenberg, 2001; Haas et al., 1999)

$$P_i = 1 - \left[1 + \frac{d}{N_{50}} (2^{\frac{1}{\alpha}} - 1) \right]^{-\alpha}$$

P_i = probability (risk) of infection

d = dose or exposure (concentration intake of bacteria)

α = parameter that characterizes dose-response relationship (from literature)

N_{50} = median infectious dose (from literature)

The calculations yielded the $P_{inf.d}$ for NHEc ($P_{inf.d \text{ NHEc}}$) and the $P_{inf.d}$ for HEc ($P_{inf.d \text{ HEc}}$). The two risks were then combined to form the total daily risk of infection by DEc: $P_{inf.d \text{ DEC}} = P_{inf.d \text{ NHEc}} + P_{inf.d \text{ HEc}}$.

3.4.4.2.2 Risk of infection per year

The probability of infection per year ($P_{inf.y}$ from Table 3.1) was calculated: $P_{inf.y} = P_{inf.d} \times 365$.

3.4.4.3 The effect of the intervention on the infection risk

The risk of infection per system was described if it could be demonstrated that a change occurred from *before* the intervention to *after* the intervention. It was a change in $P_{i,y}$, which is the annual risk of an individual to be infected. The focus for this study will be on individual risk, and includes the effect of the intervention as well as the effect of the systems' maintenance and operation since Chapter 2 showed that the systems were not compliant in terms of being accessible and available. To give a simple measure of effect, the benchmarks will be set from the results of the assessment before the potential effect values are assessed.

The benchmark for acceptable risk was therefore set at the best performance in reducing risk achieved by a basic supply service in any of the study communities. While no-risk was assumed to be "good" (0), this was hardly achievable. A basic water system that supplies water which poses a probable risk of infection of $\leq P_{inf.y}$ was therefore ranked as performing "compliant" (1). The upper limit for risk being reduced "sufficiently" was placed at $\leq P_{inf.y}$ as this was the worst performance (after adapting the risk) of the upgrades to a basic water supply system

and thereby formed the base of “non-compliance” (2). Any system that supplied water that posed a $P_{inf,y}$ at $\geq y$ was a system performing critically poor (3).

4 RESULTS

4.1 Collection time

Time spent collecting water was the cross-cutting feature amongst the access and availability service functions. Collection time was the combination of the results of measurements of the various components of time that are presented below.

4.1.1 Trip times

The trip times (walking to and from the water points) across the various levels of service, are shown in Table 3.7.

Table 3.7: Trip times (minutes at the 90th percentile) to walk from home (empty container) to water sourcing points and back (filled container)

	No service	Rudimentary service (hand-pumps)	Rudimentary service (tanks)	Basic service
Upgrade Community 1	42			10
Upgrade Community 2	24	5.5		7
Upgrade Community 3	52		4.5	6
Reference Community 1				9
Reference Community 2	16			

The trip times reflected the distances to water points, because trip time (time taken to walk to and from the water point) is largely determined by the distance to the water point. However, other conditions such as the condition of the filling point as well as topography (which did differ amongst the villages) also featured.

At the NS level, the trip times for UC3 were longest, as the distances to the water source points were farther compared to those of the other communities. These trip times were significantly reduced ($p \leq 0.001$) by upgrading the service from NS to RS conditions for both the small upgrade communities. For UC1 and UC2 the reduction in trip time from RS to BS was significant ($p = 0.001$), as the distance was also significantly shorter. For UC2, whose RS and BS distances did not differ significantly ($p = 0.738$), there was also a corresponding similarity in trip times for the RS and BS. The upgrade from RS to BS thus resulted significantly shorter trip times for all upgrade communities and were similar to those of RC1.

4.1.2 Filling time

For water points such those at river edges, this time can be relatively short, as the container can be immersed into the river and fill up quickly. For water points such as handpumps that require more physical effort, filling can take quite some time, whereas filling at a tap is mainly dependent on the flow rate. These various scenarios in essence illustrate how sourcing technology can influence the value of time-saving through activities such as filling containers. Results of the time taken to fill a 20-litre container at the various water points are shown in Table 3.8. These filling times include one standard minute for lifting and balancing containers on heads or hips of carriers.

Table 3.8: Time (minutes) to fill a 20-l water container

	No service	Rudimentary service (hand-pumps)	Rudimentary service (tanks)	Basic service
Upgrade Community 1	2.8			1.8
Upgrade Community 2	2.8	5.5		1.8
Upgrade Community 3	2.8		4.5	2.3
Reference Community 1				2.5
Reference Community 2	2.8			

Filling times at the open sources of the NS were similar for all three communities because the household water carriers all filled at the river front.

The filling times at the RS were longer than at the NS, although the UC3 filling time was a minute shorter than that of UC2, possibly because the laborious hand-pump technology in UC2 required more time for a 20-l container to get filled. The flow rates were low at the RS tanks of UC3 hence it took longer to fill up containers. At handpumps the flow rates were low as well, and filling time was also dependent on the strength of the user, and in case of children could be quite long as a lot more effort was required from them to pump up the water.

These filling times were reduced by the BS, which had the shortest filling times. Two reasons for these changes would be the improved source technology used at the water points (taps) and the flow rate (higher pressure from the new systems). The highest filling rates were at the taps of the BS (and ironically at the open sources of the NS). While at the rivers, water was abstracted mostly by immersing a container in the river at a sufficiently deep point where the container could fill quickly, the taps offered the best options in terms of filling because the flow rates were high and containers could be filled within a short space of time, while requiring little effort.

4.1.3 Extra time

Extra time in the context of the study was defined by community focus groups as the time spent in relation to the water collection activity other than what was shown above. As queuing was already ruled out (discussed above), this was considered time spent resting on the way home and other intermittent activities such as socialising on the way. Table 3.9 shows extra time spent during water collection.

Table 3.9: Extra time (minutes) across the levels of service

	No service	Rudimentary service (hand-pumps)	Rudimentary service (tanks)	Basic service
Upgrade Community 1	18			8
Upgrade Community 2	26	5		8
Upgrade Community 3	17		6	9
Reference Community 1				7
Reference Community 2	20			

The table shows that more extra time was spent at the NS level than any of the other water points. A possible reason could be that because the NS open sources were farther than the water source points for the other service levels, more time could have been spent resting along the way. Also, collecting water at open sources could have better afforded the opportunity for people to socialise than at the other RS and BS source points, as people did not have to give others a turn at the hand-pump or tap and thus spend less time socialising. Although UC2 households walked the farthest distances to the open sources, they seemed to take the least extra time. As the results for this component of time measurements are based on data collected from focus group responses, it could be that respondents under-reported this time component under the perception that the most time was actually spent in walking the long distance to the open sources.

The extra time spent for the RS using handpumps and RS using tanks was quite similar and was the shortest amongst the three service levels. These extra times at the RS were shorter than at the NS, possibly because the accompanying reduction in distance meant that less time was required to rest along the way. This extra time increased at the BS, and was quite similar for the two upgrade communities.

The aspect of queuing was already dismissed as a minor issue in earlier sections in terms of time in the specific context of this study area since the focus groups indicated very clearly that they had organised this so the minimum time is spent. Observations also revealed that it was indeed the case. When the water supply was being interrupted, people organised their containers in a row at the tap and left to attend to other chores. Alternating persons would generally act as marshals for the queued containers, and when the water was turned on, alert the surrounding community who would then gather and quickly fill their containers. There would be some time spent on queuing but not to a measurable extent.

4.1.4 Collection time per person with a 20-litre container

The collection time required for one person to collect one 20-litre container of water was calculated as the sum of the individual's trip time, filling time and extra time (Figure 3.1).

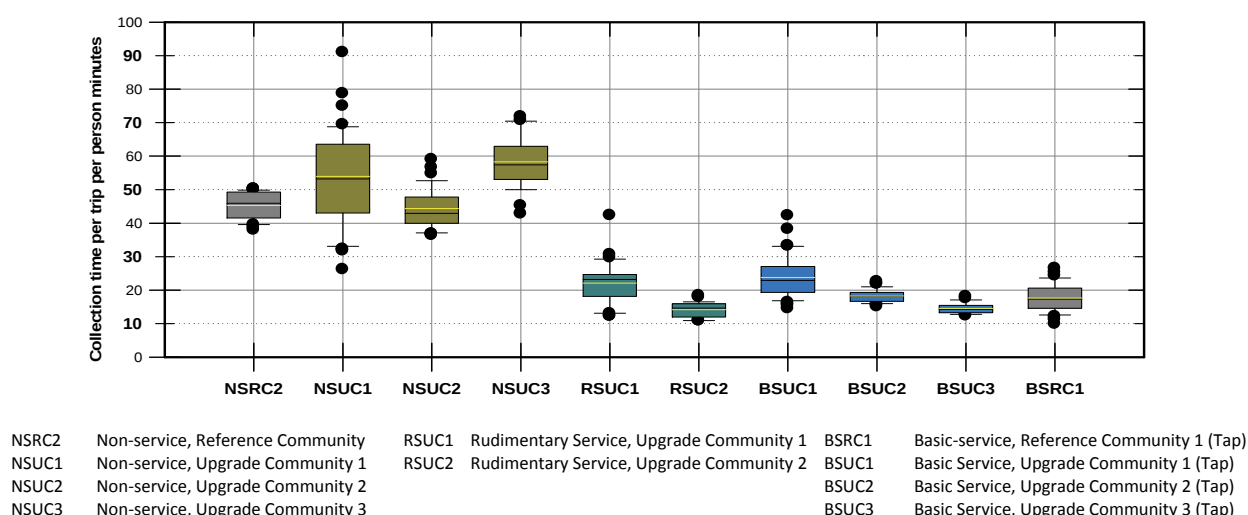


Figure 3.1: Collection time per person carrying a 20-l container across the levels of service

The individual collection time during the non-service era was significantly longer ($p \leq 0.001$) when compared to the other two levels of service. A possible reason for this could be that the trip time and extra time at the NS level were longer. The collection time at the NS for UC1, 2 and 3 was longer than that of RC2, although distances to open sources in UC2 were not significantly further than those in the RC. The collection times for the UC1 and -3 was significantly longer than for RC1 and UC2, mainly because their trip times were the longest.

These times were reduced with the upgrading to the RS in UC2 and 3. In UC3 for instance, collection time was significantly reduced from 68min to 16min at the 90th percentile. Collection time for the handpumps RS in UC2 was significantly longer than for the tanks in UC3 because of the differences in filling times.

For all the UC's there was a (further) significant reduction in collection times with their BS. This is attributed to the reduced distances and consequently trip times as well as filling times. However, for UC3 there was no significant difference in the collection time at the RS versus the BS because the trip time did not change significantly. Nevertheless, the upgrade to BS generally brought about substantial savings in collection time for individuals in the upgrade communities.

4.2 The effect of the system upgrades on per capita daily water collection

Figure 3.2 below shows the water collected by the households for each person in the household (l/cd). The per capita collection under NS conditions was above the WHO guideline of 5 l/cd at the 10th percentile. UC3 collected the lowest quantities possibly because their open source points were also the farthest.

At the 10th percentile the RS data for UC2 and UC3 was 10 and 6 l/cd respectively, which was considerably lower than the minimum 15-l/cd used as benchmark. For both these upgrade communities there were no significant changes in the quantities of water collected during the RS period compared to the NS period. The quantities collected in UC2 were however, significantly higher ($p \leq 0.001$) than those collected in UC3. The low water collection under the RS for UC3 was a direct consequence of the community tanks being filled only once a month by vehicle tanker service, and because the community tanks had finite capacity (5,000 litres, which was too low for the community's water demand), households could not continue to draw water once water ran out at the tanks.

After the upgrade from RS to BS, both communities collected significantly more water during the remaining period of the project. However, this does not imply that they now collected what was expected. At the 10th percentile, the per capita daily collection for the BS was 15 l for UC1 and 11 l for UC2, which did not comply with the 25 l/cd benchmark. The reduction in distance to the water source points as well as improved availability at source would have influenced the increased water collection for UC2 but the frequency of breakdown and greater distances back to the alternative source for UC3 accounted for why they did not at least collect similar quantities of water per person than did those of UC2.

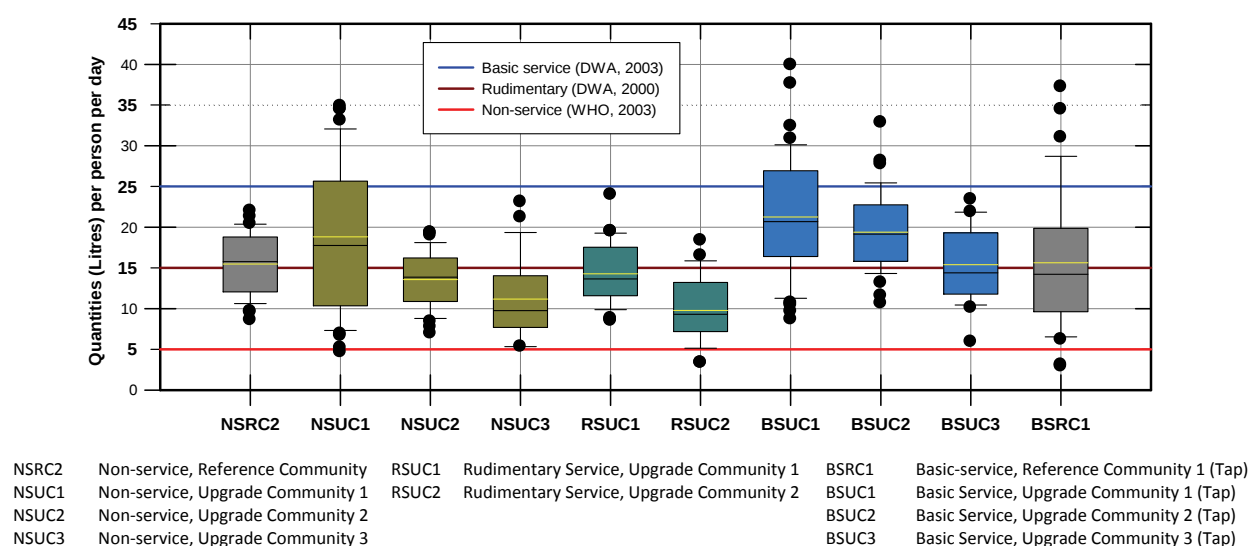


Figure 3.2: Per capita water collection across levels of service

While there was no significant reduction in distances to water points for UC3 between the RS and BS phase, availability at source did increase by 8%. Water collection per capita per day in UC3 remained lower than UC2, despite the similarity in the service. While this could suggest that the community may have adapted to set water use patterns during the other service conditions, it also reflected the lower percentage availability of the water from the upgraded system for UC3 because of the more frequent breakdowns because of poor system management.

The BS lcd for all four upgrade communities during the BS did not reach the benchmark 25 lcd at the 10th percentile despite the improved access and availability.

4.3 The risk of musculo-skeletal disorder as an effect of domestic water carrying

4.3.1 Results from the qualitative study

Analysis of qualitative data gathered from children in the study generated key themes (Table 3.10). From these themes a model of the interrelated effects of DWC and the potential ways in which DWC might impact upon health was developed.

Table 3.10: Qualitative themes

	Themes Derived From Qualitative Data
Theme 1.	Women and children collect water
Theme 2	Children's perceptions of health are broad
Theme 3	DWC has diverse effects
Theme 4	Attitudes to DWC are mixed
Theme 5	Coping strategies vary
Theme 6	Environment influences performance of DWC
Theme 7	Water supply system failures create difficulty
Theme 8	Changing DWC is important

An important property of well-designed health evaluation systems is that they should have 'content validity'; the content assessed by a measure should include elements that the target population perceive as relevant to the construct of interest (Atkinson and Lennox, 2006). Therefore, to assess the health impact of DWC on people in poor rural areas such as Limpopo, 'health' should be broadly conceptualised and incorporate impairment, but also capacity for functional activities and social participation. At the level of body functions people perceive that pain, joint mobility, energy and drive, general physical endurance, immunological and emotional functions can be affected.

In terms of activity and participation, their accounts indicated that schoolwork and housework, as well as recreation and leisure activities can be affected by DWC, particularly through time loss. Key ways in which DWC was perceived to improve health related quality of life were through facilitating water usage or generating income, so that the impact of DWC on meeting basic needs for cooking, drinking and washing should be considered as well as activities such as caring for plants and animals.

Analysis of the qualitative data gathered from adults supports the themes derived from full analysis of the children's interview and natural group meeting (NGM) data and is consistent with the model. The key findings from qualitative data were that:

- Children perceive DWC to affect their health in various specific ways, which can be mapped to ICF domains;
- The effect of DWC on the health status of children in poor rural areas should not only be evaluated in terms of body structure and function, but also in terms of functioning through activities and social participation;
- There is likely to be an association between DWC and musculoskeletal disorders, which requires further research into the type and strength of association.

4.3.2 Results from the quantitative study component

Four methods of DWC were observed. These were 1) head loading of water-filled containers, 2) rolling a water-filled drum, 3) pushing a wheelbarrow weighted with filled water containers and 4) loading filled containers on and from a donkey cart (Figures 3.5a-c).



Figure 3.3a: Head loading and wheelbarrow



Figure 3.3b: Rolling the container



Figure 3.3c: Donkey cart

The proportion of participants who were observed collecting water using different methods are shown in Figure 3.3. All methods exposed the water carriers to hazards, such as road traffic, as all who were observed to perform DWC completed at least part of their journey on a roadway. During observation in two of the study villages, the usual water service to communal taps was interrupted due to failure of the water supply system (in both cases due to breakdown of the pump). As a result of the pump failure in one village, many people were observed to collect water from a spring outflow pipe at the same time, leading to crowding and congestion around the source. Many adults and children collected water amongst vehicles, donkey carts and domestic animals trying to access water from the same source.

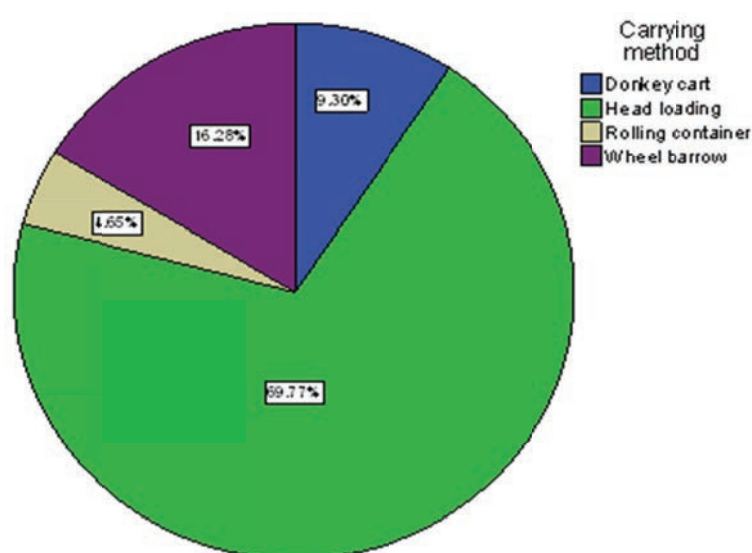


Figure 3.3: Distribution of DWC methods

All participants were judged to be at risk of trips, slips or falls due to the terrain, quality of paths or absence of suitable foot wear, especially when carrying the water home. The environment presented many physical obstacles to DWC (Figures 3.6a-d). These included barbed wire fences and gates, (Figure 3.5a), raised and often serrated (worn out) edges of concrete platforms at taps (Figure 3.5b), rocks and pipes (Figure 3.5c) as well as other

containers, equipment and people. Fifteen (75%) of the children were unsupervised during DWC and three (15%) collected from an open body of water.

The most commonly used containers for DWC were fully filled 20 to 25 litre plastic buckets or drums with inadequate or absent handles (Figure 3.5d). Container sides are smooth and were often wet, making them difficult to grasp securely.



Figure 3.4a: Obstacles to traverse with loads



Figure 3.4b: Communal tap protected



Figure 3.4c: Communal tap strengthened



Figure 3.4d: Typical containers for DWC

DWC requires awkward, repetitive or sustained end-range upper limb positions for most people (Figures 3.7a-c), either due to arm elevation above shoulder height to hold and steady head loads (Figure 3.5a), reaching down into and lifting water loads out of walled water sources such as a protected spring (Figure 3.5b), lifting containers over the sides of a donkey cart or using inadequate equipment. For example children use wheelbarrows designed for adult physical proportions (Figure 3.5c). DWC exposed most people to fatigue because of sustained adverse positions and load carriage, particularly head loading.



Figure 3.5a: Sustained arm elevation during carrying



Figure 3.5b: Reaching into a spring



Figure 3.5c: Inappropriate wheelbarrow size

Communal tap and supporting platform design as well as household storage sites frequently required awkward postures for lifting (Figure 3.6a), carrying (Figure 3.6b) as well as lowering and placement (Figure 3.6c) of containers. This was particularly evident when containers were filled or stored at ground level, or placed inside dwellings with low doorways and at times dark and smoky interiors (Figure 3.6c). Children who weren't collecting water, but accompanied or were carried by their mothers during DWC were also exposed to hazards. Babies carried on the back are in the direct line of impact should a head load fall backward.



Figure 3.6a: Full lumbar flexion for lowering and placement



Figure 3.6b: Stepping over a pipe



Figure 3.6c: Flexion and side bending for lifting

Head-loading, pushing a wheelbarrow and rolling a filled container were the three methods used by people to perform the physical work of transporting containers of water from the WSP to their homes. OWAS analysis of three cases revealed that these techniques potentially involve a high frequency of postures which have significant strain effects (Table 3.11) and for which corrective solutions would be recommended in industrial settings not even considering the potentially detrimental effects of head loading.

One of the youngest participants observed rolling a container demonstrated postures considered to have obvious harmful effects and to require an immediate corrective solution during 71% of the time that they were observed water carrying.

Table 3.11: Descriptive statistics all DWC data (excluding carrying by donkey cart method)

Variable	N	Mean (sd) ¹	Median (IQR) ²	Range
Age (years)	39	25 (15.49)	25 (12-33)	6-64
Height (cm)	39	151.5 (17.56)	158 (142-162)	110-176
Weight (kg)	39	49.5 (21.74)	55 (30-61)	16-106
Total weight containers carried (kg)	33	27.4 (21.25)	21 (19.9-26.2)	4-110
Individual container weight (kg)	33	20.8 (6.28)	21 (19.9-26.0)	4-29
Number of containers carried	35	1.23 (0.65)	1 (1-1)	1-4
Frequency per day	23	3.4 (2.11)	3 (2-4)	1-8
Total daily lifting load (TDLL) ⁴	19	166.62 (158.54)	126 (52-265)	30-650.40
Days per week	24	5.96 (2.09)	7 (7-7)	1-7
RPE ⁵	35	6.77 (2.89)	7 (4-10)	2-10
Distance (m)	35	330 (177.61)	320 (160-440)	40-650
Carrying time (minutes)	37	5m43s (4m4s)	5m9s (2m16s-7m3s)	40s-15m17s
Total daily carrying time (TDCT) ⁶	22	18m (13m)	18m (5m50s-26m40s)	1m 24s-45m39s

¹sd: standard deviation; ²IQR: inter-quartile range; ³mm: multiple modes exist;

⁴TDLL: Total daily lifting load = mean weight lifted x number of occasions of lifting and lowering the load per day ((frequency per day x2) x times number of containers per day) x mean weight of container;

⁵RPE: rating of perceived exertion measured with Modified Borg's Scale;

⁶TDCT: Total daily carry time = duration of carrying x usual number (reported frequency) of carrying episodes per day

The key findings from quantitative data were that:

- Typical techniques of DWC include handling heavy containers by head-loading, rolling or use of wheelbarrows or donkey carts, all of which impose loading and postures with high potential to produce physical strain and injury. Urgent action should be considered based on recommendations appropriate for adult workers performing similar tasks in industrial settings;
- Although compression forces generated purely by the weight of filled water containers seem unlikely to exceed tissue injury tolerance levels, women and children are potentially vulnerable to mechanisms for physical injury through sustained or repeated loading and unexpected movements or accident during DWC;
- A key recommendation is that efforts should be directed toward eliminating the need for DWC by providing piped water to households at least to the premises on which the household resides, or where DWC must continue, reducing risk factors for musculo-skeletal disorders (MSD) and physical injury. Good handling practices which exist should be supported and further education about potential risk factors for MSD and hazards provided to community members. However, improved design and maintenance of equipment and infrastructure may also reduce exposure to hazards and risk factors for injury and be important avenues for intervention. Future research should aim to better understand the type and strength of association between DWC and health particularly MSD.

4.3.3 Physical work load assessment

The results of the qualitative and quantitative data were synthesised to identify the factors which should be measured to indicate the physical workload per household imposed by DWC, particularly in a way which is feasible for use in remote rural settings and has content validity with respect to the population being measured. The key factors are distance over which water is carried in meters, which is weighted by the presence or absence of an incline, and the quantity of water collected per household.

4.3.3.1 Distance

Load weight has been shown to contribute most significantly to compression force on the spine (Murphy et al., 2007) and carrying loads on the head as observed in this study will obviously exert compression forces through the cervical spine (Wong et al., 2007). Use of light-weight plastic containers minimises the contribution of container weight to loading, however the volume of typical containers facilitated DWC with loads around 20 to 25 kg (Table 3.10). The time over which individuals are subject to sustained compressive loading will influence the physical effects of that loading on the body.

The time taken to carry water containers from WSP to home (and therefore sustained loading) was found to have a strong positive linear correlation with distance. Distance between the water source point and house can be easily measured when the location of water source points such as communal taps are known. Distance can therefore be used as an indicator of physical work load or potential strain due to carrying time; the assumption is

that reduced distance equates to reduced duration of sustained tissue loading per water carrying trip and represents a reduction of health detriment.

4.3.3.2 Daily lifting load and frequency

Frequent bending and lifting, particularly from ground level to above shoulder height is an accepted risk factor for injury and musculoskeletal disorders in western industrial settings. The median frequency of the DWC occasions per individual per day was 3 (IQR 2-4.25), with a range from 1-10. The design of communal taps together with head loading as the most commonly observed method of carrying water suggested that water filled containers are frequently handled from ground level to above shoulder height. Each DWC occasion will involve at least two 'lifts' to raise the container for carrying and eccentrically lower it for placement at home.

A recent psychophysical study of adult women (Ciriello, 2007) evaluated the maximum acceptable weights (MAW) for lifting small and large boxes from floor to knuckle height and the effect which lifting frequency had on MAW. The weight of individual containers lifted and lowered through that level by most of the participants in this study, at 21kg (IQR 20-26kg), was close to the mean MAW (24.6kg) reported by adult female workers performing one lift every 8 hours (Ciriello, 2007; Singh et al., 2009). Considering this, the more frequent lifting (for example 3 or more times per day), particularly by children in the study are means that DWC can impose load weights and lifting frequencies which exceed MAW for lifting without strain.

The impact of such frequent lifting will also be influenced by the amount of 'rest' or non-loading time between lifts, however safe parameters for repetition and rest time within loading cycles have not been established generally (Arokoski et al., 2000; Bachrach et al., 1995) and particularly for DWC. The time at which people collected water varied, and was influenced by factors such as availability of water at the tap, household water requirements and fitting in DWC with other activities such as school attendance. DWC was often organised so that several DWC episodes occurred with each immediately subsequent to completion of the previous episode. Therefore, assuming the minimum water collection frequency of once per day or median frequency of 3 times per day, and comparing the weight of containers lifted directly to the data of Ciriello (2007) and Singh et al. (2009), it is apparent that most women and children in this study lifted loads close to the maximum acceptable weight when performed by adult women in Western industrial settings.

However there may be considerable differences in physical work capacity of poor rural populations and those from a Western industrial setting, such that loading tolerance is lower in areas such as Limpopo. The age range of those collecting water (6- 64 in this study) will be greater than that in a working Western population and include children and elderly people. People in poor rural communities performing DWC may also have poorer general health or greater co-morbidity than working populations in developed countries (Hsie and Lotz, 2003).

The volume of water used in a household may not vary greatly with distance and time but the findings on household collection times earlier in this chapter suggest that contrary to the effects of sustained loading, lifting occasions may increase when water source points are at closer distances and decrease when water farther away, suggesting a trade-off between more lifting but being under shorter loading distances compared to less lifting but longer distances under load. It could be argued that those with very close connections (house or yard water connection say within 10 metres) are likely to use smaller containers (i.e. 10-l in volume) as was shown by Jagals et al. (1999) so that frequent lifting of smaller volumes becomes safer, or the requirement for lifting containers reduces altogether.

A more important driver of variation in the amount of lifting an individual performs may be the number of people in the household and whether water collection is a shared task. Therefore distance of water source points from the home and subsequent return trip travel time may influence physical loading due to the volume of water collected and the number of lifting episodes required to collect that water. However this may be a stable influence which changes little in villages with communal tap provision. It therefore would seem important to determine the number of people in a household to estimate absolute consumption levels and subsequent lifting loads, but also the proportion of people in a household who usually collect water.

The total volume of water handled and the number of times a water filled container is lifted or lowered each day per household were therefore considered to be factors influencing the physical work load of DWC and likely to be related to risk of MSD. The physical work due to DWC can be indicated by the total volume of water collected per household which will indicate the number times a water filled container is lifted and lowered. What is then likely to influence the level of impact is whether water collection is performed by one individual or is a shared task.

The deduction that can be made from these findings is that is that reduced quantities of water carried as well as the number of handling occasions per individual represent reduced risk of MSD.

4.3.4 The effect

The assessments were made of the water carriers in the communities that had basic services and in the communities that were still on no service (discussed earlier). The boxes in the plot of Figure 3.7 (next page) show the weighted scores for comparing the BS and NS condition for each factor.

There were no significant differences between any of the factors for the BS and NS conditions except for the total daily carry time – i.e. the time the water carrier was under the container filled with water, where the NS showed a significantly higher ($P = 0.004$) effect than the situation for the BS communities. This is similar to the findings about the carrying times under the total collection time discussed in Section 4.1 above.

Although not statistically significant, the higher age of the water carriers in the NS communities can be ascribed to the fact that the open water source points are much farther and often rather remote with households tending not to send young children to fetch water. The importance of these findings are that, in the context of the water carry toil in the communities assessed in this project, it really did not matter whether the water carriers fetched water from taps at communal standpipes or from water source points at their open sources.

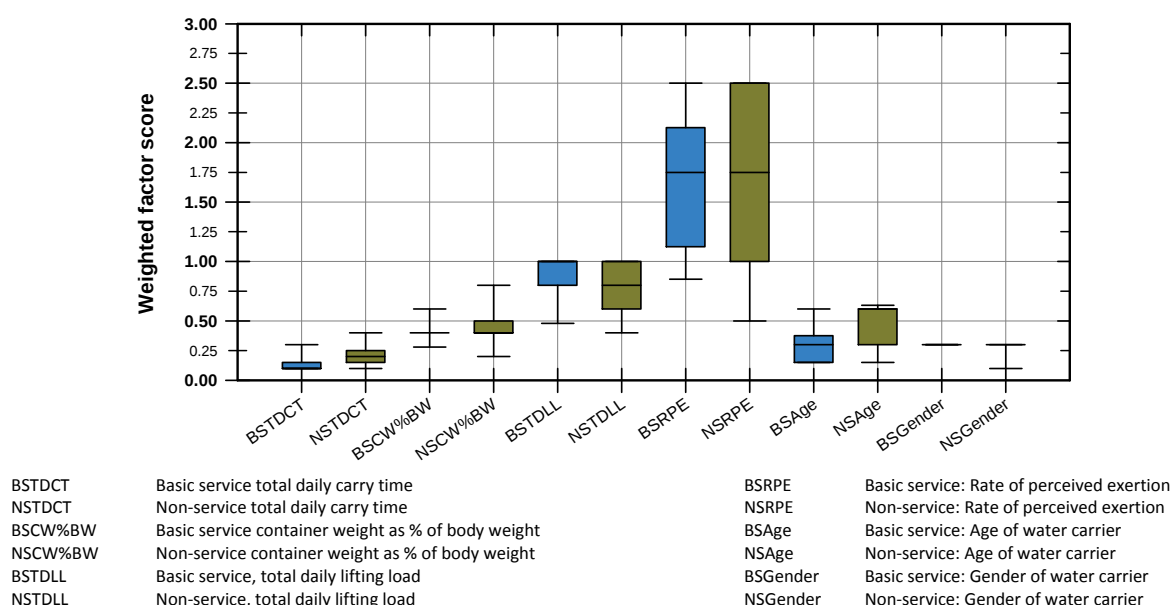


Figure 3.7: Factors that affect domestic water carriers under non-service and basic service conditions

A combination of the weighted criteria scores in Figure 3.8 show just this. The effects of domestic water carry under BS and NS conditions did not differ for the water carriers of the two sets of communities. Even if the NS effect did vary more, this was not statistically significant ($P = 0.572$).

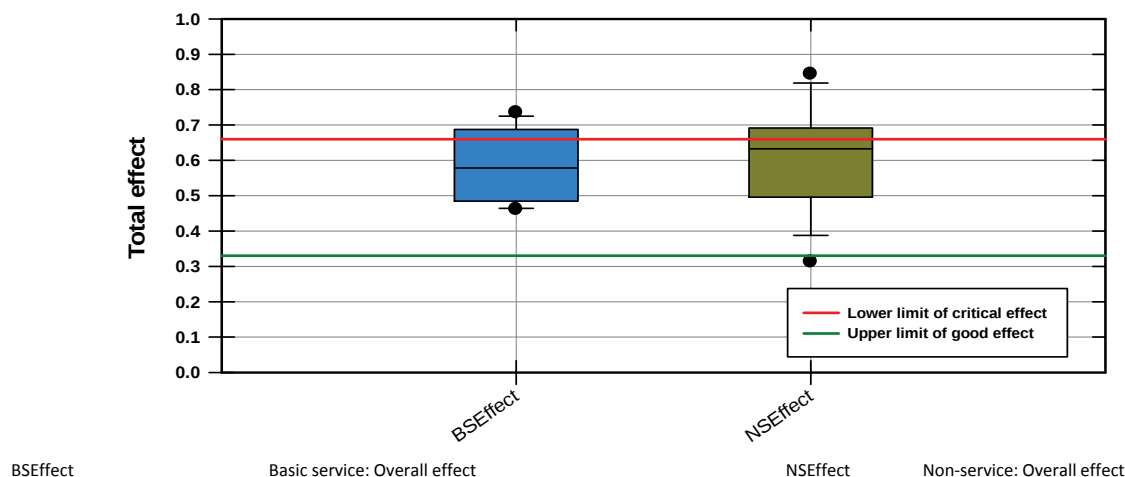


Figure 3.8: The effects of domestic water carry under non-service and basic service conditions

The NS water source points were farther (as was already shown in Chapter 2), which meant that the carriers had to stay under the load longer, tended to haul as large a container they could find to avoid extra trips and generally experienced water carry in a more negative light (RPE), although not the factor result was not statistically significant ($P = 0.983$ Figure 3.8).

On this basis it shows that the effects of domestic water carrying, at the 90th percentile (upper whisker of each boxplot) were well into the “clearly detrimental” margin and at the 10th percentile, well into the area of being merely “sufficient”.

4.3.5 Conclusions

This DWC study component, in statistical terms, was probably too limited in the numbers of respondents observed and interviewed to provide strong validity to the results. This study should at best be seen as a pilot study and the results treated as such.

Furthermore, the study was only once off, meaning that *before* and *after* intervention scenarios could not be assessed and compared. Nevertheless the study was conducted in several of the reference and upgrade communities which made it possible to use the reference community with no service as proxies for the before situations of the upgrade communities. Regardless of the fact therefore that this was a limited study, the results and literature review indicate that musculoskeletal disorders (MSD) are a likely consequence of DWC, from both the perspective of people engaged in DWC and from fieldwork observation using an ergonomic systems approach for evaluation of DWC.

4.3.6 Recommendations

The DWC Physical Burden Scale is suggested as a method of assessing the likelihood of DWC to have a detrimental health impact. The DWC Physical Burden Scale should be applied at a wider scale to validate and refine its psychometric properties, particularly reliability, validity and responsiveness. Further research should be conducted to determine the type and strength of association between the DWC Physical Burden Scale, its component parts and musculoskeletal disorders, as well as other aspects of health such as disability and social participation.

4.4 Changes risk of infection as an effect of the water supply intervention

4.4.1 Exposure

The measurements to be discussed in this section are household water consumption and container water quality based on indicator *E. coli*. Assumptions were made of pathogen fractions within indicator numbers.

4.4.1.1 Household drinking water consumption

This section presents data, compounded for all the study communities, of the daily consumption of water measured in the households. A single consumption rate is derived from this and expressed in litres per person per day (ℓpd). Table 3.12 shows the arithmetic mean and the lower and upper limits of the 95% confidence interval for unheated water used daily per individual for consumption across age groups. The water consumption (in ℓpd) in the five community groups did not differ significantly ($P=0.454$) across age groups and gender.

Table 3.12: Water consumption per age group (years) in litre per person per day (ℓcd) across the three villages

	≤1y	>1≤5y	>5≤12y	>12≤20y	>20≤65y	>65y	Average ℓpd
Mean	0.35	0.83	1.00	1.36	1.70	1.55	1.13
95%UCi	0.45	0.94	1.12	1.49	1.79	1.76	1.26
95%LCi	0.34	0.83	0.99	1.36	1.67	1.54	1.12
95% Ci	0.10	0.12	0.13	0.13	0.11	0.22	0.13

95% Ci = 95% confidence interval; 95% UCI = Upper level of the interval and 95% LCI = Lower level of the interval

Jagals et al. (2006) reported that household water consumption per person per day did not deviate markedly from their usual daily drinking water intake as a result of the intervention (closer taps). To derive a plausible and conservative expression of risk (worst case scenario), the upper level of the 95% confidence interval was used as the consumption variable (1.26 ℓcd in the grey block in Table 3.12). Mons et al. (2005) reported that in mostly developed country settings, an average consumption of cold tap water could be expected to range from 0.2-1.55 ℓper day which was in keep with the consumption volume of 1.26 ℓcd used for this component of the

work. The consumption of unheated water was higher than the WHO Guideline of 1 litre per person per day (WHO, 2003). This was expected since the study area was in a high temperature region compared to most parts of South Africa (in summer the temperature could rise to >40°C).

4.4.1.2 Indicator *E. coli* in container water

Table 3.13 shows the quality of water based on indicator *E. coli* bacteria, sampled from the containers *before* and *after* interventions. This study focused on the health-related microbial water quality (HRMWQ) of water sampled from containers that are used by households in which to collect water from the source and store it at home while they use (including consumption) the water. The source from which the water is collected played a role in the quality of water sampled from the container. Because of the different source situations of the communities, the container water quality was considered separately of each community.

Table 3.13: Indicator *E. coli* numbers (per 100 mL) in container water, grouped by the respective study communities

	RC1		UC1		UC2			UC3			RC2
	BS	BS	NS	BS	RS Handpump	NS	BS	RS Tank	NS	NS	NS
Geomean	0.2	0.3	45	0.1	0.31	15	0.15	0.3	23		25
95% UCI	0.5	0.5	98	0.2	2	28	0.30	1.3	75		61

UC1 -2 -3 = Upgrade communities; RC 1 -2 = Reference communities; BS = Basic water supply, RS = Rudimentary water supply; NS = No service; Geomean = Geometric mean; UCI = Upper limit of Confidence interval.

4.4.1.3 Diarrhoeagenic *E. coli* numbers derived from indicator *E. coli* numbers

The pathogenic *E. coli* strains were calculated from the positive indicator *E. coli* samples. All positive samples of *E. coli* were assessed for the presence of haemorrhagic (HEc) and non-haemorrhagic *E. coli* (NHEc). Table 3.14 shows the number of samples from containers that tested positive for *E. coli* indicators as well as the percentage of the indicator-positive samples that had contained diarrhoeagenic *E. coli* (DEc). The table shows only the percentages of non-haemorrhagic and haemorrhagic *E. coli* *per* and not yet any quantitative application, which will be shown in the next table (3.15). The various strains of DEc were detected randomly in the positive samples from the containers throughout the sample set, with some particular strains being more prominent in relation to the source from where the water was fetched, i.e. the container water sampled from river water sources from the NS period had a specific pathogenicity, the water for UC3 with its surface water treatment system its own unique pathogenicity as had the containers sampled from, the waters that acme from stable groundwater sources.

Table 3.14: Percentage of *E. coli*-positive container water samples containing diarrhoeagenic *E. coli*

System character	Negative samples	Indicator-positive samples	Pathogen analyses % positive indicator <i>E. coli</i> samples containing pathogenic <i>E. coli</i>	
			NHEc	HEc
Stable system with groundwater source	74%	26%	39%	22%
Unstable surface water treatment system	53%	47%	17%	40%
Untreated open sources	16%	84%	61%	14%

NHEc = non-haemorrhagic *E. coli*; HEc = haemorrhagic *E. coli*

As expected the lower pathogenicity percentage for the total DEc was found in the container waters sourced from stable groundwater sources. It was not clear why the container water from the system with surface water treatment showed such higher pathogenicity in terms of virulence (HEc more pathogenic – refer to component review above) – this was a very erratic system with many interruptions during the study period as well as intermittent filling of containers at contaminated open water sources. The open waters from the NS period showed, despite almost all samples being positive for indicator *E. coli*, a much lower virulence because of the much lower HEc percentage.

With the data in the two tables shown directly above, it is now possible to calculate the exposure for the respective communities.

4.4.2 Exposure to pathogenic *E. coli* per daily water consumption

The approximate daily intake of indicator organisms as well as the exposure to *E. coli* pathogens based on the number of indicator organisms per 1.26 Lcd is shown in Table 3.15 – *before* and *after* the intervention for the upgrade villages. The alternative river source for RC1 is shown here since this community did not enjoy a flawlessly operating system and had to use alternative open water sources during interruptions.

The numbers of indicator *E. coli* and consequently the *E. coli* pathogens were significantly reduced by the interventions, especially when the basic supply service was established in the various upgrade communities. This much lower level of exposure indicated that, once people started using water from a clean source, container water also reflected the change. However, water from the containers that were collected at the new taps still did not comply with the WHO drinking water quality guidelines (2004) or the SANS (2006) which stipulated that there should be zero *E. coli* in drinking water. Jagals et al. (1997; 1999; 2003) also reported that, although water at the taps of new systems did generally comply with *E. coli*-based drinking water safety guidelines, these levels deteriorated in containers to levels that continued to pose a risk of infection.

Table 3.15: Numbers of *E. coli* pathogens derived from indicator *E. coli* (iEc) numbers (at the 95%UCI) in 1,260 mℓ (daily per capita consumption) of container water – sourced from BS and RS/NS sources per community

	RC1		UC1		UC2			UC3			RC2
	BS	Alt	BS	NS	BS	RS	NS	BS	RS	NS	NS
Daily iEc exposure	6	25	6	1,260	3	25	479	4	16	942	786
NHEc	2	10	3	755	1	10	290	1	3	570	463
HEc	1	6	1	177	1	6	67	2	7	131	107
DEc	3	16	4	932	2	16	357	3	10	701	670

UC1 -2 -3 = Upgrade communities; RC 1 -2 = Reference communities; BS = Basic water supply, RS = Rudimentary water supply; NS = No service; UCI = Upper limit of Confidence interval; NHEc = non-haemorrhagic *E. coli*, HEc = haemorrhagic *E. coli*

What remains now to be calculated is the annual risk of infection for an individual that consumes these waters. Because of the different level of virulence (and consequently different dose-responses), the HEC and NHEC numbers are dealt with separately in the consequence assessment, hence the reason for keeping them separate in Table 3.15 above.

4.4.3 Consequence

In this section the risk of infection of an individual per year will be discussed. Table 3.16 shows the various infection rates for individuals in the study communities. These are then calculated into acceptable risk based on benchmarks derived from these findings (As there are no such benchmarks in SA). Finally, before the last section of this chapter summarises the effects, the different levels of risk as introduced by system interruption will be discussed. Section 3.4.4 above described how the risk would be calculated from the dose response parameters shown in Table 3.4. Table 3.16 shows how the probable infections (numbers rounded) were significantly reduced ($P = 0.001$) from the no service period through after the basic services were established in the study communities. The numbers in the table are the absolute numbers – that is if the community had stayed on that particular system 100% of the time during the year. As was the case with all the upgrade communities and RC1, this did not happen as was shown in Table 2.10 in Chapter 2.

Table 3.16: The risk of bacterial infection per individual per year posed by pathogenic *E. coli* in container water – sourced from BS and RS/NS sources per community

Exposure	RC1		UC1		UC2			UC3			RC2
	BS	Alt	BS	NS	BS	RS	NS	BS	RS	NS	NS
iEc	6	25	6	1,260	3	25	479	4	16	942	786
NHEc	2	10	3	755	1	10	290	1	3	570	463
HEc	1	6	1	177	1	6	67	2	7	131	107
Dec	3	16	4	932	2	16	357	3	10	701	670
Consequence											
Infections/capita/annum	3	10	3	114	1	15	82	3	11	139	85

UC1 -2 -3 = Upgrade communities; RC 1 -2 = Reference communities; BS = Basic service, RS = Rudimentary service; NS = No service

Members of the upgrade communities were often compelled to return to their alternative sources during prolonged breakdowns of their systems. These sources were mostly untreated open waters, thereby increasing their risk again. These changes in risks had to be factored in before the actual risk could be finally assessed and acceptable risk level established and the performance ranking (good, sufficient, critical) assigned. Table 3.17 shows how the system interruptions influenced the resident risk of each risk condition.

Table 3.17: Risk of infection per individual per year adapted according to percentage of time exposed alternative sources

Consequence	RC1		UC1		UC2			UC3			RC2
	BS	NS	BS	NS	BS	RS	NS	BS	RS	NS	NS
Infections/capita/annum	3	10	3	114	1	9	82	3	11	139	85
Percentage interruption time	20%		15%		11%	17%		42%	50%		
Resident risk (Based on % time on BS/RS)	2		2		1	7		2	6		
Increased risk (Based on % time on NS during BS/RS)	2		2		4	7		18	70		
Adapted annual risk	4		4		5	14		20	76		85

UC1 -2 -3 = Upgrade communities; RC 1 -2 = Reference communities; BS = Basic service, RS = Rudimentary service; NS = No service

Figure 3.9 presents a visual appraisal of the results in Table as well as shows the benchmarks for acceptable risk devised for this study. The *original* risk posed by the waters in containers sourced from open sources was substantial – much less so though for RC1, whose original (now alternative) source is a protected spring. The cleaner waters which the community now could source, eventually contributed to significantly reducing the risk from the original risk to what then should become the *resident risk* while using their basic service. However, with the breakdowns, this risk increases again as was adapted.

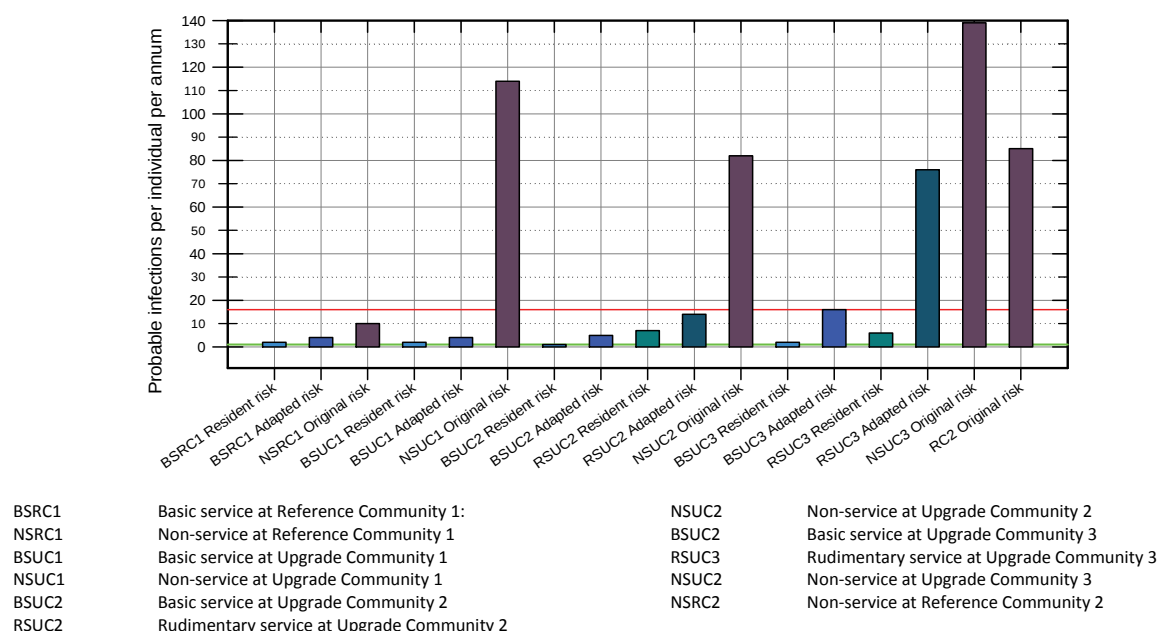


Figure 3.9: Shifts in risk attributable to the water supply service interventions

The benchmark for acceptable risk was therefore set at 1 probable infection per individual per annum ($P_{inf,y}$) because this was the best performance in reducing risk achieved (BSUC2) by a basic supply service in any of the study communities. A basic water system that supplies water which poses a probable risk of infection of 0 (zero) will be ranked as “good” (0). This is achievable where a household has an onsite connection, does not store water in containers, and the supply does not test positive for any *E. coli* bacteria. However, based on these results, $0 < P_{inf,y} \leq 1$ was ranked as (1) “compliant”. The upper limit for risk being reduced compliant (the baseline for (2) non-compliant) was placed at $\leq 16 P_{inf,y}$ as this was the worst performance (after adapting the risk) of the upgrades to a basic water supply system. Any system that supplies water at $\geq 16 P_{inf,y}$ is a system performing critically poor (3) in reducing risk.

5 SUMMARISING THE EFFECTS OF WATER SUPPLY FUNCTIONS CHANGES

The effects values reported above are posted in Appendix A and summarised here in Table 3.18. The four-tier bench-marking scheme was used.

Table 3.18: Benchmarks for the effects of functions changes

Effect	Parameter	Performance			
		Good=0	Compliant=1	Non-compliant=2	Critical=3
Time	Individual collection time in minutes per 20-l container	≤ 5	≤ 15	≤ 25	> 25
Water use	Litres per person per day @ 10 th percentile	> 50	$\geq 25 \leq 50$	$< 25 \geq 15$	< 15
Risk	Risk of musculo-skeletal disorder	< 0.1	$\leq 0.33 \geq 0.1$	$> 0.33 \leq 0.66$	> 0.66
	Risk of bacterial infection per year per individual	0	≤ 1	$> 1 \leq 16$	> 16

The interventions did not have any effects that could be described as good or compliant (Table 3.19). These effects in the end were not as much caused by the inherent quality of the system both in design as well as the quality of the water it provided, but was caused by poor maintenance and operation.

Time was indeed saved by reducing the total individual collection time from what was spent collecting water during the no-service period to what is being spent using the basic water supply service. Most water carriers were still spending “non-compliant” or “unacceptable” amounts of time to collect water for their household needs because of excessive extra time.

Table 3.19: The effects of the service function changes

Effect	Parameter	RC1	UC1		UC2			UC3			RC2
		BS	NS	BS	NS	RS	BS	NS	RS	BS	NS
Time	Individual collection time in minutes per 20-ℓ container	2	3	3	3	3	2	3	2	2	3
Water use	Litres per person per day @ 10 th percentile	3	3	3	3	3	3	3	3	3	3
Risk	Risk of musculo-skeletal disorder	3	3	3	3	3	3	3	3	3	3
	Risk of bacterial infection per year per individual	2	3	2	3	2	2	3	3	3	3

Daily water quantities were also not collected to the extent as was expected. Despite the water source points being significantly closer, and the quantities collected were significantly more using the basic water supply service, households seem to bring in the quantities according to their own specific needs, with no indication whether the much vaunted minimum of 25 ℓcd would be achieved.

Despite the method for assessing the risk of MSD still being robust at this stage of this work, it still gave a good indication of the toil that water carriers are clearly subjected to excessive risk of MSD.

While there was some relief for some of the communities in terms of the risk of infection, the container situation still continued to pose a risk.

CHAPTER 4

IMPACT ASSESSMENT

1 INTRODUCTION

The results in Chapter 2 showed that there were significant and seemingly beneficial function changes brought about by the water supply interventions – incrementally (from no service to rudimentary service to basic service) as well as direct intervention (no service to basic service). The functions of access, availability and potability were improved significantly but for the individual householder and inter alia, for the household itself, these did not appear to translate into any beneficial effects in terms of the *effect* indicators used in this study (Chapter 3). This is in all probability because of the use of containers to collect from the improved source points and store water at home while using it, as well as poor maintenance and operation of the water supply systems.

This does not however, mean that the service improvements failed. The overall impact still requires consideration based on the measured (actual) impacts of the interventions on the health, sociology and economics (HSE) of the recipient communities. These will now be discussed in terms of *benefit*, *detriment*, or simply *no measureable impact*. It could very well be, as were pointed out in the previous chapters, that the actual impact that was already achieved at this point is beneficial and with a few marginal changes in policy, forward thinking and improved service delivery, the effect values as proposed for future indicators (Chapter 3) could well be achieved.

The values reported in Chapters 2 and 3 will be the foundation of the water supply service assessment tool, with the HSE impacts as the likely outcomes.

The tool would be valuable for future assessments, as it would provide benchmarks against which to measure the many snapshots of function change situations elsewhere. Such findings can then be related to the HSE impact benchmarks developed during this study (and as hopefully refined by similar future research).

The purpose of this chapter is then to present the HSE impact assessment (methods as well as results) of the caused by the interventions on the selected communities and to benchmark the outcomes.

1.1 Aim

The changes in water supply services, as well as effects brought about by these changes, were to be described in terms of health, social and economic HSE impact (benefit, no measureable impact or detriment).

1.2 Objectives

The following impacts were assessed in terms of the system changes and their effects:

- Health – changes in the relative risk of contracting diarrhoea;
- Sociologic – the level of satisfaction amongst the members of the recipient communities relatable to the improved functions;
- Economic – a total cost benefit analyses based on the cost-benefit ratios, based on present value of benefits to the present value of costs.

2 HEALTH IMPACT

Placing an impact value to health almost proved, in the end, a superfluous exercise because the question kept arising as to what is meant by a *health benefit*? How does one quantify or even qualify a health benefit? Other than reflecting direct and measureable economic benefits (e.g. saving treatment cost), or measurable social gain (*feeling happy or feel more secure because I am not ill*), it was difficult to place a “health” value on health impact. Nevertheless, if a change in water supply services could be associated with reduction in a particular and related disease endpoint, in the case of this study it was acute diarrhoea, then it is definitely construed as a definite albeit an abstract benefit. For this project, values of health benefits were mostly presented in economic/social terms.

The World Health Organisation has estimated that 94% of diarrhoea cases can be prevented through environmental health interventions, amongst them increasing access to and the availability of safe drinking water (Bartram and Gordon, 2008). Yet despite the general acceptance of the importance of drinking water, some 272 million rural dwellers in sub-Saharan Africa still lack access to an improved supply (Rural Water Supply Network,

2009). It is in these areas that one of the key millennium goals of reducing by one half the proportions of people without access to safe water by 2015 is very unlikely to be met (Montgomery and Elimelech, 2007).

Problems of access to improved drinking water are particularly acute for rural communities who traditionally have had to obtain their drinking water from untreated surface sources, often situated some distance away from their home (Hemson, 2007). Indeed, problems with access to safe drinking water for rural communities are not restricted to developing country settings but are also an issue for most western countries (Hunter et al., 2009a). In rural South Africa, where water supply infrastructure has been largely rudimentary or non-existent, small-community water supply systems have become the common mode of water supply (Momba et al., 2008). In these areas, water supply infrastructure is usually in the form of shared facilities such as communal taps (Peter-Varbanets et al., 2009). These supplies have varying reliability, with an unacceptable proportion of apparently improved supplies being non-operational when inspected (Rietveld et al., 2009). A recent assessment of rural water services by the South African Department of Water Affairs revealed that at least one out of every ten systems was not functioning (DWA, 2008).

One of the major problems facing the drive to provide access to improved drinking water has been the lack of strong evidence of the public health benefits of these supplies. Recent reviews of reports on drinking water, sanitation and hygiene interventions found little evidence that community water interventions provided a real public health benefit in terms of reducing the incidence of diarrhoeal disease (Bartram and Gordon, 2008; Rural Water Supply Network, 2009). Zwane and Kremer (2007) state that “the case for prioritizing communal infrastructure provision needs to be made rather than assumed” while point-of-use household water treatment (HWT) and hygiene are stated to be more effective interventions. Apparent public health gain from HWT may be illusory and due to reporting bias from lack of blinding in study design (Schmidt and Cairncross, 2009).

There is a great need for more and effective studies of the health benefits that may be gained from small-community drinking water supply interventions and to assess what may and may not be effective. As was shown in the earlier chapters of this work, reliability of the supply systems was problematic. This then also called for assessment of the impact that poor reliability has on the health objectives of such an intervention.

The objective of the study presented here was to determine the impact of new small-community water supply systems on the health of the recipient communities described in Chapter 1. Using diarrhoea incidence as an indicator of this impact, this report presents evidence of how small-community water supply systems and their reliability might impact on health. In the study area, diarrhoeal incidence for children under the age of five in the area was 224.3 per 1,000 in 2002, compared to the national average of 133.4 per 1,000. At the time, the district was also below the national averages in terms access to safe water supply (Gundry et al., 2009).

2.1 Methods for measuring health impact

2.1.1 Study area

The findings reported here was from a longitudinal case-control epidemiological study done across three of the five project study communities. Two of the three upgrade communities (UC2 and UC3) were assessed because the interventions came within the study period, making these communities much more suitable for collecting longitudinal disease data instead of relying on illness recall of respondents over an unacceptably long time as would have been the case with UC1 and RC1.

UC2 had a stable groundwater-fed communal tap system and UC3 a treated surface water system with both communities feeding its own communal tap system (Chapter 1). The third community used in this particular study component was the non-serviced reference community (RC2) that received no intervention and continued to use water collected from a river throughout the study. As was demonstrated in Chapter 2, the supplies for UC2 and -3 became intermittent soon after the small systems were established in the two upgrade communities. This was mainly because of prolonged interruptions related to problems in maintenance and operation. During these non-operational periods the intervention communities used water from their original contaminated rivers sources, which were the same sources used by the reference community.

2.1.2 Ethics

Ethics clearance was obtained from the Tshwane University of Technology Research Ethics Committee. Consent to work in the area was granted by the local traditional leaders. At the households, informed consent was obtained from the household head who signed the consent form (translated into the local language) after having read and/or heard and understood it.

2.1.3 Sampling

Coordinates and a waypoint address were established for each of all the households in the study area using global positioning system (GPS) devices (Garmin 60 Csx®). The mapping software programme OziExplorer® was used to download the household addresses from the GPS devices and export them to text files from where these were imported into Microsoft Excel® spread sheets. Each household was allocated a unique identity code in the spread sheet, which was used for randomly selecting, as well as identifying all collected data, its capturing and analysis for the particular household throughout the study.

2.1.4 Data collection

The respondents were mainly the senior matriarchs in the household such as the mother, or another household member suitably in a position to provide the relevant data on behalf of the household. Demographic and socio-economic data were collected during structured interviews with the respondents. TshiVenda is the language most commonly used in the study area, so the structured questionnaires were first compiled in English then translated into TshiVenda and then back-translated to English. To determine whether the study communities were sufficiently homogenous for comparison of disease incidence, data were collected on family size, gender and age, as well as education, income and housing as indicated in Section 2.2.1 (Chapter 2).

The respondents were issued with and trained to use symptom diaries (translated to TshiVenda), for keeping daily record of diarrhoea incidences in the household. The case definition for diarrhoea was three or more loose stools within a 24-hour period. An episode of diarrhoea was considered to have ended after 48 consecutive hours without three or more loose in 24 hours. Fieldworkers collected the diaries at the end of each week, and double-checked the recorded data with respondents and other household members. Diarrhoea data were collected over a period of continuous 56 weeks (July 2007 to July 2008). Diarrhoea data for the period before the water supply intervention (baseline data) spanned a period of 17 weeks with the remaining weeks providing the post-intervention data. Fieldworkers obtained and recorded from the water supply system operators as well as the households, the periods when the water supply system was non-operational after the intervention.

2.1.5 Statistical analyses

Data analyses were done with STATA™ version 10 and SPSS™ 17.0. Comparison of illness rates between the intervention (UC2 and -3) and non-intervention communities (RC2) were done using General Estimating Equations (GEE) to handle possible clustering within communities and households and repeat sampling from individual participants.

The water systems became operational in UC2 during week 18 and in UC3 the following week. Analyses prior to the intervention were restricted to weeks 1 to 17 and then post intervention analyses from weeks 19 to 56, making up a total of 38 weeks of follow-up. The first week was after the intervention was excluded from the analyses as it was not certain whether any diarrhoea caused during the end of the last pre-intervention week. To determine the effect that interruptions in supply had on the incidence of diarrhoea, GEE were conducted with community as a covariate ranked with number of weeks in which the system was actually operational for each of the communities.

2.1.6 Benchmarks for health impact

The question that now remains to be answered is what the implication was for health impact. The answers here appeared to be found using one of two approaches – one is to look at the percentage reduction based on the incidence rate ratio. The other is to use the incidence rate per person per year. An intensive review of literature did not render any useable benchmarks. It is not clear as to what is a “good” *percentage* reduction, nor an acceptable incidence rate for rural developing country settings.

The reduction in diarrhoeal morbidity of about 57% in this study (full results reported on in the next section) is higher than has been reported in other studies and substantially greater than one would normally expect from reporting bias seen in non-blinded intervention studies (Hunter, 2009). This overall reduction is substantially higher than the 25% reduction in diarrhoea due to improved water supply reported in a systematic review by Fewtrell et al. (2005) for instance. Joubert et al. (2003) reported that studies in developing countries have shown 14-48% reductions in diarrhoeal incidence as a result of hygiene interventions, including improving access to clean water. It appears therefore that percentage reductions varied widely and it would not be plausible to try and assess impact by of way percentage reduction using the tiered benchmark system used thus far in the report.

Another approach was to consider the reduction of disease in terms of its economic impact that in the end would provide a credible impact figure in terms of saving in treatment costs and recuperating time. A measure for

economic assessment will be the incidence rate (episodes per person-year) such as for instance the baseline incidence rate for 1,000 of an exposed population per annum. The question is also here as to what this might be. According to Gundry et al. (2009) diarrhoeal incidence rate for children under the age of five in the area was 224.3 per 1,000 in 2002. This does not however give the total incidence rate for all age groups and moreover, this figure is taken from records kept by primary health care facilities while it is well known that not all diarrhoea is reported to clinics. It was therefore difficult to get a baseline diarrhoea incidence from where to derive benchmarks for beneficial impact of an intervention.

While reducing the incidence by more than half is in itself impressive, an “incidence reduction” approach would be more problematic in terms of the final tool. Another option was to simply determine shifts in what the relative epidemiological risk was of a member of a household to contract diarrhoea. But what would have constituted a beneficially low relative risk, a detrimentally high relative risk, or no impact at all in terms of the relative risk?

This component was also used to provide a measure of reduction of illness from which could be calculated the economic benefit as will be discussed later in Section 4.

2.2 Results of health impact assessment

2.2.1 Homogeneity of the study communities

Table 4.1 (as well as Tables 2.7 and 2.8, Chapter 2) show that there was no significant difference in the family sizes of the upgrade and reference communities.

Table 4.1: Demographics and socio-economics

	Upgrade community 2	Upgrade community 3	Reference community 2	P (UC's RC)
Mean family size (standard deviation)	5.7 (2.1)	4.8 (2.0)	4.9 (2.4)	0.356
Gender: % female	54	57	60	0.355
Mean age (standard deviation)	26 (21)	25 (24)	23 (21)	0.253
Mean income per head (ZAR pm) (sd)	183 (175)	218 (227)	300 (383)	0.078
Median highest level of education	Grade 11	Grade 11	Grade 10	0.028
Mean number of constructed dwellings (sd)	1.3 (0.7)	1.3 (0.5)	1.5 (0.5)	0.308
Mean number of traditional dwellings (sd)	1.7 (1.1)	2.1 (1.1)	1.9 (0.8)	0.917

There were also no significant differences in the mean income. The level of education was significantly lower in the RC2, where Grade 10 was the highest level of education in the households, compared to Grade 11 in UC2 and -3. This was not considered to have had a confounding effect on the disease outcome. The type of housing did not differ significantly, as the number of constructed and traditional dwellings between the intervention villages and control village did not differ significantly.

2.2.2 Impact of system on diarrhoea

The crude incidence rates in the three communities are shown in Table 4.2. There were a total of 20,148 person-weeks of follow-up data post intervention available of which 14,948 were in the UC (2&3) group and 5,200 in RC2.

Table 4.2: Crude incidence rates by village

	Upgrade community 2	Upgrade community 3	Reference community 2
Persons with data	234	173	146
Pre-intervention			
Person weeks of follow-up	3,735	2,592	1,765
Number of episodes of diarrhoea	55	42	27
Crude incidence rate – Episodes per person-yr (95% CI)	0.77 (0.58-1.00)	0.85 (0.61-1.14)	0.80 (0.53-1.16)
Post intervention			
Person weeks of follow-up	8,696	6,259	5,207
Number of episodes of diarrhoea	28	49	62
Crude incidence rate – Episodes per person yr (95% CI)	0.17 (0.11-0.24)	0.41 (0.30-0.54)	0.62 (0.48-0.80)

There was no difference in the incidence of diarrhoea between the upgrade communities and the reference community prior to the intervention. GEE models show that after the intervention, the incidence rate ratio between UC2 and -3 and RC2 was 0.43 (95%CI 0.19-0.96, $p=0.038$) indicating an overall reduction of self-reported diarrhoea in the upgrade communities compared to the reference community of 57% in 38 weeks follow-up. RC2, with no intervention, had a higher crude incidence rate of diarrhoea in the pre-intervention period (crude incidence rate 0.80 with 95% CI 0.53-1.16) compared to the post-intervention period (0.62 with 95% CI 0.48-0.80) but this was not statistically significant.

The baseline part of this study showed that the crude incidence rate was 110 persons per 1,000 (1.1 episodes per person-year) at the upper limit of the 95% confidence interval. Correcting for respondents' fatigue signalled in the reference community after the intervention, the reduction in UC2 was 65% (0.35 episodes) and in UC2 41% (0.59 episodes). It was then the reduction in diarrhoea morbidity of 1.1 episodes to 0.35 episodes that was used in the social cost benefit assessment done in this study to determine the economic benefit.

2.2.3 The impact of system reliability on the incidence of diarrhoea

There were two breakdowns in UC2, amounting to non-operational periods of four weeks. UC3 had five breakdowns after the intervention, amounting to non-operational periods of 16 weeks. The longest single non-operational period in this community was seven weeks. In line with Table 2.16 (Chapter 2) where the system only provided "sufficient" availability of water, this UC2 supply was, in terms of health impact, classified as a low reliability intervention and the UC3 supply as a very low reliability intervention. GEE models provided more significant fits than simply comparing interventions (Table 4.3), suggesting that system reliability may indeed have an impact on the incidence of diarrhoea.

Table 4.3: Reliability of interventions

	Relative Risk	LL95%CI	UL95%CI	P
Reference community	1			0.0002
Very low reliability intervention	0.66	0.34	1.28	
Low reliability intervention	0.27	0.14	0.54	

The low reliability intervention (UC2) had a relative risk of diarrhoea of 0.27, indicating diarrhoeal incidence reduction of 73%. However, the very low reliability intervention (UC3) had a relative risk of diarrhoea of 0.657 indicating an incidence reduction of only 34%. Consequently this study provides important evidence of the value of community drinking water interventions. However, caution must still be exercised in the interpretation and extrapolation of our findings. The study was conducted over just three small communities that were not randomly allocated the intervention. Although education in the control community differed from the intervention communities, there were little other differences and importantly pre-intervention diarrhoea incidence rates were similar across the three study communities. Because of the small number of communities, it is also possible that some other events could explain the observed post intervention difference, though none were detected.

Illness rates in all three communities declined with time, even in the reference community. This is not surprising as illness rates decline in all prospective studies of diarrhoeal disease, almost certainly due to "reporting fatigue" (Feikin et al., 2010; Strickland et al., 2006). Another potential source of bias could be under-reporting of diarrhoea, especially for the older age-groups, as the study relied on the matriarch of the household to record diarrhoeal incidence. Zafar et al. (2009) suggested that matriarchs tended to keep a closer focus on younger children, and thus not keep a consistent record for the older children in the household.

One of the most notable findings in this study has been the much lower illness reduction in the community (UC2) with the more reliable system. The observed reduction in illness in this community is not that much different than what one may expect due to reporting bias because of the lack of blinding. Results of a quantitative microbial risk assessment by Hunter et al. (2009b) indicated that interruption in water supply for even a few days can negate many of the health benefits derived from a clean water supply. Whilst the sample size in this present was too small to test this hypothesis, the trend of effectiveness with reliability does suggest that this may be true.

Though following the Hunter et al. (2009b) analysis one would have expected an even bigger decline in the estimated health benefit given the time that the systems were non-functioning. We are aware of some anecdotal evidence that within the upgrade communities some people improved their treatment of raw water during non-functioning periods. This is an important issue. In the developed world, it is often the case that during periods of inadequate water quality a boil water notice will be issued. It is plausible that in developing countries, home-treatment of water will not be practiced effectively when people only have an unimproved supply. But when they become used to an improved supply, household water treatment during non-functioning periods becomes practiced – an important behaviour change that begs further investigation. This is potentially an important public health message to give to communities when an improved supply is installed.

2.2.4 Final analysis of relative risk

The objective to be met here was whether the relative risk for contracting diarrhoea would be reduced significantly. This was achieved when the systems were established and used effectively but not achieved where systems were not properly managed. The remaining question was whether the reduced relative risk were "good", etc. remained to be answered. Benchmarks were not readily obtainable or derivable from literature. Benchmarks

were then derived from research results obtained from the reference communities and the impact assessed against these as <0.25 for (1) benefit; no impact $>0.25 \leq 0.8$ (2) and detriment (3) if the relative risks remain >0.8 . These values are shown in Table 4.18 at the end of the chapter.

3 SOCIAL IMPACT

This very understudied field of human reaction to changes in its social services did not offer many clues of how to measure the values and gains of a community's reaction to receiving a water system. Yet it is critically important to have the social values form an integral part of the impact assessment as it is now increasingly accepted that the effect of a social intervention such as an improved water supply service should not only be measured in economic terms (Hutton et al., 2007).

Reports on *"A tool for assessing social receptivity of rural water supply systems in South Africa"* and *"The impact of water service delivery on the satisfaction of people in rural communities"* (as indicated in Chapter 1) measured the social benefits of the small-water supply systems on the basis of "willingness to accept" the system as well as "satisfaction" with the system. The "willingness to accept" concept was almost immeasurable in the sense that it required paired "before" and "after" intervention data. These were not possible to measure because the proxy approach followed with the research led to much uncertainty. The "willingness to accept" work is therefore not included as part of this reporting on the social benefits. The impact assessment that follows here is based on the levels of satisfaction (with the service and the related peripherals) that the recipient communities demonstrated after the interventions. Satisfaction of members in a community is usually a good indicator of how effective water supply services are being provided, also to small rural communities.

The outcomes showed that although the study communities were mostly satisfied with the fact that they have water on tap (Satisfaction at $>60\%$), it was the unreliability of the service that negated any real benefit (Satisfaction at $<30\%$).

Improving access to as well as availability and potability of drinking water to such rural small communities is a cornerstone for improving health of the members by preventing water-borne illness that can greatly affect their quality of life (Poverty-Environment Partnership (PEP), 2006). Such a service, according to Lockie et al. (2009), also has a role in other important aspects of social and economic development in a society such as health and well-being, which contribute to social cohesion. Poor service delivery can threaten this cohesion in a community (Breeze and Lock, 2001; Jackson et al., 2001).

It is important that these benefits are realised and sustained when providing a new water supply service (Wall, 2000). Therefore the role of a water supply service, and society's response to it, must be understood especially regarding its potential effect on prosperous social development (Parkes and Horwitz, 2009).

To maintain social cohesion in a community, it is important that the clients of a public service such as water supply, have trust in service providers and that they are satisfied that the service will meet their needs (Department of Public Services (DPSA), S.A.; Doria et al., 2009).

Determining the level of impact that a public service has on a community is often not measured by what can be objectively observed but rather how it is experienced by the users of the service. Subjective indicators (such as levels of satisfaction) must be part of a service delivery monitoring system because it is a valuable tool for assessing the social impact of service delivery on a community (Sirgy et al., 2000) because the quality of public services influences the levels of customer satisfaction. Poor public services can lead to communities being dissatisfied with the service or vice versa (Joshi, 2004; Skat, 2004; PEP, 2006).

As an indicator of public response, the measures of community satisfaction have great value, especially where a situation of customer dissatisfaction develops. Service providers can be forewarned and could increase commitment to resolve the issue towards restoring and even raising the levels of satisfaction with improved service delivery (DPSA, S.A.; RSA, 2000).

Satisfaction is included in several local as well as international guidelines as an indicator of social impact in monitoring systems. It is described in the South African Municipal Systems Act (Act 32 of 2000). However, it is not regularly used in measuring a community's response to its new water system or the way in which a current one functions. Part of the reasons for this could be that a measuring instrument is not readily available.

This study was conducted to determine the satisfaction levels related to the water supply services of small communities in the far northern parts of rural South Africa. These communities used small water systems of which the service functions related to maintaining good accessibility, availability and potability of the water supplied by the system were below par – as shown by Rietveld et al. (2009).

3.1 Methods for measuring social impact

3.1.1 Description of study area and water supply conditions

The study was conducted in the 870-household Upgrade Community 1 (UC1), which is small-community cluster consisting of several neighbouring rural villages in the Limpopo Province, South Africa.

Before being provided with a tap-water supply system, the villages collected and used water from a nearby river, a canal with water diverted from the river, and a strong-flowing protected spring.

The water supply system was established in these villages in 2004, and this study was conducted in 2008. This study time lag, however unintended, allowed for all operations, maintenance and sustainability related to the system to be observed retrospectively. The water supply system was operated by the community and serviced (maintained) by the local municipality. The water source was a good quality groundwater which was pipe-distributed to communal taps throughout the community, none more than 200 metres from any particular household and accessible to the community with a typical ratio of 25 households per tap. The ground water was pumped from a single drill-well to a concrete clean-water holding reservoir (capacity of 600 m³) on a flanking hill.

The water was sourced at the taps by plastic container – as it was from the original (now alternative) source points – as was described in Chapter 2. Except for reduced daily water toil after tap installation, satisfaction with the container situation was not assessed (as potentially confounding the results) as the container operations were assumed a standard part of the households' daily water management activities.

As is shown in Chapter 2, interruptions caused by (often unannounced) breakdowns in the water system were a major operational supply problem (Rietveld et al., 2009). Although the initial design of the reservoir was to have the tank hold enough water to supply the community for 24 hours if no pumping is done (e.g. in case of a breakdown), the design capacity of the reservoir quickly proved to be insufficient to provide the community with a constant water supply. As a result, water supply cut-offs were practiced by the community – often for up to 14 hours a day to allow the reservoir time to refill. During these times, household had to carefully manage its activities regarding water collection, storage and use, otherwise the interruptions would often leave many households with no choice but to again collect water from their alternative (original) water sources that were mostly much farther and the water often not potable in terms of its health-related microbial and aesthetic quality. Moreover, these events exposed the household water carriers, who are often woman and children, to safety risks such as bodily assault by other humans and wild animals as these sources are mostly secluded from the housed area.

3.1.2 Comparing the new and old

It was not possible to directly determine satisfaction levels of the households with their original water supply (open sources) during the non-service period prior to receiving their serviced basic (improved) water supply system. For researchers to draw conclusions on changes in community satisfaction levels required finding a plausible proxy of the conditions under which households used their original water sources. Often, as was the case with the study community, the alternative water sources that households would use should their new system stop supplying water, were also their main water sources before the installation of their new water supply system. This enabled researchers to study how the situation of the households changed since they received tap water – using impact factors such as distance to travel between water source and dwelling as well as time it took to collect water.

3.1.3 The survey

Keshavarzi et al. (2006) and Hemson et al. (2002) describe the common uses of supplied water in these types of rural communities as drinking, cooking, personal hygiene (bathing, laundry, and cleaning), livestock watering, in some cases vegetable garden watering, and domestic cleaning, thus relying very much on access, availability and potability of the water.

Gathering data for this satisfaction survey consisted of three phases namely ❶ a pilot study, ❷ community level group discussions and ❸ household surveys.

The pilot study was initially conducted with community focus groups to gather information on the situation from before to after the new water supply service was established. This guided the construction of five criteria to be explored during the satisfaction survey (Table 4.4).

Table 4.4: Criteria for measuring satisfaction levels in users of rural small-community water supply services

Satisfaction related to	Indicator
The service functions	Taps closer than alternative (original) sources – distance of ≤ 200 m
	Availability of water at taps without interruption
	Maintenance of the taps making water sourcing easier
	Organised cut-off times being at suitable times
	Being able to collect enough water for to their daily needs – at least 25 litre per capita per day (l/cd)
	Potability of water in terms of its aesthetic as well as health-related microbial quality
Health and hygiene	Washing hands more frequent
	Washing bodies more frequent
	More water for personal hygiene
	Extra time for chores related to domestic hygiene
	Able to use more water for domestic chores
	Tap water good for health
	Reduced disease amongst children
	Alleviated burden of carrying filled water containers
Livelihoods and economy	Tap water now available for drinking
	Food garden potential
	Household saves time by collecting water at tap
	Extra time to start an income generating livelihood
	Extra time to tend to existing livelihoods
School	Water available to maintain livelihoods
	Children attending more school
	Children wash before school
Social and safety	Children eat before school
	Household can socialise while collecting water
	Closer taps provide safer sourcing environment
	Households have extra time for family and friends

One focus-group meeting was conducted in each of the seven villages now linked to the system, because each had a unique history and circumstances regarding the water supply service in their area. The group sizes varied from nine to fourteen people. The target population for the focus groups were the household matriarchs, i.e. the senior female of the household or a suitable proxy who was primarily responsible for water collection and use in the household. As TAC (2000) states: “It is widely acknowledged that women play a key role in the collection and safeguarding of water for domestic use”.

The sample for the household survey consisted of 270 households, calculated at the 95th percentile with a margin of error of approximately five (Rea and Parker, 2005). Systematic sampling was used to select the study households from the household population size of 870 households, with a sampling interval of three (Neuman, 2006). To complete the profile of the community, demographical as well as general water source data were collected during the satisfaction surveys.

3.1.4 The measuring tool

The satisfaction level (with the potential effects of the service), were grouped in five criteria (from the pilot study) each consisting of a suite of indicators (Table 4.4). A five-point Likert scale provided a measure of the community members’ levels of satisfaction regarding the water supply service. The scale consisted of two parts: a declarative statement and a list of response categories ranging from “very satisfied” to “very dissatisfied”.

The reliability of the survey outcomes was tested using Cronbach’s alpha (α) as 0.7, which is the accepted minimum level of internal consistency amongst standardised survey items. For this survey’s items α was calculated at 0.9, indicating that the internal consistency of the survey was reliable. The data were statistically analysed using SPSS V17.0. The Spearman’s rho (S-rho) test was used to examine relationship between the levels of satisfaction and the various criteria and their indicators.

3.1.5 Ethics

Ethics approval was obtained from the University of Johannesburg, Faculty of Humanities Research Ethics Committee. Consent to work in the particular community conducting focus groups as well as household-level interviews were obtained from the local headman. At households, informed consent was obtained from the head of the household who then formally consented and assigned a household respondent – usually a senior female.

3.2 Results of social impact assessment

3.2.1 Demographic profile

The demographical data showed that this was a poor community where the burden of water collection fell on the female adults and children.

The ethnicity of the all of the households that participated in the study was black African who mainly spoke Tshivenda (98.6%). The average resident family size was 5.8. This was quite a young community with the majority of people being 29 years old and younger (69.7%). This was mostly because the older people were working in large urban areas (cities) and not residing full time in the community, leaving their school-going children with family to look after. In terms of education, 32.4% were not educated at all (including toddlers and the elderly). Only 4.9% actually finished secondary school at the final exit level (Grade 12).

Although unemployment was high in the village, 47.1% of the residents did earn an income through a range of government grants (37.1% of the locals receive a monthly grant from government). Excluding the remittances from the migrant workers, most households (52.9%) did not receive any kind of regular monthly income. A substantial 33.2% lived on ZAR 0-500 (\$0-70) pm, which was far less than a \$1 per day, which is a landmark UNICEF benchmark of poverty.

Water collection was mainly the responsibility of females between the ages of 6-49 years (58.5%), corroborating what was reported by TAC (2000).

3.2.2 Water sources

Although several households had taps installed (8.5%) on their private premises (at their own cost paid to the local municipality who would then install a water meter and one tap at the inside edge of the premises nearest to the water main pipe), the majority of sample households (91.5%) used the taps on communal standpipes. The river (34.8%), canal (23%) and spring (18.9%) were the preferred alternative water sources with the rest finding water in neighbouring communities or remote springs in the nearby hills – there were those households that would either go to a different area where tap water was available or waited (with extreme rationing of their stored water stocks) for the water to become available at the taps before they were absolutely compelled to use the alternative water sources. This was either because they lived too far from these sources or they did not want to use the water from these sources for various reasons – such as potability.

Most of the households (86.7%) did live within the guideline distance of 200 m from house to tap, with 13.3% still exposed to longer distances from the taps. When the systems broke down, most of the households (67.8%) had to travel distances farther than 200 m from their preferred alternative water sources.

3.2.3 Overall levels of satisfaction

Table 4.5 shows the responses to the statements put to respondents during household interviews. The colour coding (for easy assessment) was assigned to the highest two percentage of responses. It shows that except for a very small margin of households who were very dissatisfied, the households overall did seem to be more satisfied than not with the total water service. Overall, 60% of the responses indicated people being satisfied and even very satisfied with the service, while 17 % responses were neutral. The dissatisfied/very dissatisfied group were 23% of the total satisfaction profile. However, these were the overall responses. Much depended on the criterion that the survey explored. These are disaggregated in the sections to follow.

3.2.3.1 Satisfaction with water service functions

There were far more dissatisfaction than satisfaction with the water supply service (Table 4.5). The survey items mostly focussed on were the main indicators of the functions of a basic water service namely ❶ accessibility, ❷ availability and ❸ good water quality.

The greatest dissatisfaction appeared to be not the distances that the households lived from their respective nearest taps (as there is a very little difference between being satisfied (27.8%) and being very dissatisfied (27.4%)), but rather with the availability of the water. The households were very dissatisfied with the organised cut-off times (65.9%), more so for the fact that the need exists for cut-off times than because these measures have been introduced rather unilaterally by the community leaders. They felt the system was designed too small from the offset. Also there is a situation of irregular availability of the water at the taps (43.7%) – this was when the system broke down over and above the organised cut-off times. The third contentious point was the maintenance of the taps (35.9%), which were often dysfunctional, denying access to the water point.

Table 4.5: Satisfaction versus dissatisfaction in users of rural small-community water supply services

Satisfaction related to	Indicator	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied
The service functions	Tap distance of ≤ 200 m	27.4	18.1	12.6	27.8	14.1
	Availability of water at taps	43.7	27.8	14.1	11.1	3.3
	Maintenance of the taps	35.9	21.5	9.6	23.7	9.3
	Organised cut-off times	65.9	16.3	6.3	9.6	1.9
	Being able to collect to their needs (25 lcd)	11.5	23	20	37.4	8.1
Health and hygiene	Potability of water	2.6	1.9	4	45.9	45.6
	Washing hands more frequent	10.7	12.2	20.4	41.5	15.2
	Washing bodies more frequent	10.7	13	19.6	39.6	17
	More water for personal hygiene	13.7	13.3	10.4	43.3	19.3
	Extra time for domestic hygiene	1.9	10.4	26.3	44.8	16.7
	Able to use more water for domestic hygiene	1.9	13	24.8	44.4	15.9
	Tap water good for health	1.5	1.5	4.8	43	49.3
	Less disease amongst children	12.6	1.5	4.1	32.2	49.6
	Alleviated burden of water containers	6.3	9.6	12.2	40.7	31.1
Livelihoods and economy	Using tap water for drinking	0.4	0	4.1	45.6	50
	Food garden	28.9	25.2	19.3	15.2	11.5
	Household saves time by collecting water at tap	1.9	6.7	11.1	49.3	30.7
	Extra time to start an income generating livelihood	3.7	14.1	41.9	31.1	9.3
	Extra time to tend to existing livelihoods	5.6	13.3	31.1	42.2	7.8
School	Water available to maintain livelihoods	6.3	26.3	21.1	36.7	9.6
	Children attending more school	7.8	2.6	20	41.9	27.8
	Children wash before school	8.1	3.3	18.5	48.9	21.1
Social and safety	Children eat before school	5.9	4.8	13.7	50	25.6
	Closer taps provide safer sourcing environment	2.2	4.8	6.7	41.9	44.4
	Household can socialise while collecting water	1.5	1.9	28.9	51.5	16.3
	Households have extra time for family and friends	1.5	3	25.6	48.9	21.1

Most households were satisfied that they could use tap water instead of their original (alternative) water sources (49.3%) and that they were able to collect at least the minimum volume (25 litres per capita per day) of water required for consumption and personal hygiene (37.4%) and that they could use good quality tap water (45.9%).

To determine the cause for the high levels of dissatisfaction with the water services, it was necessary to determine whether the high levels of dissatisfaction with availability and accessibility were indeed correlated with general dissatisfaction levels. As the community members were satisfied with the fact that they could use good quality water from taps for their daily water use, the potable water function (water quality) of water service delivery were excluded from specific assessment as a reason for the dissatisfaction and attention are specifically paid to the functions of accessibility and availability.

3.2.3.1.1 Accessibility

It became apparent in this study that the emergence of yard taps played a big role in how the people felt towards the water service and its delivery even though it was not a pronounced part of the original water system consultations with the community. The satisfaction levels of those who had yard taps (8.5%) and those who used the communal standpipes (91.5%) were first compared. It was clear that those who used the communal standpipes were mostly very dissatisfied (32.8%) with the water supply service (Table 4.6), whereas those that used yard taps were mostly very satisfied (34.8%) with the water services.

Table 4.6: Level of satisfaction between households using communal standpipes and those using yard taps (%)

Source point	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied	Total N = 270
Communal standpipe (91.5%)	32.8	17.0	13.4	28.3	8.5	100
Yard (8.5%)	17.4	8.7	8.7	30.4	34.8	100
Total	31.5	16.3	13.0	28.5	10.7	100

Satisfaction levels related to the distances of the taps (as an indicator for access) from the households were also assessed. Table 4.7 shows the distances from communal and yard taps and households and Table 4.5 the levels of satisfaction related to the distances from the water source points.

Table 4.7: Distances (metres) of communal and yard taps from households (%)

Main water source	0-10 m	> 10-50 m	> 50-100 m	> 100-200 m	> 200 m	Total N = 270
Communal standpipe (91.5%)	26.3	34.0	15.8	9.3	14.6	100
Yard (8.5%)	100.0	0.0	0.0	0.0	0.0	100
Total	32.6	31.1	14.4	8.5	13.3	100

Table 4.8 clearly shows that the farther away the taps were from the households, the more dissatisfied those households were. Households located 0-10 metres from their taps (these included all yard tap users) were also very dissatisfied with the distances from taps to households. This strange phenomenon is discussed later on. The converse is also clear in that, with the exception of those who lived 0-10 metres away from their source of water being very dissatisfied with the distance the taps are from their households, the closer the taps were to the households the more satisfied the households were with the water services.

Table 4.8: Level of satisfaction with distances of taps from households (%)

Distance to tap	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied	Total N = 270
0-10 metres	34.1	10.2	11.4	29.5	14.8	100
> 10-50 metres	16.7	23.8	14.3	33.3	11.9	100
> 50-100 metres	46.2	12.8	7.7	28.2	5.1	100
> 100-200 metres	34.8	26.1	13.0	13.0	13.0	100
> 200 metres	41.7	11.1	19.4	25.0	2.8	100
Total	31.5	16.3	13	28.5	10.7	100

3.2.3.1.2 Availability

As shown in Table 4.5, the majority of households were dissatisfied or very dissatisfied with the availability of the water at the taps (cumulatively 71%). There were three statements that referred to the availability of the water. The first was about levels of satisfaction with the overall availability of tap water in the community. The second referred to maintenance of the system, which could cause water to be unavailable at the taps. The third referred to cut-off times. No distinction was made between yard-tap responses and those for using communal standpipes – when water was cut off or there was another type of interruption in the water supply, all users were affected equally as their water came from the same reservoir using the same distribution system.

The relationship were examined between the levels of satisfaction and the maintenance of the taps as well as and the levels of satisfaction with the availability of the tap water. Both conditions had a positive association with the levels of satisfaction with the availability of the tap water ($p = 0.0001$). The satisfaction levels with the maintenance of the taps had a moderate effect ($S\text{-rho} = 0.357$) on the satisfaction levels of the availability of the tap water while the cut-off times had a more profound effect ($S\text{-rho} = 0.626$). Although the cut-off times had a much stronger relationship with satisfaction with the availability of tap water, both the maintenance of the system infrastructure and the water cut-off times caused high levels of dissatisfaction with the availability of tap water.

The relationship between the availability of tap water and the general levels of satisfaction with the water supply service showed a slight positive linear association ($p = 0.003$), but the extent of the effect-size was small ($S\text{-rho} = 0.182$), which meant that the levels of satisfaction with the availability of tap water had only a slight influence on the levels of satisfaction with the water service delivery in the community.

3.2.4 Satisfaction with health and hygiene brought about by the new system

Table 4.5 shows that households were generally satisfied with the fact that better health could be achieved from using tap water instead of water of poor quality from their alternative sources. The households were especially satisfied (95.6%) that they now could use tap water for drinking instead of river water as their perceptions were that the better quality tap water was good for their health (92.3%) and that children were experiencing less illness (81.8%). All of the indicators measured levels of being satisfied to being very satisfied.

Households were also satisfied that they could more frequently wash their hands (57%) and bodies (56.6%) with the advent of the new system. They also perceived that they were collecting more water per person (capita) per day which meant (to them) that they were able to use more water for improved personal hygiene (62.6%). The households were satisfied that they had extra time (61.5%) and more water to clean their domestic environment (44.4%).

These two aspects were very important as it also related to the hygiene of the households. A very important aspect that households felt strongly about was the burden of water toil (carrying water-filled containers). Cumulatively (satisfied to very satisfied), 71.8% were satisfied that the toil of carrying heavy water containers over longer distances was substantially reduced when the new system was established.

It can be concluded that the households were overall satisfied that they had more time and water for proper and overall hygiene and health.

3.2.5 Satisfaction with aspects relating to school attendance

Households were very satisfied (cumulatively 74%) that the new system has a positive effect on the household activities related to the children's school attendance. Children now need not use any school time to catch up on the daily household water stores. The households were satisfied that their children did not have to miss parts of school in a day to collect water because water was available much closer at the nearby taps (69.8%). They were also satisfied that the children were able to wash (70%) and eat (75.6%) before they left for school in the mornings instead of having to fetch water, which was what happened before the water supply system was established.

3.2.6 Livelihoods and economy

Here a point of contention was the item that indicated households being very dissatisfied with the fact that they were, because of the system's capacity limitations, not allowed (in fact not able) to use tap water for growing and maintaining food gardens (49.1%). Table 4.9 shows that almost 78% of the selected households did not practice any form of food gardening because of the system's limitations.

Table 4.9: Household with a food garden at the time of the study

	Frequency	%
Yes	60	22.2
No	210	77.8
Total	270	100.0

Testing the relationship between the levels of satisfaction with the water services and the levels of dissatisfaction with the households wanting to use tap water to grow and maintain food gardens showed ($p=0.0034$) with a small effect size ($S\text{-rho} = 0.175$). It can be concluded therefore that the dissatisfaction with the households not being able to use tap water for growing and maintaining food gardens did not affect the overall dissatisfaction that the households have shown for the water service delivery in general.

3.2.7 Extra time

This indicator was interesting as it was originally called extra time but in actual fact did not only measure the satisfaction levels with extra time being available to the households when they collect water. The indicators also referred to whether or not households used more water. Before the satisfaction levels can be interpreted for this indicator it was first determined whether households actually saved time by collecting water from the taps instead of the previous (now) alternative water sources, and whether the households believed that they collected more water from the taps than the natural water sources.

3.2.7.1 More time, more water?

The majority of the households (85.4%) were within 200 metres of the communal standpipes (including yard taps) (Table 4.10). This implied that it could hardly take more than 30 minutes to collect water from taps for most of the households (78.2%).

Table 4.10: Distance (metres) of tap water source from households and time (minutes) to collect water from there (%)

Distances from tap to households (m)	Time to collect water					Total
	0-10 m	> 10-50 m	> 50-100 m	> 100-200 m	>200 m	
< 15 min	96.6	67.9	28.2	21.7	0.0	58.5
> 15-30 min	3.4	27.4	61.5	56.5	25.0	26.7
> 30 min-1 hour	0.0	4.8	7.7	21.7	63.9	13.0
> 1 hour-2 hours	0.0	0.0	2.6	0.0	8.3	1.5
> 2 hours-3 hours	0.0	0.0	0.0	0.0	2.8	0.4
Total	100	100	100	100	100	100

Table 4.11 shows that the majority of the households lived more than 200 m (67.9%) from their alternative water sources. These were the water sources that the households used prior to being given access to water at communal taps. It then took the majority from 30-120 minutes to collect water, depending on the distance of the source (sometimes it took more than 3 hours).

Table 4.11: Distance (metres) of alternative water source from households and time (minutes) it takes to collect water (%)

Distances from alternative sources to households (m)	Time to collect water					0 m	Total
	0-10 m	> 10-50 m	> 50-100 m	> 100-200 m	>200 m		
< 15 min	100	50.0	14.3	0.0	0.0	0.0	3.0
> 15-30 min	0.0	25.0	42.9	25.0	5.5	0.0	10.7
> 30 min-1 hour	0.0	25.0	42.9	59.1	33.9	0.0	35.6
> 1 hour-2 hours	0.0	0.0	0.0	15.9	42.1	0.0	31.1
> 2 hours-3 hours	0.0	0.0	0.0	0.0	8.7	0.0	5.9
> 3 hours	0.0	0.0	0.0	0.0	9.9	0.0	13.7
Total	100	100	100	100	100	100	100

This meant that when the water supply system was established, water source points were not only closer to the households but water collection times were cut by nearly two hours a day. The households indicated (Table 4.5) that they were satisfied (49.3%) and very satisfied (30.7%) that they could save time by collecting water from the taps. This study did not include an assessment of whether or not the households actually collected more water since they had access to tap water, but an item in the survey did enquire from households whether they were satisfied that they could collect more water from the taps than the natural water sources. The households were mostly satisfied (49.3%) that they could do that, which implied that according to their perception, they believed they were collecting more water.

3.2.7.2 Tending to livelihoods and the domestic environment

Three items referred to increased economic productivity in terms of creating and maintaining livelihoods. The households seemed rather indifferent (41.9%) that they could use their extra time to start a new livelihood. They were, however, satisfied (42.2%) that they could use their extra time to tend to existing livelihoods such as tending to livestock or working their nearby food-production fields. The households were mostly satisfied (36.7%) that tap water could be for water dependant livelihoods, but dissatisfied (26.3%) because they realised a water-dependant livelihood such as for instance, brick making, would be limited and an intensely water-dependent livelihood such as a food garden would not be allowed.

3.2.8 Satisfaction about social and safety issues related to the water supply system

The households were 65.2% satisfied that they did not have to collect water from the natural water sources. As mentioned earlier the households were satisfied with the closer taps because they did not have to carry heavy water containers over long distances. They could also collect more water, use more water more often to for personal and domestic hygiene and it saved the households' time to collect water at the taps.

Their alternative water sources were not only far but there were other risks associated with using these remote water sources. Closer tap water created much safer environments for sourcing water. The households indicated that they often sought persons, mostly from the same household, to accompany the water carrier to the source – a reason being safety as well as assistance with heavy containers. The households were very satisfied (86.3%) that they could use the taps because it was a safer environment for them to move around as well as saving the accompanying person's time.

On the other hand, collecting water in groups was an opportunity for community members to socialise. The main reason (apart from assistance with containers) why household members were accompanied when they collected water at the standpipes was to socialise with others. The households were satisfied (51.5%) with this opportunity. The last discussion point of the satisfaction survey was the extra time households had available to spend with family and friends and 48.9% of the households were satisfied with this.

3.3 General discussion

The households were mostly satisfied that they were able to use clean tap water for their daily use. Their dissatisfaction came with poor service delivery in terms of accessibility (distance of taps from dwellings) and availability (maintenance and cut-off times). If taps could be brought even closer to the dwellings of the households it would increase the satisfaction levels. It can be inferred from the data that the closer that water source is to the households the more satisfied the households were with the service.

Although it is not clear why households that were located 0-10 metres from the tap was dissatisfied with the distance of the tap from their house, a possible interpretation (not measured – anecdotal information only) of this finding could be that despite living so close to the tap, the household members do not have ownership over the tap (it is a communal standpipe in the street in front of their dwelling).

They still had to share the tap and could not connect a hosepipe to the tap despite living virtually with the tap. A further factor could be that the sourcing activities with crowding around the tap infringed on their privacy – although this was not measured. Those with yard taps had the highest levels of satisfaction with the water supply services. Even if taps were now much closer to the homes than were the original sources, there was still the issue with the poor maintenance and the cut-off times. If the system is properly maintained and operated to ensure water is available and water cut-offs are properly scheduled or no longer practiced, it will also increase the satisfaction levels with the water services in general.

The study by Du Toit (2006) showed that communities had high levels of satisfaction with water quality as well as maintenance and operation of water supply systems in South Africa which led to communities being satisfied with water supply services in general. Contradicting the Du Toit findings, this study community was not mostly very satisfied because of poor access and availability of the tap water. It can be argued that accessibility seemed to have been a cause of discontent with the water supply service, although this finding stood out just a fraction. A sensitivity analyses of the satisfaction data confirmed the qualitative findings regarding the accessibility of the water households which were that a household would rather be more dissatisfied with the water not being available than being dissatisfied about taps being located far from the households. Ultimately households wanted to be close to a tap that consistently delivers water.

3.4 Final analysis

The households seemed mostly satisfied that their children were not prohibited from attending school due to poor water services. They were satisfied that they could pay attention to other activities such as livelihoods and other households chores because the water was closer and they had more time available because they collected water from the tap. Their main concerns seemed to have been not with the benefits that resulted from the water services but rather with the services itself such as the distances of the taps and the time when water was available.

The objective to be met here was whether the communities were satisfied with the interventions based on their levels of satisfaction. This was achieved because the communities were more satisfied than not. Benchmarks for what constitutes a “good” level of satisfaction, etc. were also not readily obtainable or derivable from literature. Benchmarks were derived from research results and the impact assessed against these as shown in Table 4.18 at the end of the chapter.

4 ECONOMIC IMPACT

A significant challenge for this impact assessment work in general, and in particular the economics part, was to show that interventions to improve water supply services produce total benefits greater than total costs. Social cost-benefit analysis (SCBA), also applicable to small-scale water supply services, is a tool to aid this assessment process (Cameron et al., 2011). While Chapters 1 and 2 demonstrated that newly established water supply systems and their services were not particularly effective in terms of certain effect-values, results of health and social impact assessment in the sections that followed showed that despite these shortcomings, there were positive gains, i.e. benefits. This economics assessment will strive to show whether these gains still proved small community water services to be a good investment despite the intermittent and often non-performance of the systems under study.

Economic assessment of water supply service interventions – especially small-scale interventions – is challenging because of the complexity of the information required to assess all direct and indirect outcomes. SCBA puts values to activities such as these interventions, especially from the public perspective – it is not just a financial cost benefit analysis method that in the end produces an expression of profitability of a venture such as a water supply intervention.

This section presents the results of the economic impact of the water supply interventions in the study area.

4.1 Economic impact assessment methodology

Social cost-benefit analysis (SCBA) as an economic assessment methodology is very clearly described by Cameron et al. (2011). The work reported in this publication also formed part of this study. The SCBA was conducted by following five steps:

- Placing the water supply service interventions in context of the communities’ livelihoods;
- Costing the interventions and assessing their discounted cost-efficiency;
- Identifying and measuring indicators of the physical benefits and assessing cost-effectiveness;

- Putting values on the benefits and undertaking the SCBA in the study area;
- Conducting sensitivity tests on four SCBA scenarios to take account of:
- Possible inaccuracies in the selected SCBA variables;
- Risks and uncertainties around engineering and institutional management of the water service intervention;
- Incremental challenges associated with demographic changes and;
- Potential changes in the aspiration of the recipient communities and then sequencing interventions.

The assessment is not typical nor is it representative of the situation elsewhere in South Africa or even in a wider regional or global context. Moreover the assessment encountered a range of characteristics that proved unexpectedly challenging in terms of small-scale water supply service interventions. Certainly the interventions in the study area seemingly did not live up to expectations for the reasons discussed in Chapters 2 and 3.

Fortunately, SCBA lends itself to robust application and could readily be conducted in the area because of the other work done before project implementation as well as during its lifetime. This provided the necessary understanding the local context within the target population. The primary data were collected using a variety of techniques:

- Questionnaire-based surveys;
- Direct expert field observation;
- Semi-structured community focus groups (which proved a very cost-effective technique for collecting the kind of broad parameters required) and finally ;
- Natural-group conversations at water source points where people were collecting water or washing clothes.

The outcomes of applying the five SCBA steps are discussed in subsections below.

4.2 Water supply service interventions in the context of livelihoods

4.2.1 Describing the context

Describing the context into which the interventions were introduced involved identifying the demographic profile of the study communities who were affected by the intervention. This demographic profiling was done during the work described in the previous chapters as well as in parts of Sections 2 and 3 of this chapter. This work also provided data for economic estimates of variables based on household and group observations to aggregate estimates, e.g. total days of illness prevented or total days saved by shorter water collection times.

Ethics clearances were obtained from the relevant government departments, non-governmental organisations and participating universities as were indicated in earlier chapters.

4.2.2 Livelihoods

Inventories of livelihoods can be quite ambitious, including all forms of wealth assets to which a household has access and all the activities that contribute to the material well-being of a household plus how households seek to preserve their livelihoods when under pressure or enhance them when new opportunities emerge, e.g. as a result of the water supply interventions. For this work the following livelihoods were identified namely monetised economic wealth, human wealth, and social wealth. Triangulation of various observations and house-to-house interviews suggested a very low level of monetised economic activity and very little locally-produced wealth – the occasional general store and vehicle maintenance/repair workshop were the only signs of commercial activity and investment in technology within the communities.

In terms of natural wealth, there was significant local agricultural activity, for instance tomatoes are marketed nationally from this area, using natural wealth of the land surrounding the study communities close to the main river. But household surveys suggested very little continual involvement of the study households in this activity. Similarly, the presence of natural wealth with tourism potential in the form of a nearby game park appeared to be having very little influence on local livelihood activities.

Direct observation and conversations about new housing construction as an indicator of the distribution of produced wealth suggested a heavy influence of remittances from urban areas – older women were often observed living often with only their grandchildren or alone in newly constructed sizable houses, some with private water connections. Protection against poverty depended on intra-family remittances and government grants, both for child support and old age pensions. There are therefore both productive and vulnerable people in the

study population, but they are spatially separated for much of the year and thus it was difficult to accurately assess the distribution of economic activities and overall labour productivity for many of the study households.

In terms of human wealth development, there were three primary and one secondary school in the area with an evident high level of attendance of formal education at both levels. Therefore, impact on school performance (including attendance) was a factor considered in the economic assessment.

Strong social wealth was not evident in the area. Kin/neighbourly support, the presence of local tribal authorities and well-attended churches seemingly operated to smooth day-to-day life, vulnerabilities and settle disagreements. But clear collective deliberative communal institutions were limited, such as collective meeting places (other than the water taps than the tribal meeting place). Neither could evidence be found of advertising events or public meetings such as posters and other advertising. This limited local social wealth was reflected in the institutional and local management arrangements for the water supply service and its support functions as was already reported in the previous chapters.

The service had not been designed or implemented by local institutions but was a devolved responsibility from the central government Department of Water Affairs to the local municipality, though the municipality is not visibly active in running the scheme. Part of the result of this distribution of authority is a widespread lack of ownership for the system among the members of the communities with respect to undertaking even minor repairs to the system, especially the taps. This was part of the general vulnerability of the systems to breakdowns and is dealt with in one of the sensitivity tests later on in this work.

With these rather limited livelihoods in the study area a cost-effectiveness analysis based on local conditions alone, would very likely not show significant net economic benefits/rate of return from the interventions since these could not be linked to significant additional high-value, local economic activities. A full SCBA was therefore undertaken to identify any significant economic benefits in terms of high value added did indeed exist in the small community water supply service context.

4.3 Costing the interventions and assessing cost-efficiency

4.3.1 Describing the context

Jagals and Rietveld (2011) set out a framework for the basic costing small-scale water supply systems. This framework is applied here to assess cost efficiency.

Cost-efficiency is the simplest form of economic assessment. A particular system might seem affordable because it has a minimum total cost (accounting) but would the system be sustainable to give a particular target group of people improved access to safe drinking-water for any length of time? This is where economics would help determine the minimum social costs (that is costs to the whole society not just the funding agency) of sustainably achieving that goal.

The first step was to decide on a realistic physical life for the water system (Cameron and Jagals, 2011), in the case of the study area 20 years (from 1998 to 2017). ALL costs to ALL affected organisations (public and private), including households, for the years in which the expenditure actually takes place and resources used, were entered onto a calculative spread sheet (Microsoft Excel). An example of such a spread sheet is shown in Cameron et al., 2011.

The total cost pattern (including capital, operation maintenance and other costs) for the systems in the study area is shown in Table 4.13 (lower down). This is a time profile of expenditures for the study systems synthesised from the technical specifications of the systems based on standard parameters used by water service planners in South Africa. The pattern shown in Table 4.13 suggests six years dominated by development through construction and then two years of normal running followed by some minor upgrading as well as maintenance, while reflecting continual normal running costs with a hypothetical major maintenance/repair cost in year 2012, for instance replacement of the pump.

An economics assessment assumes that costs are necessary and sufficient to produce a socially optimal outcome – a drinking water intervention that delivers the planned supply of safe water over the whole life-time of the intervention. The actual costs in the service provider's budget were deemed not to be necessary or sufficient for this purpose. For instance, there were assumed to be:

- Delays in construction and loss of valuable benefits to households in the early years of the intervention;
- Sub-optimal running costs below those needed to sustain the system at design level of delivery leading to loss of supply to some households;

- Sub-optimal maintenance costs leading to more system down time, and/or more repairs;
- Reduced repairs leading to more down time and/or early end to project/programme;
- Incremental growth (i.e. an increase in the numbers of households in the area over time) and sequential improvements to the system that need to be incorporated at appropriate years in the spread sheet;
- Prices for labour and/or materials that did not reflect their scarcity values to society as a whole.

In the study area the approximately 600 households participating in the economics survey part of the work received their water from a system that pumped untreated but potable groundwater to an elevated concrete reservoir from where it is gravity-fed to neighbourhood (communal) taps. Capital costs include installing the drill-well and pump, building the reservoir, assembling and burying piping and constructing neighbourhood water source points (communal taps in this case).

Running the system on a day to day basis was the duty of a community member who was paid R300 a month. These costs seem necessary to sustain the system's operational capacity, but are notably insufficient to build the social capital necessary to ensure speedy repairs, local ownership and fair distribution of the water. Running costs to genuinely sustain the system should be considerably higher than this and are shown as total costs in Table 2.12.

It was difficult to obtain information on maintenance costs for the study system – it appeared to be repaired (rather slowly in terms of the taps as reported by Haarhoff and Rietveld (2009) rather than receiving preventive maintenance. Though the pumping equipment appears to have functioned well from 2004 to 2007, in terms of likely future breakdowns requiring major repairs, the pumping equipment is a clear candidate for concern. The costing spread sheet therefore provides for the pumping equipment to be replaced in year 2012. Other than this maintenance, costs have been included at the level considered necessary to sustain the system – higher than actual expenditure in the case study system as actual expenditure involves some loss of service to significant numbers of people, which fails to meet the political objective of a sustained, good quality supply to all particularly in the target group.

Finally, the system did not cause additional expenditure on water transportation or processing by households. Observation showed that households were still using the numbers and types of containers (and occasional wheelbarrows) they have been using with their original (alternative) unimproved drinking-water sources.

It is worth noting here, that if households paid a tariff or fees for water provision this would not affect the costing methodology. In terms of a SCBA, the concern is with the monetary value of the real resources being used, not who pays the bills.

4.3.2 Discounted cost-efficiency

Discounting, in terms of finance and economics, is the process of finding the present value of something, often in terms of monetary values, at some future date. The discounted value of costs in this assessment was determined by reducing its value by a discount rate (3% as well as 16% per annum is used) for each year between the time when the cost is to be valued (e.g. from 2004-2017) from the time that the cost was incurred. To create a level playing field for comparison requires all costs be expressed in terms of one point in time (usually the first year of the intervention, t_0).

The heavy expenditure to replace the pump, e.g. in year 2012 will, at differing interest rates, have the values in 1998 as shown in Table 4.12. All the interest rates are real, in the sense that they ignore price inflation over the life of the system. The rate of 3% was used here as it is a rate often used by WHO and other public agencies. It also roughly corresponds to the historic very long term rate of return to low risk investments. The power of discounting as a way of putting a value on time is clearly revealed here.

Table 4.12: Discounted values in 1998 of spending a total real cost of R500,000 in 2012 in 1998 at differing interest rates

Discount/Interest rate (%)	0	3	5	10	15
Present value in 1998 (R)	500,000	331,125	252,500	143,600	70,188

Synthesised costs for the case study shows that the total present value, discounted at 3% pa, summed to ZAR10.7 million (Table 4.13). This was the estimated simple cost-efficiency of the system taking account of the time profile of the expenditures as shown in Table 4.13. Any other scheme proposed to provide the target population with safe drinking-water on a sustainable basis should have been able to match this total cost in 1998 expressed in early 2008 prices.

Table 4.13: Synthesised time profile as well as discounted costs for the case study drinking water intervention scheme

YEAR	TOTAL COSTS (South African Rand '000s)	COMMENTS	Discounted value at 3% per annum $(Y(0)) = Y(t)/(1.03)^t$
1998	1,500	Start of construction	1,500
1999	1,500	Period of construction	1,456
2000	1,500		1,414
2001	1,500		1,373
2002	1,500		1,333
2003	1,500		1,294
2004	175	Taps turned on for normal operation	147
2005	175		142
2006	500	Repairs of teething problems	395
2007	175		134
2008	175		130
2009	175		126
2010	175		123
2011	175		119
2012	500	Replacement of pump	331
2013	175		112
2014	175		109
2015	175		106
2016	175		103
2017	500	Costs to closure less any residual value of remaining assets (see below)	285
TOTAL	Not interpretable		10,732

All costs expressed in terms of prices prevailing in early 2008.

4.4 Assessing cost-effectiveness

This is the next step in conducting a SCBA and consists of identifying indicators of physical benefits from which to measure cost-effectiveness.

Saving (freeing) household time as a result of the water supply service intervention is a major effectiveness indicator as was shown in Chapter 4. In an economic assessment focused on time saving, saved time allows for an even wider range of interventions (aimed at improving livelihoods and well-being) to be compared. For instance, health benefits come from time, freed by fewer episodes of ill-health, which can now be used for additional livelihood activities. It may also include time made available by preventing premature deaths, which is discussed separately below. In the simplest case, the number of days ill in a year is treated as days totally unavailable for any meaningful livelihood activities. In this case study, the simple dichotomy of being either totally in or totally out of economic activity ignored the possibility that some activities can continue to be undertaken during an episode of less acute illnesses.

A more subtle approach to assessing the overall gain in human well-being from fewer episodes of illness uses the DALY (Disability Adjusted Life Year) indicator (Havelaar and Melse, 2003). The DALY summarises the total effect of all episodes of illness in a year – as a statistic it indicates the proportion of a chronological year lost due to ill-health. A year in good health has a DALY value of zero, while dying at the beginning of a year gives the year a DALY value of one. Thus DALYs allow very different forms of ill-health to be compared against a standard measure expressed in terms of time and is therefore useful for assessing overall changes in health status, as is generally shown for global comparisons in WHO publications. However, when making economic assessments of small-scale drinking-water interventions, the DALY is analytically much more sophisticated than what is really required, and simply treating a day ill as a day lost to livelihood activities is necessary and sufficient. The intensity of the illness indicator (an episode of *E. coli*-induced diarrhoea) was then indicated by the duration of the illness.

4.4.1 Benefits of reducing morbidity and mortality

The full description of this work can be found in Cameron and Jagals (2011). The estimated reduction in days affected by drinking water-related illness, proxied by days with diarrhoea, was estimated in the study area from studies on the prevalence of the disease six months before and twelve months after the intervention as well as some 12-month long longitudinal studies of incidence. This fieldwork suggested a reduction from 1.1 to 0.3 in diarrhoeal episodes per person per year in the total of approximately 600 households that had used microbially-contaminated water from open sources before the intervention.

The total time savings from diarrhoea reduction can be calculated assuming an estimated average time unavailable for livelihood activities of 3-days per episode (livelihood activities for our purpose here include any adult activity –

both productive and reproductive for the household in economic terms – plus schooling for children). Thus total time available for livelihood activities due to reduction in diarrhoea episodes as a result of the drinking-water supply service intervention for the 3,500 people (600 households) in the study area previously using open source water can then be calculated as about 20 person-years per year.

Closely related to time saved in illness are livelihood-benefits for those who previously used open source water also appear as additional time made available for other activities than for those who care for the sick person. In this study, the time dedicated to caring for sick people was directly linked to the time that the people were ill and was estimated at half a day for every day of illness (that is about 10 person-years) for the part of the study population who previously used the open sources.

Diarrhoea also is a significant mortality threat for very young children. In the study area, about 50 ‘at-risk’ (open water user households) babies were born in the year before the intervention coming into operation with a further 230 young children being in the highly vulnerable age of 1-5 years. Given the wide access to local primary health care facilities in South Africa, it might be expected that young children would be shielded from deaths resulting from drinking unsafe water to a large extent. It is also well known that providing access to safe water is an effective way to prevent early child deaths. Therefore it was assumed for the study area that five early deaths are prevented on average per annum by the drinking water intervention.

Thus five years per annum will be added on a cumulative basis to the annual person-years made available in each year over the hypothetical 20 years whole life adopted for water supply service. No account was taken for these gains that will continue after 20 years or the savings in funeral expenses. Calculations involving the valuation of a human life are always controversial. In this study, we assumed that any year of a human life saved from illness or death is given a simple time value of one year. In DALY terms, a year for an adult person with an acute debilitating illness is counted as equivalent to a year of a child’s life saved from death – the principle might be called a stock of human time available for livelihood activity. That is, the larger the increase to the stock of human time induced by an intervention, the more effective is the intervention.

4.4.2 Time saved in collecting and processing water

In many circumstances, the largest element in time available for other activities will result from less time spent in collecting and possibly treating water. Chapter 2 has shown that the interventions had led to improved water quality and reduced total collection time by providing water from a potable source and creating access points (taps) closer to people’s homes (improved access). There were time savings in collecting water from the taps instead of from the more remote open water sources. Washing clothes and increased personal hygiene could also be considered as benefits but were not assessed in this study.

As were shown in Chapters 2 and 3, the time saved in collecting water for all activities was very varied given the large area covered by the study systems, wide differences in distances from previous open water sources and interruptions of supply due to system breakdowns. Using an average saving of 1.5 hours a day per household seemed therefore reasonable. There was no evidence that home-treating of water was a common practice before the intervention, so no savings (time or produced inputs) were assumed. Therefore, total time saved for the previous open source households in a year was estimated at 330,000 person-hours ($1.5 \times 600 \times 365$). If on average a person spends ten hours a day on very broadly defined, socially valuable livelihood activities (including care for children and the elderly, pre-school learning, formal schooling and community decision-making) that would otherwise have been interrupted by water collection, then this is equivalent to 33,000 days or 90 person-years a year.

4.4.3 Savings on health care expenditure

This estimate of the cost of health sector treatment per episode of diarrhoea is based on the cost of private sector consultation and treatment. In an economic assessment, this can be justified as representing the “social” cost of treatment by assuming private sector charges represent market-tested pricing. Consulting a private sector doctor in the broader areas surrounding the study area can incur a fee of at up to R250 and with medicine, a total cost of up to R1,000 per treated episode is indicated (given the private sector is quite competitive, we treat this as the economic cost to society of health care, the opportunity cost of the resources in economics terms).

For time the study population used open sources, this suggested maximum savings from reducing the number of episodes of diarrhoea by 0.8 episodes per person per year for 3,500 people of R2.8-million per year if all episodes were treated privately. But in many cases, symptoms would be recognised but medical advice would not be sought or only sought from a nurse in the local primary health care facilities (free to the household but a social cost in public sector resources). Therefore a much lower figure for health sector treatment would be reasonable.

Assuming this to be the equivalent of about one in seven episodes being treated privately, then the total monetary equivalent of the social cost to households and the public sector in providing subsidies in public sector health treatment would be R400,000 a year.

4.4.4 The complete cost-effectiveness analysis

From here the cost-effectiveness analysis was undertaken of the impact of the water supply water intervention in the study area.

Firstly, discounting was used for all indicators of effectiveness, e.g. preventing an illness now is more socially valuable than preventing the same illness in the future. There is an element of inter-generational bias in favour of the current generation in this approach, but at a discount rate of 3% pa, this bias should be acceptable as hopefully future generations will have an advantage in terms of access to future medical technology.

An additional complication was three different dimensions of effectiveness measured in three different units discounted over the whole life of the intervention:

- Reduction in total numbers of episodes of diarrhoea;
- More time available for broadly defined livelihood activities for the sick, those caring for the sick, and time released from collecting and treating water;
- Monetary/budgetary savings in disease treatment costs by households and the public sector.

The first indicator was simpler from a health perspective and interventions could be compared by just estimating engineering costs, and health service statistics of prevalence of episodes of ill-health – and in this case, diarrhoea. This minimises the need for collecting data from the study population. The second indicator is evidentially richer in that it includes both the health and the wider livelihood impacts, but is more demanding in terms of local household data and observations. A conventional cost-effectiveness approach to the last indicator was to subtract the monetary present value saved in health care from the present value of building, operating and maintaining the system, i.e. we treated the savings as a negative cost. This reduced the total cost of the intervention and making it more of a “social” cost as it was beyond direct costs to the agency building and operating the drinking water intervention.

For this study, calculations suggested the following values for cost-effectiveness indicators:

- Deducting the present value of financial savings on disease treatment from the present value of capital investment the system and its operation and maintenance costs. At a discount rate of 3% pa, the net present value after this deduction falls significantly to R3.67-million (instead of the simple-cost efficiency calculation of R10.7-million derived in Table 4.13 in the previous section);
- Total discounted reduction in numbers of episodes of diarrhoea was estimated at 25,700. Dividing this figure into the total discounted social costs of R3.67 million gives a cost-effectiveness measure of about R150 per episode prevented in addition to the costs of health treatment;
- Total discounted gains in terms of time for livelihood activities released by less illness, less caring for the sick, less time collecting water, and reduced infant mortality was estimated at 1,400 person years. Dividing this into R3.67 -million gives a cost effectiveness figure of R2,555 per person-year of livelihood activity gained.

By themselves, the absolute values of both these cost-effectiveness indicators have no meaning. Putting them in a South African context, the sum of money involved in preventing one episode of diarrhoea does not appear cost-effective – R150 is equivalent to almost a week’s wages for a low paid, full time employee – but remember we have used private sector charges as an opportunity cost rather than actual expenditure.

The livelihood-time cost-effectiveness indicator looks more cost effective – a low paid, full-time worker might expect to receive an income of over R12,000 a year. So R4,800 may be an acceptable price for gaining a whole year of activity. These results are consistent with global economic assessments of small-scale drinking-water schemes which conclude that a large proportion of the benefits come from time saved in collecting water.

As a final point on using cost-effectiveness analysis for prioritisation, cost effectiveness statistics need caution in making comparisons. Before comparing and making decisions informed by that comparison it is crucial to ensure like is being compared with like in terms of the specification of the cost-effectiveness indicator. For instance:

- Have monetary savings been deducted as negative costs in all cases?
- Is the effectiveness indicator identical in specification for all cases?
- Have the same discounting procedures been followed for all variables at an identical discount rate?

4.5 Social cost benefit analysis

4.5.1 Describing the context

SCBA is an extension of cost-effectiveness analysis that ensures comparability, not just between drinking water interventions or across the whole health sector. It can be used to compare all interventions coming from every sector that claim to offer improvements in human well-being anywhere in the world. Therefore as the logical next step in economic assessment, Section 5 shows the final results of the SCBA done in the study area.

This section is about putting values on the benefits and undertaking a full SCBA. The cost-effectiveness analysis in the previous section arrived at two estimates of cost effectiveness namely cost per diarrhoea episode prevented and cost per year of human life made available for livelihood activities (including all learning and schooling). SCBA methodology will allow unit cost comparisons between any interventions aimed at reducing episodes of diarrhoea and/or any interventions aimed at increasing time available for livelihood choices.

SCBA demands that all costs and benefits be given a monetary equivalent value. The analyst must choose these values even where there is no buying and selling in observable markets on the basis of choosing a price that reflects the scarcity of the good or service, e.g. water in a depleting aquifer. If there is no market but there exists a public sector charge for a good or service, the analyst should reflect on how that charge was decided and how far this charge represents what a competitive market price might be.

4.5.2 Estimating costs and benefits for a full SCBA

Fortunately, SCBA for most small scale drinking-water service supply interventions are not complex, and robust conclusions can be drawn from a relatively simple framework. For this study costing was provided by a very experienced water engineer plus some direct observations from the field supplemented with expert judgement and direct local observations, all of which met the broad assumptions required for relatively simple application. Given this, the pattern of costs derived in discussion with the engineer applying the then current (2008) prices discussed in 4.5.3, are acceptable for SCBA purposes.

In terms of the benefits, we treated the savings in health care costs as a monetary benefit rather than as a saved cost as we did in in Section 4.4 where we used the price that people pay for private health treatment as a current market tested monetary value. This was therefore a “shadow” price (i.e. not the real cost paid by most study households, but a price representing an open market valuation assuming competition in the private health treatment sector). People, especially in rural areas, predominantly use subsidised public sector clinics/hospitals when they seek treatment, but what they pay does not reflect the full value of the resources used in diagnosis and treatment of illness to South African society.

A present value of the savings on health treatments was calculated in the cost-effectiveness analysis in Section 4.4 at about R4 million per annum in the study area. This sum is assumed to have become available to support changes in livelihood activities and provide produced assets. These assets can be used to complement additional human time freed by the drinking water intervention. Thus the freed time could be used more productively in livelihood terms, including possibly purchasing more and/or better hygiene related items.

While we now have monetary values for treating an episode of diarrhoea, we have no monetary value for the benefits expressed in terms of gains in person-years of livelihood choices as a result of time released for livelihood activities through less sickness, less caring for the sick, and from collecting water. The starting point is “*what activities will now be chosen to utilise the saved time?*” and whether there is a market price for those additional activities. In the study area the proportion of adult people’s time that is directly sold locally is very low because so much of the time is that of people under 18 (over 40% of the population). It might be assumed that there is little monetary value that can be attached to additional time available therefore a monetary equivalent close to zero was considered appropriate.

We assumed that, in the study population, episodes of diarrhoea are evenly distributed by gender and age. This meant around 25% of time sick will involve adult men, 35% adult women and 40% young people under-18 years of age. For time savings in caring for sick people and collecting water for all its uses, it was assumed that about 75% will be adult women’s time, 5% adult men’s and 20% that of young people.

In a typical year therefore, adult women will gain a large proportion of the time saved (about 60%) followed by young people under 18 (25%). Therefore placing a value on time for these two groups is crucial. Given the high level of local male open unemployment and their limited contribution to work in the home in the study context, men over 18 and resident in the study area were given a zero value for their time. The men working as migrants outside the case study area were vital to the local economy in terms of remittances, but are less likely to suffer

from local drinking-water induced illness, care for the sick, or be involved significantly in water collection and therefore do not receive significant time saving benefits from the drinking water intervention. Their livelihood activities are therefore assumed to be unaffected by the intervention.

Adult women in the study area reported that they use time saved to improve the quality of life in the home environment by spending more time in improving hygiene and for better child care. This time has indirect economic value in terms of facilitating other people working (including physiological and psychological impact on rural-urban migrant workers when visiting home) and young people at school. We calculated the gains induced by increased studying time when looking at economic gains by young people. The indirect monetary equivalent gains for supporting other adults generating incomes outside the household (in the local economy or as temporary migrants), can be looked at from a wages-for-housework perspective. That is the additional time freed by the water intervention will enable other household members to be more productive in the wider economy and this can be expressed in monetary terms. On this basis, it was thought reasonable to attribute a shadow price with a minimum value of R50 a person-day to the additional time made available by the drinking-water intervention (the local wage of a woman working as an employed cleaner in 2008). Thus in a typical year, 72 years of adult women's time freed up by the drinking water intervention will be worth a monetary equivalent of R1.3 million (72 x 50x365).

It will be almost impossible to estimate with any precision the qualitative educational gains from the increased total time for studying by people under 18 due to less illness and caring as well as collecting water (plus the extra support available from adults) as a result of the drinking-water intervention. However, an order of magnitude for the study was made from the following assumptions:

- There were 200 young people in each one-year cohort of school who benefitted from the intervention;
- Assuming that as a result of the increased study time, energy and adult support attributable to the drinking-water intervention, 10% of each cohort (20 young people) leaves formal education having successfully completed one more year than they would have done before the intervention;
- An additional year in formal education is assumed to be worth on average an additional R1,000 a year over a 30-year working life after the intervention to each person achieving the extra grade.

From these assumptions, each young person who achieves an extra year of formal education can expect an increased income valued at a present value of R20,000 on a 3% pa discount rate. Thus 20 young people a year will add a present value equivalent of R400,000 to the benefits in every operational year of the intervention.

To put an economic value on infant deaths saved by the intervention will mean that they will be a net cost to their family in terms of consumption costs for much, if not all, of the twenty years of the intervention. Demographically, an additional 65 people (five deaths prevented in each of the thirteen years (2004-2017) in which the system is in operation) will be alive at the end of the intervention but who would not have been alive without it. Calculating a value for the net contribution of these 65 people to South African society is a challenge as the eldest will only be thirteen years of age in 2017. Thus significant additional incomes will start around 2020 and from that year more incomes will be added until the oldest start to retire in about 2060 after which total income start to fall until the last person retires in around 2075. The highest annual total income could be around R1.3 million (65 people earning an average of R 20,000). Setting this up in spread sheet format and discounting at 3% pa gives a present value in 1998 of about R15 million.

Putting all these benefits into a spread sheet gives the pattern shown in Table 4.14.

Table 4.14: Summary of total discounted benefits (See Cameron and Jagals, 2011)

Year(s)	Discounted benefits in R'million (at 3% pa)	Comments
1998	15	Discounted flow of income from earnings of saved lives (2020 to 2070)
2004-16	19	2,100 each year (400 from medical cost savings, 1,300 from added adult women time for livelihood choices, 400 from income effect of improved school performances). Each year is credited with the same sum of R2,100 -thousands in benefits – so the discounting calculation can be simplified to Benefits x (sum of all the discounting factors from year 7 to year 19 inclusive), i.e. $PV = 2,100,000 ((1/1.03)^7 + (1/1.03)^8 + (1/1.03)^9 + (1/1.03)^{10} + (1/1.03)^{11} + (1/1.03)^{12} + (1/1.03)^{13} + \dots + (1/1.03)^{19}) = 2,300,000 \times 9.2 = 21,160,000$
TOTAL	34	

Thus the total present value for 20 years of intervention for all four types of benefits in monetary equivalent form was R34 million.

4.5.3 Bringing costs and benefits together for analysis

The original cost estimates in Section 4.3 were rounded total present value of the costs was R11-million. This indicated a Net Present Value (Present Value of Benefits minus Present Value of Costs) of R23-million. The NPV was converted into a ratio of the Present Value of Benefits (PVB) to the Present Value of Costs (PVC) to remove in any sensitivity to scale of operation. For this study the PVB/PVC ratio = $34/11 = 3.1$. This is a very impressive ratio by any standards and certainly suggests the investment was justified (while the general benchmark of the PVB/PVC ratio is 1, a ratio greater than this is judged to be very satisfactory in assessing public sector investments).

Another way of taking account of scale is to calculate the discount rate that would reduce the NPV to zero. In economics language this is the Internal Rate of Return (IRR). The IRR was calculated by trial and error and by varying the discount rate and considering the relative sizes of total costs and benefits (Table 4.15). The results were that the totals of costs and benefits approached each other, i.e. the NPV got close to zero and the discount rate approached the IRR.

Table 4.15: Comparing costs and benefits at varying discount rate

Discount rate	Discounted total costs (in R-million)	Discounted total benefits (in R-million)	Comments
15 %	7.2	7.7	Need to raise interest rate (IRR) to reduce value of later benefits relative to earlier costs
16 %	7.0	6.9	The interest rate (IRR) that almost equates costs and benefits, i.e. the rate the intervention could afford to pay and therefore the higher the better
17 %	6.9	6.2	Costs are now higher than benefits and the rate of interest (IRR) needs to fall to increase the value of later benefits relative to earlier costs – that is the intervention can afford to pay a higher rate of interest on a loan

At the time of the study, the IRR was about 16% per annum – a very creditable rate of return by commercial standards. It must be emphasised that this return comes over a period of 20 years. It must always be emphasised that the SCBA estimates were based on estimates of future values of variables, often far into the future. This involves considerable uncertainty. This may even apply to impact evaluations if, for instance, they involve estimates of future incomes for people still in school.

This concern with uncertainty about the future (added to doubts about the accuracy in current observations) explains why all the data cited in this chapter are expressed in rounded numbers. Therefore this section, as previous sections, must end with a warning. Beware of the temptation of offering or demanding spurious accuracy from a SCBA. Citing numbers which give the illusion of much greater accuracy than justified by the procedure for deriving the numbers is very unprofessional and verges on being unethical if it is intended to inhibit discussion of both the assumptions being made by the analyst and/or likely sampling and measurement errors in the data. These concerns lead us to the final section of this chapter and also demonstrate the necessity of sensitivity tests.

4.6 Sensitivity testing to determine the robustness of the SCBA results

4.6.1 What are sensitivity tests?

In economics estimates of any mean are only deemed accurate to plus or minus five percent (often attributable to sampling error). If then other forms of inaccuracy are factored in and the margin of error approaches plus or minus ten percent (or more), the situation requires sensitivity tests.

A sensitivity test constructs additional scenarios that adjust some of the values of variable to be used in a SCBA on the grounds that they are comparatively:

- Vulnerable to sampling or wider measurement error (in which case both high and low values may be tested to assess impact on cost-benefit ratio or IRR), e.g. choice of respondents;
- Influential on the SCBA results because of the sheer scale of their effects (large numbers occurring relatively early in the intervention life), e.g. delays in construction;
- Open to future uncertainty in the judgement of local key informants or judging by experiences of similar interventions elsewhere, e.g. breakdown of key equipment;
- Of particular concern to decision makers, that is the some variables have a higher weighting in the political decision than the monetary equivalent value they have been given in the “most likely” SCBA scenario, e.g. increasing social cohesion;
- Of particular concern to people in greater poverty and suffering greater discrimination, that is some variables have a higher weighting for such people than the monetary equivalent value they have been given in the

“most likely” SCBA scenario, e.g. livelihood damage caused by having to provide “voluntary” labour to construct a new drinking water system.

4.6.2 Deciding which variables to include in a sensitivity test

The major variables in the study SCBA are shown in the first column in Table 4.16 (next page), with these variables lined up against the criteria for prioritisation in sensitivity testing. The X’s indicate increasing sensitivity of the column criteria to changes in the value of the row variable – in economic language the relative degree of elasticity of percentage response of the column variable to a percentage change in the row variable.

Table 4.16 suggests sensitivity tests on all of these variables. Rather than treat each variable separately, it is often more convenient and more stimulating to group the modifications to variables into scenarios with a plausible story to bring out any interrelationships between the variables.

Four scenarios are presented for this chapter that can be applicable in almost any situation and is not just dependent on the specific context of the case study area:

- Given the positive results of “most likely” SCBA scenario that we have been creating up to now in the preceding text, it seems appropriate to first test changes in those benefits most vulnerable to measurement inaccuracy. The SCBA reported on up to this point could be described as a “most likely” scenario. This was Scenario A;
- Scenario B focussed on the system’s vulnerability to breakdown due to poor maintenance and the vulnerability of the SCBA results to such a breakdown;
- Scenario C looked to future population pressure on the system and modified the parametric variables to include increments in the population using the drinking water system;
- Finally Scenario D takes a more optimistic view and models increasing incomes and higher aspirations to include a sequence of incremental improvements.

Table 4.16: Indicative framework identifying variables for sensitivity testing

Parameter variable/ Criteria for selection	Measurement inaccuracy	Scale of influence	Vulnerability to future uncertainty	Interest to decision makers	Interest to poor people
Total costs in each year from 1998 to 2017	X	XXX	XXX (histories of poor maintenance locally and globally)	XXX	X
Livelihood time benefits from fewer diarrhoea episodes	XX	XX	X (if system maintained and population using system remains manageable)	X	XXX
Livelihood time benefits from caring for fewer sick people	X (once episodes reduction known)	XX	X (if system maintained and population using system remains manageable)	X	XX
Proportion of people seeking formal health treatment for diarrhoea episodes	X	XX	XX (availability and quality of health services)	XX	XX
Health treatment cost per episode of diarrhoea	XXX	XX	X	XX	XXX
Livelihood time benefits from improved access to water	X	XX	X XX (rising aspirations to have in-house connections)	X	XX
Numbers of infant deaths prevented	XX	XX (through monetary equivalent value attributed)	X (if system maintained and population using system remains manageable)	XX	XXX
Putting a value on each infant death prevented	XXX	XXX (distant in time but very high value)	XXX (development of economy)	XX	XXX (source of social security for current generation)
Savings from reduced societal resources needed for health treatment	XX	XX	X (if system maintained and population using system remains manageable)	XXX	XX
Proportion of young people improving school performance	XXX (attribution to drinking water improvement?)	XX	X	XXX (especially girls)	XX
Lifetime income gains from better school performance	XXX	XX	XXX	XX	X (poorest unlikely to get the highest gains)
Valuation of livelihood time gains differentiating between adult women and adult men	XX	XX	X	X	XXX (social justice/inequality dimension)

4.6.2.1 Scenario A

Given the very positive results from the “most likely” SCBA scenario in the previous section, Scenario A tested whether changes in the variables where accuracy is most in doubt can reverse this positive conclusion. If the SCBA “most likely” result had been negative then it would be logical to reverse the argument and see whether modifying these variables in a positive direction may produce a positive SCBA result.

Each variable could be tested in turn and see if any feasible value exists that can reverse the SCBA result and reduce the IRR below three percent or the Benefit/Cost Ratio below one. But visual inspection shows changing individual benefits cannot reverse the SCBA result in a negative direction, so instead we created a scenario in which all the benefits variables with three XXXs in the appropriate column of Table 4.16 are radically modified in value as shown in Table 4.17.

Table 4.17: Variables modified for Scenario A

Parameter variable	Adjustment made
Health treatment cost per episode of diarrhoea	Reduced to R500 from R1000
Value of infant deaths prevented	Reduced to zero
Proportion of young people improving school performance due to drinking water intervention	Reduced to five percent of each cohort
Lifetime income gains from better school performance	Reduced to zero

These modified values did not affect the Present Value of the costs, but it reduced the Present Value of the benefits to R14-million. Therefore, the Benefit/Cost ratio falls to 1.3 which, while is still significantly greater than one, may make it more vulnerable in terms of prioritisation compared with other uses of the resources the intervention utilises.

At a conceptual level, this scenario does raise important issues of inter-generational relationships. Any estimates of the future state of the world in 15 to 45 years’ time must be subject to doubts about the accuracy of the variables involved. The “most likely” scenario puts a considerable value in economic terms on young people’s long term futures and saving infants’ lives. There will always be controversy over putting a value on a human life and Scenario A brings that issue into stark focus. It encourages decision-makers to take responsibility for long term change and to think about the world of work that will be accessible to the next generation of people.

4.6.2.2 Scenario B

This scenario focused initially on the costs, because of the reported poor maintenance of the water supply systems (Chapters 2 and 3) and therefore these had much shorter technical lives than envisaged in the original design. To capture these concerns the operating and maintenance costs were reduced by half. The sensitivity of this modification is then estimated by calculating the number of years the scheme would need to run to give a Benefit/Cost ratio of one, which is to break even in Present Value terms at a discount rate of three percent per annum.

For the case study this comparison shows that the scheme breaks even in year 12 (2009), and moves over a Benefit/Cost ratio of 1.3 in year 14 (2011). Of course, it requires an engineer to judge whether a scheme operating on only half the maintenance costs needed for sustainability can operate as designed for 12 years before completely breaking down. There is a conventional wisdom that a chronically under-maintained scheme will break down in five years, and the schemes in the study areas were a chronic economic failure on that time horizon as the Benefit/Cost ratio was well below one.

We also examined the influence of speeding up implementation from the start of construction. If the schemes were constructed in two years instead in six, the breakeven point then occurs in the sixth year of operation and the Benefit/Cost ratio of over 1.3 in the seventh year. The schemes were still economically a clear failure if it collapsed in five years, but more cost-efficient construction does offer significant protection – more than just the time saved in construction.

4.6.2.3 Scenario C

This scenario involves increasing the size of the population using the scheme on the SCBA variables. Increasing population increased all the benefits in terms of people either being born into an improved drinking water situation than before the intervention or migrating towards a superior drinking-water system than in their places of origin. If this were the only consideration then all the benefits would be simply scaled up, the scheme would be more unit cost-efficient in terms of cost per m³ of water and the SCBA would produce an even more positive economic assessment result than in the “most likely” scenario.

But more people may also put pressure on the scheme as it depends on communal standpipes being up to the strain of greater use. The form of the strain and who receives it will depend on where new people accommodate themselves. If they are evenly distributed among the pre-existing population (as would be expected with natural population growth among the existing population) then everyone may spend more time queuing for water. If newcomers are concentrated in the area closer to the reservoir and therefore access the system at the upstream taps in increasing numbers, then pre-existing users may also experience diminished water pressure and diminished access times, or even complete loss of water at the taps lower down the distribution pipeline. Also breakdowns may be more frequent. If the newcomers are scattered on the periphery of the scheme then the newcomers will take the strain since they will not have the same benefits per household as the original beneficiaries. Also as population pressure rises then pressure on the infrastructure will increase and breakdowns become more frequent. In any of these cases, some people may start using the original water sources again, and health benefits will be reduced.

To capture such effects, the most plausible model is an inverted u-shaped curve in which initially the benefits of increased population outweigh the disbenefits but after a tipping point level of population, the disbenefits will increasingly outweigh the benefits.

For Scenario C, a simple model was used in which the population grows by four percent per annum and the benefits grow proportionately until the population has increased by 25% compared with the original population. Once this tipping point population is reached then benefits are assumed to fall by six percent per annum.

The scenario has a significant impact on total discounted benefits compared with the most likely scenario. The Benefit/Cost ratio falls from 3 to 2. An earlier tipping point in terms of increased size of population and/or a higher rate of loss of benefits after the tipping point could have a dramatic effect on the SCBA results, pushing them towards economic non-viability. The scenario encourages decision-makers to think about the demographics of the local context and consult engineers on the maximum carrying capacity of the system in terms of both total water availability and the effects of increasing demand on the physical delivery of water at critical points in the system. It also raises issues of possible socio-political tensions arising if there is conflict over access to water.

4.6.2.4 Scenario D

This scenario might be thought to be more optimistic as it looked towards raising real incomes for the poorest and rising aspirations for all over time. Raising incomes of the poorest means the shadow price of adult women's time will increase and their time saved becoming more valuable in terms of its monetary equivalent. Rising aspirations means everyone will aspire to have household connections rather than standpipes. The more affluent parts of the community may be willing to pay for such connections and the associated increased access to water. For others, meeting these aspirations may be funded by the public sector out of general taxation – especially for the poorest households.

The sensitivity test used five modified variables (which were applied to the whole local population not just those who previously used the open sources):

- An increase in system costs to bring water closer to all households over a period of four years is started in 2009 and completed by 2012. It is assumed that this will involve a total cost per year of making connections of R750,000 (also assuming no increased maintenance will be involved);
- A further reduction in cases of diarrhoea due to diminishing need to use contaminated container water transported from standpipe to household of 2 cases per 1,000 people a year (3,000 days for 6,000 people) with a proportional reduction in days caring;
- A reduction of medical treatment costs (saving a further R170,000 in addition to the previous R400,000 a year);
- A further reduction in time collecting water of half an hour a day a household;
- An increase in benefits from increased real income per capita for the poor and hence increased value of adult women's time saved by 5 percent per annum starting from R50 a day. For this scenario, the value of future incomes for young people with additional schooling and infants whose lives have been saved by the original drinking water intervention will not be changed.

In this scenario, the present value of costs rises to R13-million and benefits rise to R46-million giving a Benefit/Cost ratio of 3.5 with an IRR still close to 16 percent. This was an improvement means to the "most likely" scenario. This result suggests the intervention could have included on-plot water connections at the outset of providing the water supply service.

However, if cases show a higher discount rate and relatively low additional benefits (in economics terminology marginal or incremental benefits) from later interventions, then a SCBA may indicate that incremental upgrade

interventions may yield a more positive economic assessment than including all interventions in the initial construction phase, especially if the extra work involves delaying the scheme becoming operational.

4.6.3 Final analysis

The four scenarios offered here in addition to the “most likely” scenario were intended to show how SCBA can help the would be analyst explore issues surrounding a particular small scale drinking water intervention in order to offer decision makers options. They were not applicable to all contexts and do not exhaust all the possibilities for the populations assessed in this study. They show how an SCBA economics assessment can be used as a tool to assist, rather than dictate decision making. Any economic assessment should provoke thought and inform debate not close the decision-making process.

The objective was to a total cost benefit analyses based on the cost – benefit ratios, based on present value of benefits to the present value of costs. This was achieved and the interventions certainly seemed hugely cost-beneficial when measured against international benchmarks. Tables 4.19 and 4.20 below summarises the PVB:PVC ratios for the study interventions.

5 SUMMARISING THE IMPACTS

Appendix A shows the summarised data from this study and Table 4.18 shows the summarised benchmarks of impact derived from the research work and where obtainable, from international literature and guidelines. These were placed in a three-tier benchmarking approach, showing whether an outcome was a benefit (1), a detriment (3) or had no impact (2)

Table 4.18: Benchmarks for the HSE criteria

Impact	Parameter	Benefit (1)	No impact (2)	Detriment (3)
Health	Relative risk of contracting diarrhoea	<0.25	>0.25≤0.8	>0.8
Social	Scale of Satisfaction	<60%	>60≤30%	>30%
Economics	Social cost benefit analyses using PVB/PVC ratio (including sensitivity testing)	≤1.5≥1	<1	<0.5

As the basic services were the primary level of service targeted for assessment in this project, the outcomes of the research clearly show (in Table 4.19) that the impacts were mostly beneficial for the *basic services*. Except for UC3, where the frequent interruptions caused the basic system to have no real impact in terms of reducing the relative health risk.

Table 4.19: Outcomes of the HSE impact assessment

Impact	Indicator	RC1		UC1		UC2			UC3			RC2
		BS	NS	BS	NS	RS	BS		NS	RS	BS	NS
Health	Relative risk of contracting diarrhoea	1	3	1	3	2	1		3	2	2	3
Social	Scale of Satisfaction	1	3	1								
Economics	Social cost benefit analyses	1	2	1								

In the context of health, the beneficial impact was based on an arbitrary figure of what constitutes an acceptable level of *diarrhoea* in a community. This figure could change as the concept is further explored in future research. If it is made more conservative in the South African context, then the impact might change from beneficial to no impact or even show the original detriment to remain.

Using only *satisfaction* as the social parameter is too conservative. While relatively high satisfaction levels within the receptor communities were sustained even throughout the times that the systems were not well maintained, more detailed factoring in of the receptivity results (shown in the report attached as Appendix C) would have shown that disappointment with the system failures could offset the positive findings that only the satisfaction indicator produced. However, for the receptivity approach (Theory of Planned Behaviour) to provide feasible results, more real-time before and after studies were required than the study could provide. This is a point that should be researched further.

By far the most influential economic impact indicator was the *social cost benefit* analyses (SCBA). Many areas of social life not often thought of, showed where an improved basic water supply service adds value to the daily lives of people beyond the classical indicators of disease risk reduction, people behaviour change and indeed cost-effectiveness. The reader is referred to the more comprehensive work on SCBA that is referred to under Cameron et al., 2011.

Conclusion

The main purpose of the project was to produce a generic tool that can be used for assessing the impact of improving small community water supply services. The tool is found in WRC Supplementary Report 1700/2/12. Application of the tool requires only limited data inputs as it is largely based on the research reported in the previous chapters. The research was also used to try and test the tool against real-time research data.

Developing an understanding of how to measure and interpret impact across three primary pillars of sustainability namely health, sociologic and economic impact of improving the water supply services in small and rural communities was challenging, especially in the context of providing a single impact value that would form the output for the tool.

It follows therefore that the main body of research findings reported on in this document was focussed on the primary aim of the project namely to assess the changes in the functions, effects and impacts brought about by supplying basic water services a specific set of small and rural communities in the Limpopo province in South Africa.

To achieve this aim, the five project objectives (Section 4.1, Chapter 1 Introduction; p 4) were met:

- Several topic related literature searches were conducted to provide research frameworks for the various function-, effect- and impact-criteria, their indicators and associated parameters;
- A range of rural villages were selected according to situations *before* as well as *after* their basic water supply services were implemented;
- A suite of instruments were developed and used to measure the changes brought about by the water service system and their related functions including the management of the systems;
- The impact of the domestic water container-water supply link between the system endpoints (e.g. communal taps) and the households were also factored in;
- The effects of these changes (and the influence of the container situation) were quantified and described in terms of a suite of measurable effects;
- These water supply system changes and their effects were then translated into impacts (ranging from detriment to benefit) on the health, social and economic conditions of the households in the study communities.

1 WHAT WAS THE IMPACT?

The impact was beneficial overall. However, coming to this finding has conditions and also raised several questions – which will be discussed below as well as in the next sections.

The beneficial impact should come as no surprise, as substantial international literature on this issue shows that the impacts would be more beneficial than detrimental at a point in the time almost immediately following the implementation of a new, or an upgrade to, basic water supply service (BS).

Clearly not all of the functions and effects were attributes to the beneficial impact. Effects such as the bacterial risk of infection as well as the risk of musco-skeletal disorder were indicative of things not going well, but were in turn strongly associated with the use of containers. The real benefits of having a yard tap or an in-house connection and its relationship to the use of containers have not been assessed.

How is it that the *effect* categories performed so poorly and yet the *impacts* of especially the final upgrades were still beneficial? Clearly, the lower relative risk of contracting diarrhoea should be ascribed to a whole system effect as was so effectively demonstrated by the ❶ benefits of working systems versus the ❷ no impact of struggling systems and the ❸ detriment of non-systems (Majuru et al., 2010).

Relationships between risk assessments such as the QMRA and the epidemiology-based relative risk are precarious exercises and with the limited data sets used in this study, the actual findings of the epidemiological study done for impact assessment should be the more plausible impact rather than predicting the risk as the QMRA is often used for.

Another significant finding is the fact that people do not bring in more water into their daily water use pattern despite the fact that water sourcing is closer and more convenient and regardless of the fact that they appear to be quite satisfied with the fact that they could bring in more water if they felt they needed it. Yet the risk of a household member to contract diarrhoea is less. More study will be required to unravel this phenomenon.

Although there were substantial savings in treatment cost, the predominant factor that made for a sound economic benefit is the savings in time and less disruption of social life, in terms of increased school attendance that bolstered the beneficence.

The main question that arose from this research (and also subsequently answered) was whether this benefit was sustainable.

2 WAS THE BENEFICIAL IMPACT SUSTAINABLE?

Two major conditions dominated the answering of this question. Its outcomes clearly indicated that the BS, as delivered to the study communities, were NOT sustainable, and the benefits initially achievable by such a service, substantially negated.

2.1 Communal taps and containers

The first condition was the primary condition by which the BS was provided namely communal tap endpoints. As long as the general first tier service aspect of the BS was based on delivering clean water at communal taps, it keeps the use of domestic water containers with all its detrimental side effects (negative impact on microbial water quality and musculo-skeletal impact on the water carriers who were mostly women and children), within the service. Enabling private connections was not a viable option in the study communities as the households clearly felt that in-house water provision should have been the endpoint and not communal taps.

Three sub-conditions need to be attached to this though:

- As long as people are provided clean water consistently at taps, the seeding of pathogenic bacteria into containers and subsequent increased risk of infection will be limited. However, people do need to be made aware of keeping containers clean;
- If the expectation of increasing people's daily household water use to support health and hygiene is to be realised, people need closer access to water in more amicable conditions;
- While the evidence of potential musculoskeletal impacts of water carry were effectively ruled out of consideration for this study because of the size of the study group, the study did indicate the potential for this situation to be one that can cause a serious chronic disease burden. If these findings were indeed to be universally true, then it is a plausible theory that the cost of treating musculo-skeletal injury might be an economic burden that can render the impact of improved basic water service delivery as detrimental instead of beneficial. More research is urgently required to assess this impact.

2.2 System management

The second aspect was the management of the systems. The results clearly showed that where the systems of basic supply services were properly managed (Reference community as well as Upgrade communities 1 and 2), the impact was consistently beneficial for the study period with no reason to believe that it would be otherwise over a longer time provided the conditions do not change.

The findings were clear on the inefficiency of the operations and maintenance of the systems in the area and how these consistently threaten the immediate benefits that are achieved with the implementation of a basic water supply service. No doubt this will be receiving serious attention as the government is putting measures in place to improve this.

What is a greater point of concern was the urban growth that was observed during the study. In especially the Reference Community and Upgrade community 1, the strain on the systems was already evident with evidence on enlarging the system showing it to be some time still before this would happen. Meanwhile the communities will continue to be at risk of failing systems.

3 IN CONCLUSION

This report does not provide definitive answers on the impacts on a country or global scale. While the results are by no means presented here as an accurate and total assessment of situations elsewhere in the country, it nevertheless should be a plausible reflection of what can be expected from similar situations elsewhere.

It was also not intended to be the ultimate research on the topic. Hopefully that the Water Research Commission as well as researchers elsewhere work more with the methods that were used during the research to refine them and increase the resolution of the results.

These systems need to be properly maintained and operated so people can have clean potable water consistently available and accessible at taps.

The use of large domestic water containers (the likes as is being described in this document) *has to be eliminated* by providing private connections and not communal taps. Taps need to be put as close to homes as possible, at least one tap per living unit, if not in-house, than directly adjacent. The WRC should consider soliciting research into the social cost-benefits of providing in-house water versus communal taps. It will not be surprising if such findings would show it cost-beneficial for houses to have on-premises water instead of communal taps.

On-premises taps will rule out heavy container carry and enable people to use smaller containers (more economical in term of acquisition cost) with larger openings to enable cleaning. However, if people were to continue using containers because of the model of basic water service delivery to communal taps remain unchanged, the communities should at least be made acutely aware – even trained – as to optimal hygiene maintenance of containers as well as the ergonomically correct way to carry these.

Furthermore, if people were to continue using containers, more consideration should be given to improving dedicated container technology (for transport and hygiene) as well as to subsidy for households to acquire these.

This was not happening at the time of this research, and there was also no evidence that this was on any engineering, social or health service agenda at any level of government. It demands urgent attention.

In terms of finally developing the monitoring tool as a product of this study, the focus was far more on using variables from what the actual basic water supply service was designed to deliver – with some limited variables from the effects and impacts. While the container situation needs to be addressed at a different forum, it could not be left out of the monitoring tool and was factored in for variables where it had the most demonstrated effect namely access to and potability of water.

4 A FEW LAST WORDS

The author is very happy to say that the district council in the research area is in the process of constructing a substantial regional water scheme that would provide a substantial supply of piped and treated surface water to many small communities in the area, including the communities that participated in this study. One can only congratulate the service provider and the communities for making this happen. However, on the other hand one can only hope that the treatment storage and supply of water would be managed proportionate to the investment and better. In the final analysis this means that the villages and towns will always have access to available and potable water. Anything less would be a sad reflection on delivery of service delivery.

This study has shown that substantial health, social and economic benefits can be achieved with a proper water supply service supported by a proper delivery system. A sustainable water supply service will improve and accrue these benefits.

Which after all is what our society is aiming for when investing billions in water supply interventions for small and rural communities in South Africa.

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Appendix A: Summaries of function changes, effects and impacts

Table A1: Changes in the water supply service functions after the interventions

Function Input parameters		Performance (S= score; P = performance)				RC1		UC1			UC2				UC3				RC2						
		Good (0)	Compliant (1)	Non-compliant (2)	Critical (3)	BS	NS	RS	BS	NS	RS	BS	NS	RS	BS	NS	RS	BS	NS						
						S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P				
Access	Water point density	≤10	>10≤200	>200	>500	146	1	742	3	143	1	493	2	321	2	103	1	1,1K	3	106	1	102	1	465	2
		>25	≥15	<15≥5	<5	35	1	4	3	15	1	8	2	8	2	33	0	9	2	24	1	45	0	4	3
		1:20	≤1:40	>1:40≤1:80	>1:80	13	0	68	2	19	0	30	1	30	1	8	1	32	1	12	0	6	0	15	0
Access	Sourcing technology	1:100	≤1:250	>1:250≤1:500	>1:500	75	0	406	2	114	1	165	1	165	1	41	1	143	1	53	0	29	0	68	0
		1	<1≥0.75	<0.75≥0.5	<0.5	0.62	2	0.45	3	0.58	2	0.4	3	0.45	3	0.8	1	0.45	3	0.5	3	0.84	1	0.5	3
Availability	Capacity of system	1	<1≥0.75	<0.75≥0.5	<0.5	1	0	1	0	0.99	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
		1	<1≥0.75	<0.75≥0.5	<0.5	0.59	2	1	0	0.53	2	1	0	0.83	1	0.6	2	1	0	0.5	3	0.2	3	1	0
		1	<1≥0.75	<0.75≥0.5	<0.5	0.59	2	1	0	0.53	2	1	0	0.83	1	0.6	2	1	0	0.5	3	0.2	3	1	0
		20	≥10	<10≥7	<7	40	0	11	1	40	0	11	1	4	3	36	0	11	1	4	3	25	0	11	1
Potability	Supply hazard condition	ND (100)	ND (95)	≤0 (95)	>0 (95)	ND	0	3	3	ND	100	3	3	ND	1	ND	0	4	3	4	3	ND	0	3	3
		ND (100)	ND (95)	≤0 (95)	>0 (95)	1	3	3	3	1	3	2	3	2	3	1	3	3	3	2	3	2	3	3	3
	Supply hygiene condition	ND (100)	≤10	≤100	>100	3	3	5	3	2	3	5	3	3	3	2	3	5	3	4	3	0	2	4	3
		ND (100)	≤10	≤100	>100	3	3	5	3	2	3	5	3	3	3	2	3	5	3	4	3	0	2	4	3
		ND (100)	≤10	≤100	>100	3	3	5	3	2	3	5	3	3	3	2	3	5	3	4	3	0	2	4	3
	Water quality (aesthetic) at source	1	<1≥0.75	<0.75≥0.5	<0.5	1	0	31	3	1	0	15	3	1.93	2	1	0	12	2	3.7	2	1	0	31	3
		1	<1≥0.75	<0.75≥0.5	<0.5	1	0	7.3	1	1	0	6.7	0	7.62	0	1	0	6.7	0	7.4	0	1	0	7.3	0
	Conductivity (water aesthetics) mS/m at source point EC @ 95 th %ile	1	<1≥0.75	<0.75≥0.5	<0.5	47	0	57	1	1	0	50	0	25	0	1	0	50	0	39	0	1	0	1	0

The technical availability criterion informed whether the system could deliver both in quantity as well as the general quality of the water. The quantity indicator aligned with the function criterion of availability (can the source and system provide continually?) and the quality part with potability (can the system deliver good quality water?). The capacity of the system aligns with the function of access in the sense that it refers to the distribution of the water from the source to the consumer, including the distance from home to tap, which is also a function of water point density. Continuity aligns with the service function criterion of availability as it reflects measure of distribution reliability while condition aligns with access refers to the maintenance of the system as it reflects in the condition of standpipes and taps and also provides a base from which to appraise its possible impact the three HSE categories.

Table A2: Categorising the effects of the changes in the water supply services

Effect	Input parameters		Performance			RC1			UC1			UC2			UC3			RC2	
						BS	NS	P	BS	NS	P	RS	BS	NS	P	RS	BS	NS	P
Time	Individual collection time	Minutes per 20-ℓ container	Good (0)	Compliant (1)	Non-compliant (2)	Critical (3)	S	P	S	P	S	S	P	S	P	S	P	S	P
Water demand	Litres per person per day	Household lcd @ 10th percentile	>50	≥25≤50	<25≥15	<15	7	3	11	3	9	10	3	14	3	5	3	11	3
	Risk of musculo-skeletal disorder	Carrying filled water containers	<0.1	≤0.33≥0.1	>0.33≤0.66	>0.66	0.7	3	0.8	3	0.8	3	0.8	3	0.8	3	0.7	3	0.8
	QMRA	Risk of bacterial infection per year per individual ingesting container water	0	≤1	>1≤16	>16	4	2	114	3	82	14	2	5	2	139	3	20	3

Table A3: The HSE impacts of the changes in the water supply services

Impact achieved (Research based)	Impact criteria	Performance			RC 1			UC1			UC2			UC3			RC2		
		Benefit	No impact	Detriment	S	P	Taps	Open water	Taps	Open water	Hand pumps	Taps	Open water	Com tanks	Taps	Open water	S	P	Open water
Health	Relative risk of contracting diarrhoea	<0.25	>0.25≤0.8	>0.8	0.22	1	1	3	0.23	1	0.6	2	0.17	1	3	1	1	2	3
Social	Scale of Satisfaction	>60%	≤60≥30%	<30%	60%	1	1	3	60%	1									
Economics	Social cost benefit analyses	>1.5≥1	<1	<0.5	3	1	1	2	3.1	1									

Appendix B: The potential impact of domestic water carry

Jo-Anne Geere* and Paul Jagals†

*Faculty of Health, University of East Anglia, Norwich, UK

†Water and Health Research Centre, University of Johannesburg

‡Department of Environmental Health, Tshwane University of Technology, Pretoria, South Africa

1 INTRODUCTION

Improved health-related water management could prevent one tenth of the current global disease burden and investments in improved access to safe drinking water may realize at least ten fold economic returns (Prüss-Ustun et al., 2008). Yet lack of access to safe water remains the third most significant risk factor for poor health in developing countries (Haller et al., 2007).

It is likely that the health impacts and costs of sub-optimal water supply are frequently underestimated, because effects other than acute diarrhoeal illness are not usually considered (Prüss-Ustun et al., 2008). The health impact of various interventions to improve access to safe water has been extensively reviewed, but primarily focusing on rates of acute infectious diarrhoeal illness to evaluate outcome (Haller et al., 2007; Gundry et al., 2004).

Chronic health impacts can be caused by carrying heavy loads of water for domestic use. Not assessing these impacts may lead to underestimates of costs and benefits of the investments intended to improve safe water access. Comprehensive understanding of both beneficial and detrimental health impacts of water-supply interventions, is crucial for appropriate water resource development and management towards improving access (Bartram et al., 2005).

The World Health Organisation defines 'domestic water' as that 'used for all usual domestic purposes', categorized variously as: water use for consumption, hygiene and amenity use (Howard and Bartram, 2003). In African countries water use for domestic activities such as animal watering, construction and gardening should also be considered (Thompson et al., 2000). Domestic water carrying (DWC) is defined in this study as any method of collecting and transporting water, on or by a person over distance for domestic use, from a source outside of the home.

The health impacts of DWC appear not to have been researched, neither frequently or intensively. Ferguson (1986) suggested that women are subject to high physical stress when carrying heavy water loads. DWC may also have complex health consequences that may be related to exposure to environmental hazards (Briggs, 2003), the physical effects of manually handling, lifting and carrying loads (Joosab et al., 1994; Jager et al., 1997; Levy, 1968), increased risk of physical abuse (Chan, 2007), loss of time for income generating activities and education (Haller et al., 2007) or positive engagement with culturally appropriate roles (Leavit, 1999). As the health impacts of DWC may be wide ranging and complex, a broad conceptualisation of 'health', functioning and disability may be necessary to fully appreciate how DWC might impact upon the health of different individuals.

The International Classification of Functioning, Disability and Health (ICF) categorizes functioning in relation to health at the levels of body structure and physiological function, engagement with activities and social participation (ICF, S.A). It incorporates environmental factors and provides a coherent view of different perspectives of functioning and disability in relation to health and a common language through which to communicate ideas. The ICF is legally binding as an information standard and has been ratified by 192 countries worldwide. Coding and mapping people's perceptions of the relationship between DWC and health to ICF categories is therefore a potentially useful strategy to clearly identify and communicate the health domains which are potentially affected by DWC.

The Vhembe district in the Limpopo province of South Africa has high levels of poverty in some areas (Hope, 2003) where DWC and suboptimal water supply may have detrimental impacts on health. Like elsewhere in South Africa, interventions to improve access to a potable water supply are being gradually implemented in the district. Questions being asked by water service authorities are whether the impacts of these interventions are measurably beneficial both from service provider and service user perspectives.

Consequently, assessment of the impact of current water supply systems is underway in parts of the province to evaluate, across health, environment, social, economic and technical domains, the development and sustainability-management of water services in the region. An important expectation of water service authorities is that the burden of carrying water would be lessened by placing communal taps not further than 200 metres from each household (Jagals, 2006). However, it should not be assumed that provision of such infrastructure necessarily translates into sustainable reduction in the physical burden of DWC. For example, in East Africa various factors, such as poor system

maintenance and stress on infrastructure due to population growth, can affect the outcomes of water interventions over time, such that expected benefits may not be realised (Thompson et al., 2000). Appropriate assessment methods or measurement tools are necessary to evaluate whether existing interventions do successfully and sufficiently reduce the physical burden of DWC and to monitor whether expected benefits are sustained.

The aims of this study were threefold:

- To investigate whether appropriate risk assessment or health outcome measurement tools currently exist to measure the health impact of domestic water carrying (DWC);
- To identify the variables which should be measured to investigate the health impact of DWC;
- To develop a method of efficiently gathering information to assess the health impact of DWC (for piloting).

2 METHODOLOGY

Three approaches were used to address the aims of the study. Firstly, a review of the literature was conducted to investigate whether any risk assessment or health measurement tools currently exist to measure the impact of DWC. Secondly, an exploratory study using mixed methods was conducted to determine the domains of health potentially affected by DWC and which are important to people who perform DWC. Finally, a further review of literature was conducted, to compare the findings of this exploratory study to research into the relationship between physical work and health conducted in other settings. The results of these approaches were synthesised to identify the outcomes and potential risk factors for those outcomes which should be investigated to determine the health impact of DWC.

2.1 Structured Review

2.1.1 Search strategy

An electronic search of the Medline database, from inception to March 2008 and updated in March 2009, was performed. The key words (carrying OR transporting) AND (drinking water OR domestic water) AND health were used to identify any studies investigating water carrying and health impact. 445 citations with titles and abstracts were retrieved and screened by the author. Of these, four potentially relevant studies were identified and full text versions of the papers retrieved. Review of the full text articles revealed that they were not relevant to the aims of this study.

2.1.2 Results

No articles describing an investigation into the relationship between DWC and health were found. Similarly, no reports were found describing specific tools for evaluation of the physical burden of DWC or adaptation of existing health measurement or risk assessment tools for such purposes. As there appears to have been no research into the effects of DWC on health, the pilot study was conducted to develop insight into the nature of the task and through observational and qualitative research methods, to develop understanding of the potential health impacts of DWC.

2.2 Mixed methods pilot study

2.2.1 Design

A phenomenological methodology was used with collection of both qualitative and quantitative data to explore the phenomena associated with DWC performed by adults and children in Limpopo Province. The aim was to identify the health domains likely to be affected by DWC which are relevant to both the target population and service providers and establish the grounding from which tools to measure the health impact of DWC can be developed.

The aim of the quantitative aspect of the study was to better understand how DWC is performed, gain insight into the potential health effects of the task and identify potential risk factors related to it. An ergonomic systems approach (Buckle, 2005), to gather information about various factors accepted to pose health or injury risks during physical work in other settings (Briggs, 2003; Wearing et al., 2006; Cote et al., 2008; Adams et al., 2002; Bongers et al., 2006) is likely to be useful for initial appraisal of work related to DWC. An ergonomic systems approach can gather information from observation and verbal report (David et al., 2008), to evaluate individual, task, psychosocial, organisational and environmental factors which may impact on the relationship between health and work (Pheasant, 1986; Grandjean, 1988). Therefore a descriptive observational approach, informed by ergonomic principles, was used to answer the following quantitative research questions:

- Who collects and carries water for domestic purposes?
- How do people carry water for domestic purposes?

- What factors considered to pose risk of injury (and disease) in other settings, are people exposed to during DWC?

The aim of the qualitative aspect of the study was to develop understanding of the potential health impacts of DWC, particularly from the perspective of people who have experience of performing DWC and therefore specific insight into the relationship between DWC and health. Such knowledge is essential for the development of health impact assessment tools with 'content validity', defined as measures which assess content that the target population perceive as relevant to the construct of interest (Atkinson and Lennox, 2006). Qualitative research methods were used to answer the following research questions:

- Which domains of health do people with experience of DWC perceive to be affected by DWC?
- Do people with experience of DWC perceive that DWC should change?

2.2.2 Sampling strategy and participant recruitment

Data was collected from 6 villages in Limpopo Province, purposively selected to include a range of water service situations and environments which might have different physical effects or expose people to different risk factors for injury or disease. Specific water source points (WSP) were chosen to include varying infrastructure (for example types of water outlet pipes, communal tap design or protective walls around natural springs) and terrain which might influence methods and effects of DWC in different ways (Figures 1-4).



Figure 1 Water source: Communal standpipe



Figure 2 Water source: River



Figure 3 Water source: Spring



Figure 4 Water source: Spring outflow pipe

Before commencing research, permission to work in each village was sought from the village 'headman'. Each village was then visited over a period of two to three consecutive days. The researchers drove to chosen water source points and waited to identify through observation people carrying water or clearly intending to carry water. In this way a convenience sample was generated by inviting individuals observed at the time during which the researchers visited WSP to participate in the study. From the convenience sample individuals were purposively chosen and invited to participate, to recruit adults and children of both genders and with a range of ages according to the following inclusion and exclusion criteria. Such factors are likely to influence physical capacity for DWC and therefore might also result in different experiences of the health impact of the task.

2.2.2.1 Inclusion criteria

- Current or past personal experience of DWC
- Informed voluntary consent to participate

2.2.2.2 Exclusion criteria

- No experience of DWC

- Refusal to participate

2.2.3 Consent

Informed voluntary consent was sought from adult participants before recruitment into the study. Information about the study purposes and procedures was provided through verbal and written explanation in the participants preferred language. Although some children collected water in the company of an adult, in many instances, children collected water without adult supervision. Where children were observed to collect water with an adult, informed voluntary consent for the child to participate was sought from the adult. Agreement was also sought verbally from the child in a non-coercive manner by the RA, who was a local Venda male, sensitive to culturally appropriate ways to interact with the children. Care was taken to monitor from children's behaviour that they were not adversely affected by participating in the study.

When children were observed to collect water unaccompanied by an adult, the study purpose and procedures were first explained to the children by the RA in a manner culturally appropriate to their age and level of understanding. Once voluntary verbal agreement was obtained from the children, measurements of their weight and height and the weight of filled containers they intended to carry were taken. They were then video recorded and observed while filling containers and carrying water from the collection point to their home. On arrival at the house, a parent or adult guardian was advised of the study purpose and procedures, and formal consent for the child's participation sought. This gave an opportunity for the video capture and observational data to be erased in the event of the parent or guardian not consenting to participation of their child – however such a situation did not arise.

Ethical approval for the study was obtained from the International Development Ethics Committee, University of East Anglia, Norwich and the Higher Degrees and Ethics Committee for the Faculty of Health Sciences, University of Johannesburg.

2.2.4 Data Collection

Quantitative data was gathered through simple measurement (for example measuring height, body weight and the weight of water carried), observation and self-report. Simple measurements were taken after voluntary verbal agreement was obtained from participants. Observation was performed by the PI and RA while children carried water and recorded through video capture, photography and recording of field notes in a structured observation schedule. Information on the usual frequency and quantity of water carried and demographic information was obtained through participants' self-report and for children from their own or their guardian's verbal report. This information was also recorded on the structured observation schedule.

Methods of DWC and the environment in which it occurred were captured through observation with a structured observation schedule, video-recording and photography. Procedures were piloted with an adult woman in the study area and adapted to improve feasibility and ease of use. Data about individual and task related factors were gathered from self-reports as well as simple observations and then immediately entered onto the recruitment form as well as a structured observation form for each participant.

A tape measure was used to measure participants' height, using a flat standing-platform and a clipboard placed horizontally on the head to provide level points for measurement. The weight of participants (Figure 5) as well as the water carried (Figure 6) were measured in kilograms, both calculated from the average value of three consecutive weighing scores.



Figure 5 Measuring participant weight



Figure 6 Measuring container weight

A video recorder (Panasonic Mini-DV digital video camera Model NV-GS320) was used by the RA to capture DWC from the water source to the participant's home. Four observed subtasks of DWC were 1) preparing and filling, 2) lifting, 3)

carrying and lowering and 4) placement of containers. Video recordings also captured the times taken for each subtask. Occasionally brief pauses in video recording were necessary between subtasks and some participants were observed not performing all subtasks. A GPS unit (Garmin CSX 60) was used to measure the distance travelled between the WSP and house.

Participants reported the sensation of effort required for DWC immediately on completion of DWC using the modified Rating of Perceived Exertion (RPE) scale also known as the Modified Borg scale, which was translated into Venda. The modified RPE is a 12 point categorical scale which has ratio properties and has been validated for use with healthy adults and children of both genders and in hot environments (Finch et al; 2002). RPE scores have been correlated with heart rate in healthy adults and children during workloads ranging from moderate to heavy intensity ($r = 0.80-0.90$), with oxygen consumption ($r = 0.76-0.97$) [36] and OWAS and Body Part Discomfort scores (Olendorf and Drury, 2001).

Qualitative data was collected through semi-structured interviews and informal natural group meetings (NGM) which were conducted with participants near their own home. The two forms of semi-structured interviews were used as different kinds of information may be disclosed in each. The use of NGM as described by Green and Thorogood (2004), rather than formal focus group meetings, was adopted for efficiency and to minimise disruption to participants by interviewing people already gathered together. NGM can also maximise interaction between participants, as well as between researchers and participants. Interview guides were developed in English, translated into Venda, back translated and piloted in the study area. They were modified in response to piloting and discussion with the RA, a 29 year old Venda male with tertiary level education, fluent in English and Venda, and with experience of verbal and written translation work for social and scientific research projects.

Interviews and NGM were audio-recorded and conducted with immediate translation between the PI, RA and participants. For all interviews, the English questions and RA's immediate English translation of participant responses were fully transcribed by the PI. Two semi-structured interview recordings were fully translated and transcribed by a second, independent translator. Two interviews with children were excluded from analysis, as meaningful data was not collected on those occasions.

2.2.5 Data Analyses

Quantitative observational data was entered into and descriptive statistics generated from SPSS 15.0. Video material, photographs and field notes for each participant were reviewed to identify hazards and risk factors for injury. Video observation was also used to time DWC. The times at which subtasks commenced and finished were identified from the video recordings according to specified criteria (Appendix). For the purpose of this analysis, the times calculated from observation of video material for each participant on two separate occasions were averaged to estimate the time taken by each participant for each subtask. Descriptive statistics of the time for each subtask were then generated (Table 4).

The Ovako Working Posture Analysis System (OWAS) (Karhu et al., 1977; Kee and Karwowski, 2007) was used to analyse video capture of DWC. It was used to classify the type of postures adopted and estimate the frequency in which postures considered to impose physical strain occurred during DWC. The tool was applied to three selected cases, chosen to represent the different methods of DWC observed during the study. Analysis of the entire data set is ongoing.

Two techniques were used to gain insight into the level or intensity of work which people performed. Firstly, the weight of water carried was measured in kilograms and considered as a percentage of body weight and in Newtons of force (N) for head loading. Secondly, participants reported the sensation of effort or 'rating of perceived exertion' (RPE) required for DWC using the Modified Borg scale (Finch et al., 2002).

For qualitative data, thematic content analysis of transcripts was manually performed using 'framework' analysis (Ritchie and Spencer, 1999). Of eleven interviews with children, and a sample of x adult interviews, all transcript data was independently coded into units of meaning by two researchers, who then compared interpretation of the data and agreed the final coding strategy. Codes from the children's data with similar meanings were then categorised together to generate sub-themes which were considered in light of the original research questions to generate themes. Data from individual interviews were triangulated with that from group interviews. The qualitative data was also mapped to ICF categories as a strategy to promote clear identification and communication about the health domains potentially affected by DWC.

2.2.6 Results

2.2.6.1 Qualitative pilot study

Analysis of qualitative data gathered from children in the study generated key themes (Table 1). From these themes a model to depict the interrelated effects of DWC (figure 7) and the potential ways in which DWC might impact upon health were developed.

Table 1: Qualitative Themes

	Themes Derived From Qualitative Data
Theme 1.	Women and children collect water
Theme 2	Children's perceptions of health are broad
Theme 3	DWC has diverse effects
Theme 4	Attitudes to DWC are mixed
Theme 5	Coping strategies vary
Theme 6	Environment influences performance of DWC
Theme 7	Water supply system failures create difficulty
Theme 8	Changing DWC is important

An important property of well-designed health evaluation systems is that they should have 'content validity'; the content assessed by a measure should include elements that the target population perceive as relevant to the construct of interest (Atkinson and Lennox, 2006). Therefore, to assess the health impact of DWC on people in poor rural areas such as Limpopo, 'health' should be broadly conceptualised and incorporate impairment, but also capacity for functional activities and social participation. At the level of body functions people perceive that pain, joint mobility, energy and drive, general physical endurance, immunological and emotional functions can be affected.

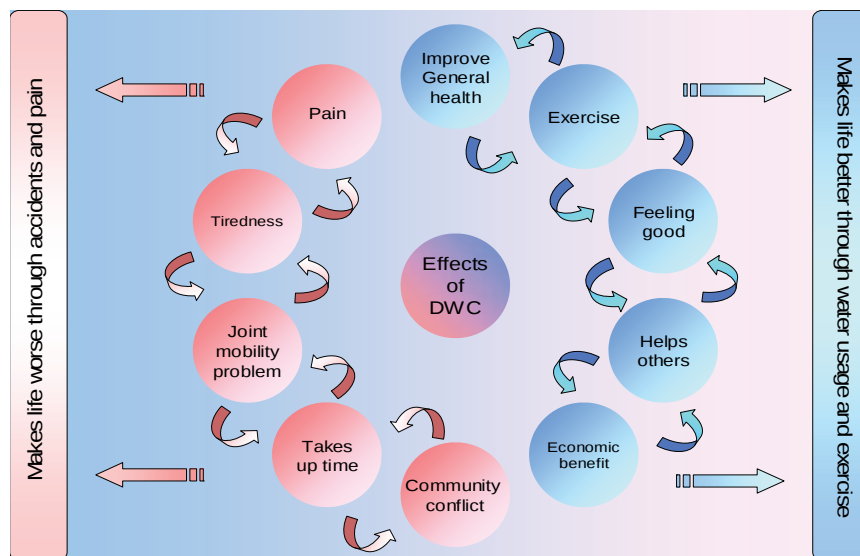


Figure 7: Effects of DWC reported by children.

In terms of activity and participation, their accounts indicate that schoolwork and housework, as well as recreation and leisure activities can be affected by DWC, particularly through time loss. Key ways in which DWC was perceived to improve health related quality of life were through facilitating water usage or generating income, so that the impact of DWC on meeting basic needs for cooking, drinking and washing should be considered as well as activities such as caring for plants and animals.

Preliminary analysis of the qualitative data gathered from adults supports the themes derived from full analysis of the children's interview and NGM data and is consistent with the models. The key findings from qualitative data are that:

- Children perceive DWC to affect their health in various specific ways, which can be mapped to ICF domains
- The health status of children in poor rural areas such as Limpopo should not only be evaluated in terms of body structure and function, but also in terms of functioning through activities and social participation

- There is likely to be an association between DWC and musculoskeletal disorders, which requires further research into the type and strength of association

2.2.6.2 Quantitative pilot study

Four methods of DWC were observed. These were 1) head loading of water-filled containers, 2) rolling a water-filled drum, 3) pushing a wheelbarrow weighted with filled water containers and 4) loading filled containers on and from a donkey cart (Figures 8-10).



Figure 8 DWC Methods: Head loading and wheelbarrow



Figure 9 DWC Method: Rolling the container



Figure 10 DWC Method: Donkey cart

The proportion of participants who were observed collecting water using different methods are shown in Figure 11. All methods exposed the water carriers to hazards, such as road traffic, as all who were observed to perform DWC completed at least part of their journey on a roadway. During observation in two of the study villages, the usual water service to communal taps was interrupted due to failure of the water supply system (in both cases due to breakdown of the pump). As a result of the pump failure in one village, many people were observed to collect water from a spring outflow pipe at the same time, leading to crowding and congestion around the source. Many adults and children collected water amongst vehicles, donkey carts and domestic animals trying to access water from the same source.

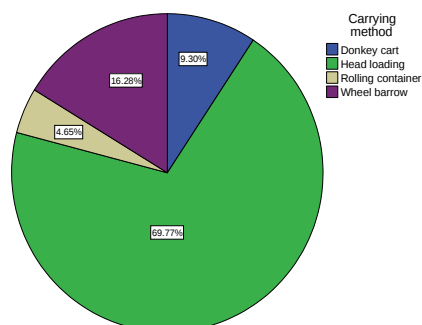


Figure 11: Distribution of DWC methods

All participants were judged to be at risk of slips or falls due to the terrain, quality of paths or absence of suitable foot wear, especially when carrying the water home. The environment presented many physical obstacles to DWC. These included barbed wire fences and gates, (Figure 12), raised and often serrated (worn out) edges of concrete platforms at taps (Figure 13), rocks and pipes (Figure 14) as well as other containers, equipment and people. Fifteen (75%) of the children were unsupervised during DWC and three (15%) collected from an open body of water (river in Figure 2).

The most commonly used containers for DWC were fully filled 20 to 25 litre plastic buckets or drums with inadequate or absent handles (Figure x). Container sides are smooth and were often wet, making them difficult to grasp securely.



Figure 12: Obstacles to carry over



Figure 13: Communal tap with protection



Figure 14: Communal tap strengthened



Figure 15: Typical containers for DWC

DWC requires awkward, repetitive or sustained end-range upper limb positions for most people, either due to arm elevation above shoulder height to hold and steady head loads (Figure 16), reaching down into and lifting water loads out of walled water sources such as a protected spring (Figure 17), lifting containers over the sides of a donkey cart or using inadequate equipment. For example children use wheelbarrows designed for adult physical proportions (Figure 18). DWC exposed most people to fatigue because of sustained adverse positions and load carriage, particularly head loading.



Figure 16: Sustained arm elevation during carrying



Figure 17: Reaching into a spring



Figure 18: Inappropriate wheelbarrow size

Communal tap and supporting platform design as well as household storage sites frequently required awkward postures for lifting (Figure 19), carrying (Figure 20) as well as lowering and placement (Figure 21) of containers. This

was particularly evident when containers were filled or stored at ground level, or placed inside dwellings with low doorways and at times dark and smoky interiors (Figure 21). Children who weren't collecting water, but accompanied or were carried by their mothers during DWC were also exposed to hazards. Babies carried on the back are in the direct line of impact should a head load fall backward.



Figure 19: Full lumbar flexion for lowering and placement



Figure 20: Stepping over a pipe



Figure 21: Flexion and side bending for lifting

Head-loading, pushing a wheelbarrow and rolling a filled container were the three methods used by people to perform the physical work of transporting containers of water from the WSP to their homes. OWAS analysis of three cases revealed that these techniques potentially involve a high frequency of postures which have significant strain effects (Table A2) and for which corrective solutions would be recommended in industrial settings (Table A) not even considering the potentially detrimental effects of head loading.

Table A2: Descriptive statistics all DWC data (Adults and children, all carrying methods)

Variable	N	Mean (sd) ¹	Median (IQR) ²	Mode	Range
Age (years)	43	24 (15.26)	22 (11-32)	mm ³	6-64
Height (cm)	43	150.14 (17.30)	157 (139-161)	mm	110-176
Weight (kg)	43	47.57 (21.65)	54 (28-61)	mm	16-106
Total weight containers carried (kg)	37	67.70 (118.99)	21.70 (20-39.8)	20	4-400
Individual container weight (kg)	37	20.73 (5.93)	21.00 (20-26)	20	4-29
Number of containers carried	39	3.15 (5.80)	1 (1-1)	1	1-20
Frequency per day	26	3.58 (2.42)	3 (2-4.25)	3	1-10
Total daily lifting load (TDLL) ⁴ kg	22	652.99 (1718.24)	126 (53.50-357.72)	126	30-8000
Days per week	26	6 (2.03)	7 (7-7)	7	1-7
RPE ⁵	39	7.1 (2.91)	7 (5-10)	10	2-10
Distance (m)	35	330 (177.61)	320 (160-440)	mm	40-650
Carrying time (minutes; seconds)	41	5m 46s	5m47s (3m7s-6m-41s)	6m14s	39s-15m17s
Total daily carrying time (TDCT) ¹	25	18m57s	15m1s (6m6s-26m42s)	mm	1m24s-62m20s

¹ sd: standard deviation; ² IQR: inter-quartile range; ³ mm: multiple modes exist;

⁴ TDLL: Total daily lifting load = mean weight lifted x number of occasions of lifting and lowering the load per day ((frequency per day x2)

x times number of containers) x mean weight of container));

⁵ RPE: rating of perceived exertion measured with Modified Borg's Scale: score out of 12;

⁶ TDCT: Total daily carry time = duration of carrying x usual number (reported frequency) of carrying episodes per day

One of the youngest participants observed rolling a container demonstrated postures considered to have obvious harmful effects and to require an immediate corrective solution during 71% of the time that they were observed water carrying.

Table A3: Descriptive statistics all DWC data (excluding carrying by donkey cart method)

Variable	N	Mean (sd) ¹	Median (IQR) ²	Mode	Range
Age (years)	39	25 (15.49)	25 (12-33)	mm	6-64
Height (cm)	39	151.5 (17.56)	158 (142-162)	mm	110-176
Weight (kg)	39	49.5 (21.74)	55 (30-61)	mm	16-106
Total weight containers carried (kg)	33	27.4 (21.25)	21 (19.9-26.2)	20	4-110
Individual container weight (kg)	33	20.8 (6.28)	21 (19.9-26.0)	20	4-29
Number of containers carried	35	1.23 (0.65)	1 (1-1)	1	1-4
Frequency per day	23	3.4 (2.11)	3 (2-4)	3	1-8
Total daily lifting load (TDLL) ⁴	19	166.62 (158.54)	126 (52-265)	126	30-650.40
Days per week	24	5.96 (2.09)	7 (7-7)	7	1-7
RPE ⁵	35	6.77 (2.89)	7 (4-10)	10	2-10
Distance (m)	35	330 (177.61)	320 (160-440)	mm	40-650
Carrying time (minutes)	37	5m43s (4m4s)	5m9s (2m16s-7m3s)	mm	40s-15m17s
Total daily carrying time (TDCT) ¹	22	18m (13m)	18m (5m50s-26m40s)	mm	1m 24s-45m39s

¹ sd: standard deviation; ² IQR: inter-quartile range; ³ mm: multiple modes exist;

⁴ TDLL: Total daily lifting load = mean weight lifted x number of occasions of lifting and lowering the load per day ((frequency per day x2)

x times number of containers per day) x mean weight of container;

⁵ RPE: rating of perceived exertion measured with Modified Borg's Scale;

⁶ TDCT: Total daily carry time = duration of carrying x usual number (reported frequency) of carrying episodes per day

The key findings from quantitative data were that:

- Typical techniques of DWC include handling heavy containers by head-loading, rolling or use of wheelbarrows or donkey carts, all of which impose loading and postures with high potential to produce physical strain and injury. Urgent action should be considered based on recommendations appropriate for adult workers performing similar tasks in industrial settings.
- Although compression forces generated purely by the weight of filled water containers seem unlikely to exceed tissue injury tolerance levels, women and children are potentially vulnerable to mechanisms for physical injury through sustained or repeated loading and unexpected movements or accident during DWC.
- A key recommendation is that efforts should be directed toward eliminating the need for DWC by providing piped water to households at least to the premises on which the household resides, or where DWC must continue, reducing risk factors for MSDs and physical injury. Good handling practices which exist should be supported and further education about potential risk factors for MSDs and hazards provided to community members. However, improved design and maintenance of equipment and infrastructure may also reduce exposure to hazards and risk factors for injury and be important avenues for intervention. Future research should aim to better understand the type and strength of association between DWC and health particularly MSD.

2.3 Physical work load assessment tool

The results of the qualitative and quantitative data were synthesised to identify the factors which should be measured to indicate the physical workload per household imposed by DWC, particularly in a way which is feasible for use in remote rural settings and has content validity with respect to the population being measured. The key factors are distance over which water is carried in meters, which is weighted by the presence or absence of an incline, and the volume of water collected per household.

2.3.1 Distance

Load weight has been shown to contribute most significantly to compression force on the spine (Murphy et al., 2007) and carrying loads on the head as observed in this study will obviously exert compression forces through the cervical spine (Wong et al., 2007). Use of light-weight plastic containers minimises the contribution of container weight to loading, however the volume of typical containers facilitated DWC with loads around 20 to 25 kg (Appendix). The time over which individuals are subject to sustained compressive loading will influence the physical effects of that loading on the body (see 3.4.2 below).

In this study, time taken to carry water containers from WSP to home (and therefore sustained loading) was found to have a strong positive linear correlation with distance (Figure 15). Distance between the water source point and house can be easily measured when the location of water source points such as communal taps are known. Distance can therefore be used as an indicator of physical work load or potential strain due to carrying time; the assumption is that reduced distance equates to reduced duration of sustained tissue loading per water carrying trip and represents a reduction of health detriment.

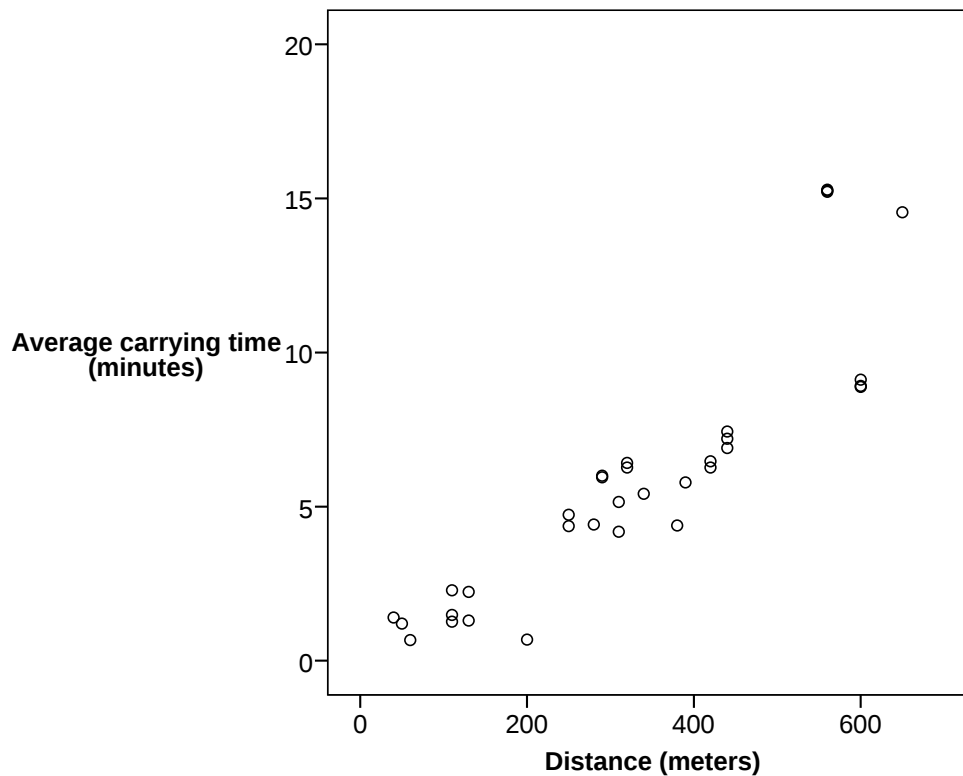


Figure 22: Scatter plot of carrying time to distance. Strong positive linear correlation ($r_s = 0.93$ $p > 0.01$)

2.3.2 Daily Lifting Load and frequency

Frequent bending and lifting, particularly from ground level to above shoulder height is an accepted risk factor for injury and musculoskeletal disorders in western industrial settings [29, 44, 45]. The median frequency of reported DWC occasions per individual per day was 3 (IQR 2-4.25), with a range from 1-10. The design of communal taps (Figures 13 and 14) together with head loading as the most commonly observed method of carrying water (Figure 11) suggests that water filled containers are frequently handled from ground level to above shoulder height. Each DWC occasion will involve at least two 'lifts' to raise the container for carrying and eccentrically lower it for placement at home.

A recent psychophysical study of adult women [46] evaluated the maximum acceptable weights (MAW) for lifting small and large boxes from floor to knuckle height and the effect which lifting frequency had on MAW. The weight of individual containers lifted and lowered through that level by most of the participants in this study, at 21kg (IQR 20-26kg), was close to the mean MAW (24.6kg) reported by adult female workers performing one lift every 8 hours [46, 47] (Table 7). However more frequent lifting (for example 3 or more times per day), particularly by children, may mean that DWC can impose load weights and lifting frequencies which exceed MAW for lifting without strain.

Table 3: DWC observed and recommended safe load weight and lift frequency guidance

Sample and report	DWC ¹	Children DWC (HL) ²	Women [44]	Men [44]	Women [47]	Women [47]	Women [46]
Weight ³	21kg	20kg	7kg (3kg) ⁴ 16kg (10kg) ⁵	10kg (5kg) ⁴ 25kg (15kg) ⁵	19kg	21 kg	24.6kg
DWC ⁶ or Lifting freq ⁷	3 per 12 hrs	3 per 12 hrs	1 per 2 min	1 per 2 min	1 per 30 min	1 per 8 hrs	1 per 8 hrs

¹Observations from this study of domestic water carrying;

²Children head loading;

³Observed median container weight lifted for DWC or guidance on maximal weight to reduce risk of strain for given lifting frequency;

⁴Handled above shoulder height or from floor with weight kept close to body (and with extended arms);

⁵Handled between elbow and knuckle height with weight kept close to body (and with extended arms); ⁶ Reported frequency of DWC per day (assuming performance occurs in day light hours); ⁷ Frequency of lifting procedure

The impact of frequent lifting will also be influenced by the amount of 'rest' or non-loading time between lifts, however safe parameters for repetition and rest time within loading cycles have not been established generally (Arokoski et al., 2000; Bachrach et al., 1995) and particularly for DWC. The time at which people collected water

varied, and was influenced by factors such as availability of water at the tap, household water requirements and fitting in DWC with other activities such as school attendance. DWC was often organised so that several DWC episodes occurred with each immediately subsequent to completion of the previous episode. Therefore, assuming the minimum water collection frequency of once per day or median frequency of 3 times per day, and comparing the weight of containers lifted directly to Ciriello [46] and Singh et al.'s [47] data (table 3), it is apparent that many women and children in this study were observed to lift loads close to the maximum acceptable weight when performed by adult women in Western industrial settings. However there may be considerable differences in physical work capacity of poor rural populations and those from a Western industrial setting, such that loading tolerance is lower in areas such as Limpopo. The age range of those collecting water (6- 64 in this study) will be greater than that in a working Western population and include children and elderly people. People in poor rural communities performing DWC may also have poorer general health or greater co-morbidity than working populations in developed countries (Hsie and Lotz, 2003).

The volume of water used in a household may not vary greatly with distance and time, other than at the extremes of travel time, such that when household or yard connection is provided or return trip collection time exceeds thirty minutes, consumption levels increase or decrease respectively (Figure 16). This could imply that contrary to the effects of sustained loading, lifting occasions may increase when water is closer and decrease when water is more than 15 minutes away, suggesting a possible detrimental effect from closer access and reduced detriment with distant water sources. However, those with house or yard water connection are likely to use small containers or hoses to distribute water in the home, so that frequent lifting of smaller volumes becomes safer, or the requirement for lifting containers reduces altogether. Consumption levels are likely to remain stable within the distances observed in this study as return trip time remained within 30 minutes (carry time x2; Tables 1 and 2). A more important driver of variation in the amount of lifting an individual performs may be the number of people in the household and whether water collection is a shared task. Therefore distance of water source points from the home and subsequent return trip travel time may influence physical loading due to the volume of water collected and the number of lifting episodes required to collect that water. However this may be a stable influence which changes little in villages with communal tap provision. It therefore would seem important to determine the number of people in a household to estimate absolute consumption levels and subsequent lifting loads, but also the proportion of people in a household who usually collect water.

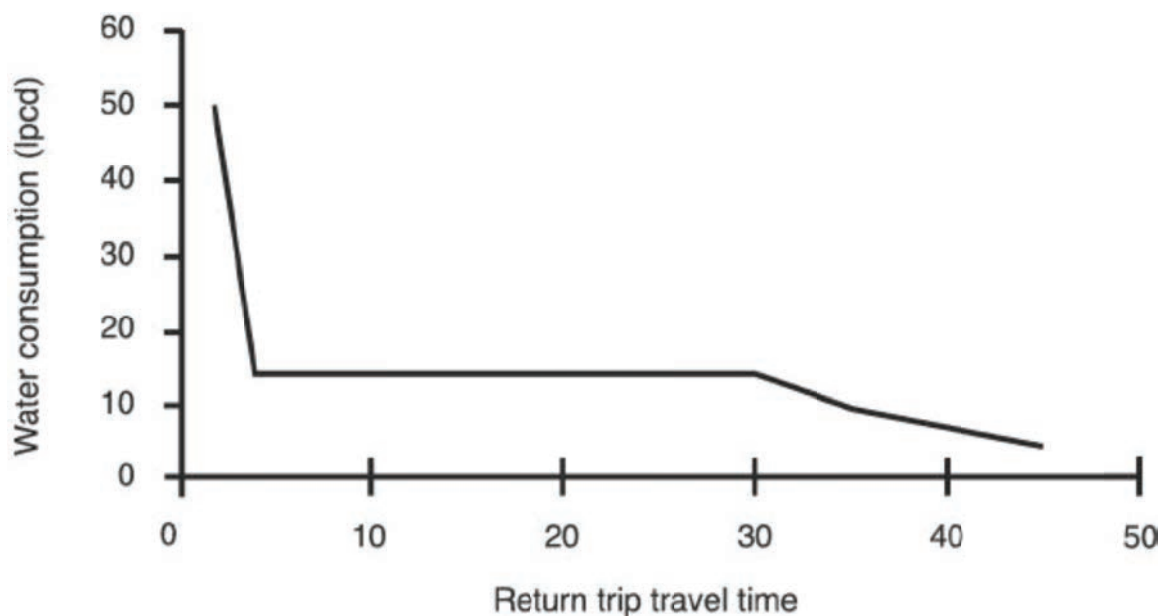


Figure 16: Graph of travel time (in minutes) versus consumption (taken from WELL, 1998)

The total volume of water handled and the number of times a water filled container is lifted or lowered each day per household were therefore considered to be factors influencing the physical work load of DWC and likely to be related to risk of MSD. The physical work due to DWC can be indicated by the total volume of water consumed and therefore collected per household and the number times a water filled container is lifted and lowered. The total volume of water consumed can be estimated by knowing the distance or travel time to the water source (figure 16) and the number of people in the household. As typical container volumes are 20-25 litres, a given water consumption volume is likely to be associated with a number of handling occasions (lifting and lowering), which could be calculated by dividing the total water consumption volume by 25 (= number of containers handled) and multiplying that number by

2 (= number of occasions it is lifted and lowered). What is then likely to influence health impact is whether water collection is performed by one individual or is a shared task. The assumption is that reduced volume of water carried and number of handling occasions per individual represent reduced health detriment.

3 IMPACT ASSESSMENT TOOL

The results of the qualitative and quantitative data were synthesised to identify the domains of health which should be measured to capture the health impact of DWC, particularly in a way which has content validity with respect to the population being measured. As both qualitative and quantitative data indicated that musculoskeletal disorders (MSD) are likely to be associated with DWC, a further review of literature was conducted to identify factors which have been identified as risk factors for MSD in other populations and settings. Factors relevant to DWC were incorporated into the tool as specific items. By drawing on the qualitative and quantitative information gathered in this study and published literature reporting risk factors for MSD, a tool has been proposed as a practical method of gathering information about the factors which are likely to influence the health impact of DWC (Appendix). The rationale for incorporating each item into the tool is presented below.

3.1 DWC Method

People were observed to use four distinctly different methods of DWC (Figure 11). Distinctly different methods of DWC will have different physical loading effects and may be associated with different symptom reporting in terms of location and number of areas of pain. A United Kingdom study of school children showed that slightly differing methods of carrying schoolbags were significantly associated with widespread pain (Odds Ratio 2.08) (Murphy et al., 2007). Carrying method is therefore likely to be an important variable to investigate in studies of the association between DWC and health, particularly MSD symptoms such as pain and number of pain sites.

A key factor related to the impact of DWC method may be whether the method allows opportunity for an individual to rest, as this will influence the duration of sustained physical loading and strain. The postures required by the carry method will also influence the extent of physical strain. These factors were therefore taken into account in scoring the methods of DWC which were observed in this study and incorporated into the assessment tool.

3.1.1 Total daily carrying time (TDCT)

In this study, the mean total time people spent physically carry loads of water each day was 18 minutes (standard deviation 13 minutes). However the reported TDCT ranged from 1.5 minutes to 46 minutes, indicating that some individuals may spend substantially longer periods of time carrying water loads. Effects of sustained or repeated loading on biological tissues are complex and varied (Wong et al., 2007). Loading within an individual's capacity for adaptive responses may lead to tissue strengthening, however frequent loading beyond capacity for adaptation or repair may lead to injury through fatigue failure, accumulation of fatigue damage (Adams et al., 2002) or early degenerative changes in bone and soft tissues (Joosab et al., 1994).

Connective tissue cells respond metabolically to compressive loading (Wong et al., 2007; Yuang et al., 1997; Nugent, 2006; Thibault, 2002) and have been shown to respond differently to static and dynamic loading and at different maturational stages (Li et al., 2001). Animal studies indicate that articular cartilage and intervertebral discs may have reduced matrix synthesis (Arokoski et al., 2000), increased matrix catabolism (Hsie and Lotz, 2003), cell death (Loening et al., 2000) or degeneration (Thibault et al., 2002) in response to static compressive loading and that cartilage has limited ability to heal following injury (Adams et al., 2002).

Sustained compressive loading will also cause connective tissues such as intervertebral discs or ligaments to 'creep' (Adams et al., 1996). Creep is the gradual displacement which occurs when a constant force is applied to biological tissues and is thought to occur because of gradual rearrangement of collagen, proteoglycans and water within the structure being stressed (Bogduk, 2005). Restoration of normal tissue structure after creep requires time, so that structures may be vulnerable to injury if load is re-applied with insufficient rest between loading cycles (Bogduk, 2005). Fatigue failure can occur after only a few loading cycles if the load is greater than 60% of the strength of the structure but may require millions of loading cycles if the load is below 30% of the structure strength (Adams et al., 2002). The compressive loading effect of cervical and axio-scapular muscles have not been quantified, so it is not possible to fully evaluate whether observed loads together with muscle action were likely to generate forces greater than 60% of the strength of cervical tissues.

Particularly for head loading, sustained static compression and creep deformation are known biological mechanisms through which fatigue failure may occur even when loading forces remain within tissue injury tolerance limits. However, recommendations to reduce injury risk with manual handling in respect of time factors are usually described

qualitatively and lack operational definitions (Bogduk, 2005; Wells et al., 2007) so that safe parameters for duration, repetition and rest time within work cycles of loading, are difficult to establish. In general, the literature indicates that duration of static compressive loading should be minimised and rest periods between loading episodes maximised to reduce risk of negative impacts. Total amount of time spent carrying water each day was therefore considered a potentially important factor which will influence the health impact of DWC. The total daily duration of loading time or 'total daily carrying time (TDCT)' is defined as the usual time taken to carrying water from the source point to home times the usual number of carrying episodes per day.

3.1.2 Frequency

For many study participants collecting water was reported to be a daily activity which they performed, however some reported collecting water less frequently and sharing the task with other family members. In concordance with physical training principles (Mueller and Maluf, 2002), individuals who are able to have rest days from DWC may have better opportunity for tissue adaptation or repair and be less vulnerable to strain from DWC. The usual number of days per week in which an individual collects and carries water is therefore included as a scale item.

3.1.3 Total daily lifting load (TDLL)

3.1.3.1 Load weight and injury forces

Load weight has been shown to contribute most significantly to compression force on the spine (Davis and Marras, 2003) and carrying loads on the head as observed in this study will obviously exert compression forces through the cervical spine (Nordin, 1989). Use of light-weight plastic containers clearly minimises the contribution of container weight to loading, however the volume of typical containers facilitated DWC with loads around 20 to 25 kg. Forces generated by external loading of the head and neck, have been linked to serious injury such as fracture or dislocation of the cervical spine (Levy, 1968; Frymoyer, 1997). Compressive loading at injury threshold mainly produces vertebral fracture (Pintar et al., 1998) but failure data for specific soft tissue structures of the cervical spine, such as the intervertebral discs have also been calculated (Yoganandan et al., 2001). Cervical spine compressive tolerances are reported to vary from 7kN in the young adult (3rd decade) to 2kN (Pintar et al., 1998) or 1.23kN (Przybyla et al., 2007) in the very old (9th decade) and the force to failure of adult intervertebral discs ranges from 602 to 910N (Yoganandan et al., 2001). However, adult injury tolerance data must be cautiously applied to interpret the potential effects of loading on children such as those observed in this study, as spinal morphology and biomechanics will alter with age and growth related processes (Nuckley and Ching, 2006).

Scaling factors have been developed to allow calculation of paediatric neck injury tolerance parameters, considering neck geometry and developmental growth changes (Kumaresan et al., 2001; Nuckley et al., 2002). Under compression loading, the 6 year old paediatric cervical spine tolerance is 35.5% that of the adult (Kumaresan et al., 2001). By applying paediatric scaling to adult cadaveric studies and considering the age range of children in this study, the compressive injury tolerance of children's cervical spines could be estimated to vary between 2.5 kN (6 year old) and close to 7kN (adult), or for cervical discs between 214N (6 year old) and 910N (adult).

The median force generated by the weight of water carried by head-loading in this study was 196.2N and ranged from 39.2 to 215.8N. The higher container weights and therefore loading forces tended to be carried by older children whose tolerance limits may be closer to adult tolerances. Therefore compression forces generated purely by the weight of water carried through head loading in this study (Table 6) may be unlikely to exceed tissue tolerance if applied briefly during a single loading occasion. However, injury tolerance limits based on cadaver studies can only provide estimates of living tissue strength and therefore very rudimentary estimation of maximal loading tolerance (Marras et al., 2003). Tissue strength may be reduced by factors such as malnutrition or chronic illness (Grinspoon et al., 2003), both of which are highly prevalent among children in poor rural areas such as Limpopo Province (Bradshaw and Nannan, 2006).

Children may be subject to sufficient stress during head loading to cause symptoms of musculoskeletal disorder such as pain, without obvious or acute tissue injury. A recent U.K. study found that self-report of upper back pain is associated with school bag weights of 3.5-4kg and that as schoolbag weight increased relative to the carrier's weight (Odds Ratio 1.12) it was more likely for individuals to be classified as having widespread pain (Murphy et al., 2007). The mean value of school bag weight to carrier's weight was 6.93% (sd 3.76%), much lower than the proportion of load to carrier's weight for head loaders in the current study, which had a median value of 50.7%, ranging from 22-78%. The high container weights in proportion to body weight carried by children in this study therefore seem to be a likely risk factor for pain associated with DWC.

3.1.3.2 Peak compressive forces

Peak compressive forces generated during DWC may be much higher than the forces expected due to container weight alone, and are a mechanism by which tissue injury may occur despite forces generated by container weights remaining within injury tolerance limits determined from cadaveric studies. Peak compressive forces generated during manual handling are influenced by muscle action (Adams et al., 2002) as muscles assist the osteoligamentous spine to support the weight of the head and external loads applied to it (Panjabi et al., 1998) and prevent spinal buckling. Because of their anatomical arrangement, the cervical and axio-scapular muscle action required to prevent buckling must exert additional compressive force on cervical structures (Jull et al., 2008).

Therefore even with loads carried within injury tolerance limits (as shown in the previous section) people may be vulnerable to injury from high peak compressive loads generated by the additional effects of muscle contraction. Peak compressive forces due to muscle action are influenced by load mass and position, asymmetry, technique and speed of lifting and sudden events such as stumbling or misjudging container weight (Adams et al., 2002). Lifting objects in a rapid or awkward manner, emergencies during manual handling or accidents can generate compressive forces higher than injury threshold, but may also create torsional, shear or bending moments which injure the spine (Adams et al., 2002). Hazards for slips, trips and falls include wet and uneven surfaces, obstacles, poor equipment, unwieldy loads and exposure to traffic, all of which were typical environmental and task related factors of DWC. Strain due to inadequate active stabilisation to prevent buckling of the spine, particularly with unexpected events, may also place children at high risk of acute musculoskeletal injury.

The median frequency of reported DWC occasions per individual per day was 3 (IQR 2-4.25), with a range from 1-10. Each DWC occasion will involve at least two 'lifts' to raise the container for carrying and eccentrically lower it for placement at home. A recent psychophysical study (Ciriello, 2007) evaluated the maximum acceptable weights (MAW) for lifting small and large boxes from floor to knuckle height and the effect which lifting frequency had on MAW. The weight of individual containers lifted and lowered through that level by most of the participants in this study, at 21kg (IQR 20-26kg), was close to the mean MAW (24.6kg) reported by adult female workers performing one lift every 8 hours (Ciriello, 2007, Singh et al., 2009). Therefore, whilst a lift of 20kg performed once every 8 hours (or once per day) may be within the MAW for individuals in this study, more frequent lifting (for example 3 times per day) may mean that typical DWC patterns impose load weights and lifting frequencies which exceed MAW for lifting without strain.

Ciriello (2007) also determined the 'frequency factor' or ratio of MAW at various lifting frequencies over MAW at a frequency of 1 lift per minute (Ciriello, 2007). When lifts were performed once every 8 hours compared to once per minute the ratios for the MAW of small and large boxes were 1.67 and 1.80 respectively. The U.K. Health and Safety Executive (HSE) offer guidance to reduce risk of injury during manual handling operations and indicate safe load weights for a lifting operation performed every 2 minutes, to be reduced by 30% if performed every minute (HSE, 2007). Applying a similar but more generous 'frequency factor' ratio than calculated by Ciriello (2007), to double the HSE guidance on safe weights for lifting close to the body from floor height once per minute (7kg – (30% x 7)), suggests a MAW of 9.8kg for adult women to lift once every 8 hours. This value is much lower than the median container weight of 21kg, which was observed to be lifted by women and children in the study area at variable lift frequencies per day.

The time at which people collected water varied, and was influenced by factors such as availability of water at the tap, household water requirements and fitting in DWC with other activities such as school attendance. DWC was often organised so that several DWC episodes occurred with each immediately subsequent to completion of the previous episode. Therefore, even assuming the minimum DWC lift frequency of once per day, and by either comparing the observed weight of containers carried directly to Ciriello (2007) and Singh et al's (2009) data (table 5), or by applying Ciriello's 'frequency factor' ratio to HSE guidance (HSE, 2007) it is apparent that the women and children were observed to lift loads which would be considered risky for MSD if performed by adult women in Western industrial settings.

The total volume or weight of water carried each day was therefore considered a factor likely to be related to MSD. Depending on the method of carrying water, people were observed to handle a variable number of containers. The total daily load handled by an individual will depend on the number of containers used and the number of occasions in which the containers are lifted and lowered each day. Total daily lifting load (TDLL) was therefore incorporated into the tool and defined as the mean weight lifted (mean weight of a typical container when full x number of containers handled or lifted per usual DWC trip) times the number of occasions of lifting and lowering the load per day (frequency of DWC trips per day x2).

3.1.3.3 Rating of Perceived Exertion (RPE)

Absolute 'safe limits' for manually handling loads have not been established, as the risk posed to an individual will depend not only on the physical factors related to the task, but on multiple factors including an individual's strength, fitness, age and gender (HSE, 2007). Whilst age and gender can easily be determined in the field, activity specific strength and fitness are more difficult to measure. A subjective measure of the level of exertion an individual experiences during DWC is therefore a potentially valid method of evaluating the extent to which the work of DWC matches the physical capacity of that individual to perform the task.

The RPE reported by people in this study had median value of 7 (IQR 5-10) and ranged from 2-10. Therefore the RPE scores reported in this study suggest that for many people DWC requires high levels of physical and physiological exertion. This together with observational data considered above indicated that DWC is a strenuous task for many children and adults, which potentially creates risk of MSD and physical injury. Whilst total load weight and carrying time are likely to be important task related factors for determining the health impact of DWC, the extent to which a given load tests an individual's capacity for the task is also likely to be an important indicator of injury risk and is therefore included as a test item.

3.1.3.4 Age and Gender

Previous studies (Cleaver, 1996; Annon, 1996) indicate that it is usually women and children who collect water for domestic purposes and this was confirmed to be the case in Limpopo Province through both observational and qualitative research. This is important as the effects of physical loading have been shown to vary with age (Nuckley et al., 2007; Mosekilde and Mosekilde, 1990) and gender (Marras et al., 2003).

Women and children are at greater risk of injury than men when lifting heavy or asymmetric loads (Marras et al., 2003). Carrying water loads on the head will generate compressive forces on the cervical spine (Frymoyer, 1997) and injury thresholds during cervical spine compression have been quantified as a function of age, gender and external loading rate (Pintar et al., 1995). Through loading to failure tests conducted on human cadavers, mean failure forces for women were found to be on average 75% that of men (Pintar et al., 1998). Gender differences in the dimensions of cervical vertebrae, such that men have more stable inter-vertebral coupling, are proposed to alter physical control of dynamic loading and explain the increased susceptibility of women to cervical spine injury (Stemper et al., 2008).

Compressive tolerance and neuroprotective ability of the cervical spine is directly related to maturation and age (Kumaresan et al., 2001; Nuckley et al., 2007; Kumaresan et al., 2000), such that children have lower capacity to tolerate loading stresses. In the elderly age related changes to the anatomical structures and tissues of the spine are also likely to reduce physical capacity and make individuals more vulnerable to detrimental effects of carrying or lifting loads (Twomey et al., 1983; Taylor and Finch, 1993; Taylor and Levander, 2000).

Such studies suggest that because of their reduced size and strength, women and children are less physically suited than men to lifting and carrying heavy loads such as containers filled with 20-25 litres of water, and particularly vulnerable to physical strain when carrying containers by head loading. Therefore in the DWC physical burden scale both age and gender are included as items. The middle age ranges are given lower scores, with the very young or very old scored more highly.

4 CONCLUSIONS

The results of this pilot study and literature review indicate that musculoskeletal disorders are a likely consequence of DWC, from both the perspective of people engaged in DWC and from fieldwork observation using an ergonomic systems approach for evaluation of DWC. The DWC Physical Burden Scale is suggested as a method of collecting information about aspects of DWC which are likely to determine the health impact of the task.

5 RECOMMENDATIONS

The DWC Physical Burden Scale should be piloted for its psychometric properties, particularly reliability, validity and responsiveness. Further research should be conducted to determine the type and strength of association between The DWC Physical Burden Scale, its component parts and musculoskeletal disorders, as well as other aspects of health such as disability, functioning and social participation.

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Appendix: DWC Physical Burden Scale

Scale Item		Score	Weighted Score
Method¹	No DWC	0	
	Vehicle/cart	1	
	Wheel barrow	2	
	Rolling	3	
	Head loading	4	Score x2 = /8
TDCT²	0	0	
	x≤15	1	
	15< x ≤ 30	2	
	30< x ≤ 45	3	
	45< x ≤ 60	4	
	x >60	5	Score x1 = /5
Frequency³	0	0	
	1	1	
	2	2	
	3	3	
	4	4	
	≥5	5	Score x1 = /5
TDLL⁴	0	0	
	x≤100	1	
	100< x ≤ 200	2	
	200< x ≤ 400	3	
	400< x ≤ 600	4	
	x >600	5	Score x2 = /10
RPE⁵	Nothing at all	0	
	Very, very weak	0.5	
	Very weak	1	
	Weak	2	
	Moderate	3	
	Somewhat strong	4	
	Strong	5	
	6	6	
	Very strong	7	
	8	8	
	9	9	
	Very, very strong	10	
	11	11	
	Maximal	12	Score x1 = /12
Age	x≤15	3	
	15< x ≤ 30	0	
	30< x ≤ 45	1	
	45< x ≤ 60	2	
	x >60	4	Score x2 = /8
Gender	Male	0	
	Female	2	Score x1 = /2
	Summary Score		/50
	Summary Score %		/100

¹ Method

- Prompt question: 'How do you usually collect and carry water for use by your household and in your home?'

² Total daily carry time = duration of carrying x usual number of carrying episodes per day

Prompt questions:

- 'How long do you estimate it takes you to physically carry your water container(s) from the water source you usually use to your home?'
- 'How many times do you usually go to collect water on the days when you collect water?'

² Frequency of collecting water for domestic purposes per week

Prompt question:

- 'How many days of the week do you usually go to collect water?'

³ Total daily lifting load = mean weight lifted (mean weight of a typical container when full x number of containers handled or lifted per usual DWC trip) times number of occasions of lifting and lowering the load per day (frequency of DWC trips per day x2)

Prompt questions:

- 'What is the volume of the containers you usually use to collect water?' (convert litres to kg) or 'Can you show me the containers you would usually use for collecting water?'
- 'How many containers do you usually fill to carry each time you collect water?'
- 'How many times per day do you usually go and collect water?'

⁴ Rating of perceived exertion (RPE) or difficulty of carrying water using the Modified Borg Scale (categorical scale (scored out of 12) with ratio properties)

Standardised RPE Explanation:

- 'Think about how hard you feel the work of carrying water usually is for you. This feeling should reflect your total amount of exertion and fatigue, combining all sensations of physical stress, effort and fatigue. Don't concern yourself with any one factor such as leg pain, shortness of breath or exercise intensity, but try to think about your total inner feeling of exertion. Try not to underestimate or overestimate your feeling of exertion; be as accurate as you can.'

Appendix C: Social receptivity of small-community water supply systems in South Africa

Eli Lai[†], Rachelle Koekemoer* and Paul Jagals^{#†}

[†]Water and Health Research Centre, University of Johannesburg

*Department of Sociology, University of Johannesburg

^{#†}Department of Environmental Health, Tshwane University of Technology, Pretoria, South Africa

1 INTRODUCTION

This tool is about measuring the effect of an intervention at a social level.

The tool is important because understanding how receptive people and communities are to improved access to water before an intervention and their continued receptivity following the intervention will support management of small water systems by service providers and communities. Such knowledge can especially support the design and deployment of future tap water interventions.

This is therefore a tool to capture the vital role that the community plays in the success of any water intervention and is based on the concept of “receptivity” as developed by Jeffrey and Seaton (2003/2004) to better comprehend how humans understand, interact with and behave in anticipation and response to a social scale intervention such as a water supply intervention in this case.

In the context of this project, a measure of receptivity was assumed to be a measure of a community’s *willingness* to accept (being receptive to) a water supply intervention. This can be a complicated set of measurements depending on the criteria that are chosen. For this project the criteria were aimed at people’s willingness to “receive” a new event in terms of *expectation* (before the intervention) of the benefits that the system may bring, and their willingness to continue being “receptive” of the system based on their *experiences* of the benefits that the system had brought *after* using it for some time.

To apply this in the toolset development will therefore be to measure for shifts in people’s receptivity *before* and *after* the intervention, which would reveal more about people’s experiences with the system in relation to the initial expectation, and from which conclusions could be drawn on the motivational and impeding factors of optimally using such a system. Such conclusions would not be readily made on information captured by conducting a direct assessment of for instance tap water usage.

The receptivity model used in this tool development consisted of four phases of receptivity namely Awareness, Association, Acquisition, and Application. The first two phases (awareness and association) are knowledge-related, whereas the last two (acquisition and application) are related to human behaviour. The first two phases are readily measurable in terms of the specific approaches for these in the model of Jeffrey and Seaton (2003/2004). However, to improve on the overall model, the last two phases were adapted for this study to include Ajzen’s (1991) Theory of Planned Behaviour (TpB) as a tool to better describe and understand human behavioural disposition.

1.1 Receptivity

Receptivity is defined as “*the extent to which there exists not only a willingness (or disposition) but also an ability (or capability) in different constituencies (individuals, community, organisation, agencies, etc.) to absorb, accept and utilise innovation options*” (Jeffrey and Seaton 2003/2004). Definitions of the four phases are given in **Table 1**. The adapted version of the four receptivity phases used in this study is described in the Research Methodology (Table 4).

Table 1: The four receptivity phases of the model (Jeffrey and Seaton 2003/2004)

Receptivity phase	Definition
Awareness	Capability to search and scan for new knowledge
Association	Recognition of the potential benefit of this knowledge by associating it with needs and capabilities
Acquisition	The ability to internalise new knowledge and technologies through adapted behaviour
Application	The ability to actually apply the knowledge to achieve a benefit as judged by the recipient.

Situations before and after the provision of tap water were first compared using this basic receptivity model. The reason for this was to determine a reference receptivity level as a benchmark to evaluate the changes in people’s willingness to continue optimal use of their water system after they had received tap water. A higher receptivity level

in the “after” scenario would suggest that the people had positive willingness towards continuing the optimal use of the system.

1.2 Theory of Planned Behaviour (TpB)

The TpB, developed by Ajzen (1991), provides the conceptual framework to understand perceptions that guide human behaviour and has been applied widely (Armitage and Conner 2001). The theory’s model is illustrated in

Figure 1 and the corresponding definitions for the specific terms are given in **Table 2**. The theory is based on strong evidence that particular behaviour can be predicted by corresponding intentions guided by attitude, subjective norm and perceived control (Sutton 1998).

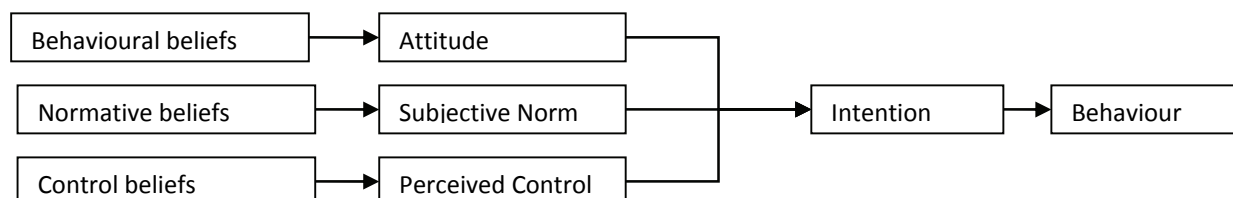


Figure 1: Theory of planned Behaviour (TpB) (Ajzen 2005)

Table 2: The specific terms used in the Theory of planned Behaviour (Ajzen, 2005) – examples are our own

Factors/Beliefs	Definitions
Behavioural beliefs	A belief that will influence behaviour towards a given outcome – e.g. supplied water is healthier than river water so I will use it if I get it.
Attitude	Attitude is formed by behavioural beliefs. An individual’s positive or negative belief about something forms a given behaviour, e.g. because of the perception that the supply water is healthier I am looking forward to receiving supply water (positive attitude)
Normative beliefs	The attitude of an important individual or a group will form a given general behaviour – we are all looking forward to receiving the new supply.
Subjective norm	It is formed by normative beliefs. Specific individuals or groups will approve or disapprove a given behaviour, e.g. not accept a person’s behaviour that leads to damage of the system. These beliefs and norms can also be termed “social pressure”
Control beliefs	The perceived factors that may facilitate or impede a given behaviour – Should the system fail us then we will not look after it.
Perceived control	It is formed by control beliefs. Peoples' perception of their ability to perform a given behaviour, e.g. we should ensure that the system continues to work, so it does not fail us and invoke negative behaviour towards it.
Intention	Intention is formed by attitude, subjective norms and perceived control and is an indication of a person's readiness to perform a given behaviour. For example, a person’s intention to use supply water depends on his/her perceived benefits of using it (attitude), social pressure from family/friends (subjective norm) not to damage the system and to ensure the systems works top avoid the difficulties of using the system because of failure (perceived control).
Behaviour	The manifest, observable response in a given situation with respect to a given target, e.g. we all work towards a maintained system in order to have the benefits and avoid negative responses to the system should it fail.

The TpB model was applied to the last two receptivity phases (acquisition and application) to determine from the optimal use-variables the ones that would motivate and/or prevent people from using the system.

2 METHODOLOGY

2.1 Study framework

Data collection was done in four steps as shown in Table 3

Table 3: Data collection framework

Step	Details
1) Elicitation study	- Initial survey to capture commonly-held beliefs about perception about tap water supply systems and the benefits that could be expected from these. This step was required to obtained data points for formulating the questionnaire; 21 elicitation interviews were conducted in Folovhodwe.
2) Pilot study	- Testing the questionnaire for amendments; 18 interviews were conducted in Folovhodwe and 21 in Musunda.
3) Main survey	- Main survey for the study based on the model of receptivity with the four distinct phases; 94 interviews were conducted in Folovhodwe and 31 in Musunda.
4) Focus groups	- To provide feedback and confirm our findings with the community; 4 focus groups were held in Folovhodwe and 1 in Musunda & same questions to all groups.

- Average 8-10 people attended the focus groups with mainly adult female.

Figure 2 shows that for the first two phases in the receptivity model, a true and false response format was used to determine people's awareness of, and association with, the benefits and impacts that the intervention would bring. TpB was applied for the last two phases of the adapted receptivity model to capture people's perceptions of, and intentions toward, using the intervention (acquisition) and taking responsibility to use and maintain the system properly (application).

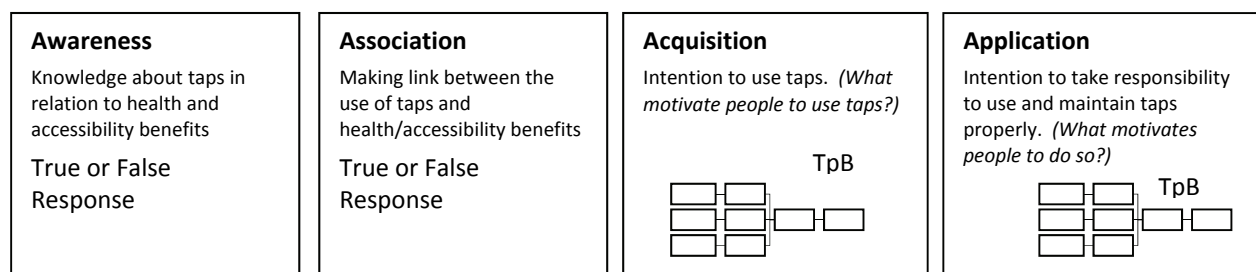


Figure 2: Questionnaire structure for the main survey (see to

Figure 1 for TpB model description)

The indicators for the four phases and the associated measurement and scoring methods are presented in Tables 4, 5 and 6. The model was practically applied in two rural villages (A and B) in the north eastern part of the Limpopo province of South Africa.

Table 4: Interpretation of the two knowledge phases of the basic receptivity model and its measurement/scoring methods

Phase	What to test for	Indicator	Scoring methods
Awareness	Knowledge about supply water with respect to benefits	- Improved access; - Improved availability; - Improved health-related water quality.	- A true-or-false response format was applied; - An <i>awareness</i> score was given if a question was answered correctly. The summated scores reflect the awareness level for each participant; - The maximum score was 6; - An overall awareness score was given to each group by averaging the summated total scores and expressing in percentage <i>awareness</i>; - A response below 60% is assumed a low awareness.
Association	Association between the use of supply water from a system and health/accessibility benefits.	- The use of better quality water from taps and health improvement; - Changes to distance for collecting water and: - Time saving; - Less physical burden from carrying water containers.	- A true and false response format was applied; - An <i>association</i> score was given if a question was answered true (meaning an association was made). The summated scores reflect the association level for each participant; - The maximum score was 4; - An overall association score was given to each group by averaging the summated total scores and expressing in percentage <i>association</i>; - A response below 60% is assumed a low association..

Village A (864 households) has been using potable water from communal taps since February 2004. Before February 2004 the inhabitants used untreated water of poor health-related microbial quality from a nearby river (Jagals *et al.*, 2006). The ideal situation would have been to compare the current experience of the tap water system in village A to that of the expectation that would have been existing amongst them villagers just before February 2004. However, this was considered not feasible since the long time lapse would render respondents' recall suspect. The alternative was to use a proxy.

Village B was selected as a proxy for the "before February 2004" scenario for Village A. Village B (120 households) was, at the time of this study, about to receive a tap water supply, but was still using poor quality untreated river and spring water as was A back in January 2004. The two villages were similar in cultural setting and both had relied on river and spring water as their primary water sources. Both villages had similar levels of socio-economic status with an income level ranged from R1K-R2K per month. Family sizes were also similar with A having a family size of 5.2 and B, 5.3. The setting in B was a plausible reflection of the situation in A before tap water intervention was introduced there.

Table 5: Measuring Acquisition using Theory of planned Behaviour**Measurement for ACQUISITION – Attitude, subjective norms and perceived control**

	Belief strengths (From elicitation study)	Outcome evaluation	Calculation
<i>Behavioural beliefs to measure attitude</i>	- Six behavioural beliefs that dealt with the motivation for using water were identified in the elicitation study on health impact and accessibility. These entailed time saving, reduced physical burden and gain in productive activities; - Questions were asked in relation to the likelihood of the beliefs (Table 4) to test their <u>strength</u> (i.e. “If I use tap water, I will save time/have less physical burden/better health or”) on a uni-polar 7-point <i>unlikely – likely</i> scale. A uni-polar scale was used to capture the strength of the beliefs.	Participants were asked to rate the desirability of <u>beliefs outcome</u> (i.e. It is to save time/have less physical burden/better health or) on a bi-polar -3 to +3 <i>extremely undesirable – extremely desirable</i> scale. A bi-polar scale was used here to capture both positive and negative impressions of the outcomes.	The scores for the corresponding set of <u>belief strength</u> and <u>beliefs outcome</u> were multiplied and summated across the six behavioural beliefs as an estimate for <i>Attitude</i>. The total score was compared to the possible score range given by 7 (max score on 1-7 uni-scale) x ± 3 (max score in bi-polar scale -3 to +3) x 6 (i.e. 6 behavioural beliefs) = ± 126.
<i>Normative beliefs to measure subjective norms</i>	- Three normative beliefs were identified in the elicitation study (i.e. social pressure from family, neighbour and community); - For belief <u>strength</u>, of these normative beliefs, statements such as “My family think that I use tap water” were asked in a uni-polar scale 7-point <i>should – should not</i> scale.	For <u>motivation to comply</u>, the participants would rate statements such as “What my family think about the use of tap water is”, on a -3 to +3 <i>not important at all – very important</i> scale.	The summated product of <u>belief strength</u> and <u>motivation to comply</u> across the three normative beliefs gave the overall score for <i>Subjective norm</i>. The total score was compared to the possible score range ± 63 (7 x ± 3 x 3).
<i>Control beliefs to measure perceived control</i>	- Four beliefs that would pose difficulty for the participants to use tap water were identified in the elicitation study (i.e. queue is too long, long distance, low water pressure when a number of taps were turned on, and stolen containers). - For testing the <u>strength</u> of these specific control beliefs, statements such as “The queue for tap water is generally too long” were rated on a 7-points strongly disagree – strongly agree scale.	The corresponding measurement for the control power (i.e. how <u>easy</u> the participants find it to <u>overcome/employ</u> the specific <u>hindering/aiding</u> factor) was asked in the format of “if the queue for tap water is too long, I am to use tap water” on a -3 to +3 <i>extremely unlikely – extremely likely</i> scale.	The summated product of <u>belief strength</u> and ease to overcome (control power) hindrances across the four control beliefs yielded estimates for <i>Perceived control</i>. The total score was compared to the possible score range ± 84 (7 x ± 3 x 4).

Table 6: Measuring *Application* using Theory of planned Behaviour**Measurement for APPLICATION – Attitude, subjective norms and perceived control**

	Beliefs strength Belief strengths (From elicitation study)	Outcome evaluation	Calculation
<i>Behavioural beliefs to measure attitude</i>	- Two <u>behavioural beliefs</u>, i.e. help reduce water shortage problem and avoid paying for water wastage; - A set of two questions were asked for each behavioural belief. A statement for assessing belief strength is rated on a uni-polar 7-point extremely <i>unlikely</i> – <i>extremely likely</i> scale, “If I look after the tap, I will help reduce water shortage problem/avoid paying for water wastage”. A uni-polar scale was used to capture the strength of the beliefs.	The corresponding statement for assessing the <u>desirability</u> of the outcome was rated on a bi-polar -3 to +3 <i>extremely undesirable</i> – <i>extremely desirable</i> scale (i.e. It isto help reduce water shortage problem/avoid paying for water wastage). A bi-polar scale was used here to capture both positive and negative impressions of the outcomes.	The scores for the corresponding set of <u>belief strength</u> and <u>evaluation outcome</u> were multiplied and summated across the two behavioural beliefs as an estimate for attitude. The total score was compared to the possible score range given by ± 42 ($7 \times \pm 3 \times 2$).
<i>Normative beliefs to measure subjective norms</i>	- The same <u>normative beliefs</u> identified for <i>acquisition</i> were adopted here for <i>application</i>; - Statements for assessing belief strength would become “My family/neighbours/community think that I take responsibility to look after the tap” on a 7-point <i>should not</i> – <i>should</i> scale.	For <u>motivation</u> to comply, the participants would rate statements such as “What my family/neighbours/community think about maintenance of the tap is”, on a -3 to +3 <i>not important at all</i> – <i>very important</i> scale.	The summated product of belief <u>strength</u> and <u>motivation</u> to comply across the three normative beliefs gave the overall score for subjective norm. The total score was compared to the possible score range ± 63 ($7 \times \pm 3 \times 3$).
<i>Control beliefs to measure perceived controls</i>	- Two <u>control beliefs</u> that would affect intention to maintain and use the system in a responsible manner (i.e. tap not inside house and penalty by community leader); - The participants were asked to rate to what extent these controlling factors would hinder them, such as “It is difficult to look after the tap because it is not inside my house” on a 7-point <i>strongly disagree</i> – <i>strongly agree</i> scale.	For <u>easiness</u> to overcome the specific control beliefs, questions were asked to assess the likelihood for these events to occur. Statements such as, “If the tap is not inside my house, I am to look after it” was asked on a -3 to +3 <i>extremely unlikely</i> – <i>extremely likely</i> scale.	The summated product of belief <u>strength</u> and control power across the four control beliefs yielded estimate for perceived control. The total score was compared to the possible score range ± 42 ($7 \times \pm 3 \times 2$).

For both the measurement activities shown in Tables 5 and 6, we used Spearman’s rho (r_s) correlation to assess the strength of association between intention and the specific beliefs under attitude/subjective norm and perceived control. This was to trace the strength of the causal relationships among variables that were not based on linear relationship. Spearman’s rho was used because the variables were measured in the form of continuous ordinal numbers, ranging from 0 (no association) to ± 1 (perfect association). For the purposes of this study, we assumed a strong association to be $>0.75 \leq 1$, moderate but still plausible association to be $\leq 0.75 > 0.5$. ≤ 0.5 was seen as no plausible association.

2.2 Households sample size, selection and participants for the main survey

In the main survey, the target sample size (number of households to interview) for A was calculated to be 103 according to Cochran's formula (Bartlett *et al.*, 2001), with a specific margin of error of 3% and an alpha level at 0.05. For B, the required sample size was 30 with a 5% margin of error and an alpha level of 0.05. The smaller margin of error (3%) was used for A because it had a larger population size.

To select the participating household a Global Positioning System (GPS) (Garmin 60CsX, Olathe, Kansas) was used to mark all the households in the two villages. The households for each village were then selected randomly from the marked household list using Microsoft Excel. 94 households were eventually interviewed in A (11% of the total number of households) which was slightly less than the target sample size of 103 households. In B, 31 households were interviewed (26% of the total number of households). The interviewees consisted of 92 females (74%) and 33 males (26%). The ages ranged between 17 to 88 years old (mean = 39).

Further information on water accessibility for the two villages were collected from the survey which included people's perceptions on walking distance to water sources and average time spent per water collection. Participants were given choices for different levels of walking distance (0-5 m, 10-50 m, etc.) and average walking time (< 15 min, 15-30 min, etc.).

3 TESTING THE TOOL

3.1 Measuring receptivity – the basic model

For the elementary application of the receptivity model the final scores for each phase are shown in **Table 7**. The scoring method can be referred to in Table 4. The overall receptivity percentage for A (90%) was considerably higher than B (64%).

Table 7: Receptivity results

	Max score	Village A (with system)		Village B (about to receive system)	
		Average score	Average in %	Average score	Average in %
Awareness	6	4.6	85%	3.2	46%
Association	4	3.8	94%	3.3	83%
Overall receptivity			90%		64%

The results from the TpB model which was applied to acquisition and application provide further insights to other possible factors explaining the discrepancy between usage and access provision.

3.1.1 Awareness

The comparison between the two villages is for highlighting the general awareness level between the two groups. The higher awareness level among Village A participants (77%) compared to Village B participants (53%) is logical because B had no taps as yet (**Table 8**).

Table 8: Results for Awareness

AWARENESS	% of participants who answered "true"	
	Village A (with taps) n=94 Answering from experience	Village B (without taps) n=31 Answering from expectation
Tap water is from a safer source than river water	82	16
Tap water quality is better than river water quality	97	84
Tap water is not (for A) or might not (for B) always be available	82	42
Tap is closer to house than river, so more accessible	98	61
Taps could be connected to inside the yard at a fee	57	26
Average	85 %	46 %

A breakdown of these results shows the value of awareness testing if the indicators are carefully chosen. The awareness that the proxy group (B) has shown on the issues on which their awareness of the pending system was tested was assumed to have been that of A, just before the system was installed four years ago.

The key message from these results is the generally low awareness level of Village B, which suggests they might not fully understand and therefore not fully know what to expect of the potential benefits and/or problems associated with the use of tap water. Judging by these results, people before receiving a system would tend to harbour a blind belief that tap water is better than river water (84%) without understanding the reason behind (i.e. tap water is from a much safer source; 16%). They also seem to not understand that these systems do break down, as well as not being aware that yard connection options are available to improve access (as is still the case with the experienced group). Finally they did not appear to grasp yet that the taps would be closer to homes to the extent that they would have improved accessibility.

3.1.2 Association

Both groups made a strong association between the use of tap water and the positive impacts on their lives. Of A, 94 % experienced this to be so. Of B 83 % expected this to be so (Table 9).

Table 9: Results for Association

ASSOCIATION	% of participants who answered "true"	
	Village A (with taps) n=94 Answering from experience	Village B (without taps) n=31 Answering from expectation
Using tap water reduce risks of water-borne disease	97	94
Drinking tap water leads to better general health	98	94
Using tap water means less physical burden because of shorter distances over which to collect and carry water	86	68
Improved access means more time to do other thing and/or I can bring home more water	95	77
Average	94	83

In particular, they very strongly associated the use of tap water with reduced risk of contracting waterborne diseases and general health improvement. In terms of improved accessibility, participants from A made stronger association between the use of tap water and shorter travel distance to which were also attributed with less physical burden from carrying water container. This is probably because of the experiences of A, as opposed to B not yet knowing what to expect.

3.2 Measuring receptivity – using Theory of Planned Behaviour

3.2.1 Acquisition

The summarised total scores for attitude, subjective norm and perceived control are shown in Table 10.

Table 10: Summary of total scores for attitude, subjective norms and perceived control for Acquisition

	Village A (with taps)			Village B (about to receive taps)		
	Attitude	Subjective Norm	Perceived control	Attitude	Subjective Norm	Perceived control
Total scores	102	58	-26	96	51	-16
Possible range for total score	±126	±63	±84	±126	±63	±84

Note: Refer to Table 5 for calculation of scores

The detailed scoring is shown in Table 11.

Table 11: *Attitude/Subjective norm/Perceived control* as described by the TpB model results for *Acquisition*

	Village A (with taps)						Village B (about to receive taps)					
	Belief strength (b) (Max 7)		Outcome evaluation (e) (Max 3)		Total score	r_s of $b_i e_i$	Belief strength (b) (Max 7)		Outcome evaluation (e) (Max 3)		Total score	r_s of $b_i e_i$
	Mean	Stdv	Mean	Stdv			Mean	Stdv	Mean	Stdv		
Behavioural beliefs												
Shorter distances save more time	6.56	0.96	2.54	1.22	16.66	0.58	6.23	1.36	2.42	1.50	15.08	0.60
Water food garden	5.12	2.50	2.67	1.05	13.67	0.49	5.35	2.32	2.26	1.73	12.09	0.51
Less physical burden	6.18	1.69	2.46	1.37	15.20	0.57	5.87	2.05	1.94	2.17	11.39	0.62
Better water quality	6.60	1.25	2.86	0.68	18.88	0.69	6.68	0.91	2.90	0.40	19.37	0.68
Health improves	6.67	1.10	2.87	0.68	19.14	0.79	6.74	0.82	2.84	0.73	19.14	0.72
More time to do housework	6.68	0.96	2.77	0.68	18.50	0.59	6.68	0.75	2.84	0.52	18.97	0.70
102						96						
Subjective norms, i.e. social pressure from:												
Family	6.97	0.18	2.89	0.56	20.14	0.81	6.87	0.56	2.55	1.36	17.52	0.76
Neighbours	6.90	0.30	2.74	1.03	18.91	0.83	6.48	1.57	2.55	1.36	16.52	0.72
Community	6.90	0.30	2.74	1.03	18.91	0.83	6.48	1.57	2.55	1.36	16.52	0.72
58						51						
Control beliefs												
Queues at taps too long	3.20	2.67	-1.04	2.71	-3.33	0.35	4.55	2.92	0.32	2.91	1.46	0.53
Water collection easier if only taps are closer to home	6.79	0.80	-2.65	1.32	-17.99	0.53	6.90	0.30	-1.77	2.40	-12.21	0.62
Long to fill container because the pressure is too low	2.61	2.49	-0.07	2.80	-0.18	0.44	4.81	2.74	0.13	2.93	0.63	0.52
Stolen container	3.95	2.90	-1.24	2.59	-4.90	0.29	4.90	2.88	-1.13	2.68	-5.54	0.55
-26						-16						

The results on belief strength (b), outcome evaluation (e) and Spearman's rho correlation (r_s) with the product of the two parameters (b & e) for both villages are presented in **Table 11**. A description of Spearman's rho correlation and its use in this study appears below Table 6. A strong positive correlation between a specific belief and intent suggested the two variables were consistently related (i.e. when one variable increases, the other variable also increase). Total scores in columns indicate how each test variable have fared against a maximum variable score of 21. These are totalled to show how each factor of the TpB (Attitude/Subjective norm/Perceived control) would have fared as per the total max score shown in Table 11.

The high total attitude and subjective norm scores for both groups reflect strong positive attitude and community approval. The closer each score would be to its positive maximum the more the specific variables under Behavioural beliefs and Subjective norms hold to be plausible if not absolutely the fact.

For Perceived control the closer the score gets to the negative maximum, the more the variable is seen as a problem that would not be readily overcome. The generally low level of perceived control suggested "problems" that could prevent people from optimally using the system, i.e. long waiting queue, long distance, low water pressure and stolen container. Village A had lower perceived control compared to Village B which meant that the problems were more practically experienced and therefore real to report as compared to the people of Village B who would have low expectations of problems and therefore it would show as "easier" to overcome.

3.2.1.1 Attitude

The health-related beliefs were moderately associated with intent to use the system for access to better water quality for both A and B ($r_s = 0.69, 0.68$). General health improvement fared better ($r_s = 0.79, 0.72$). This suggested that gaining improved health benefits ranked more consistently with the intention to use the system, thus these benefits were quite plausible motivation for using future taps (B) or continue using the current system (A).

For the accessibility-related benefits, the associated with intention were moderate but not as high as health-related beliefs (time saving $r_s = 0.58, 0.60$, physical burden $r_s = 0.57, 0.62$, more time to do housework $r_s = 0.59, 0.70$ for A and B respectively). This suggested that despite people's awareness and association of the benefits both through

experience and expectation (Tables 8 and 9), their actual beliefs about this would not be a major driver of a positive attitude towards the system.

The correlation between beliefs about food garden and an intent to have one was weaker compare to the others for both groups (A $r_s = 0.49$, B $r_s = 0.51$). IN terms of experiencing this, the reason could be the unofficial but enforced water conservation policies introduced by the community leader in Village A discouraged the community from growing food gardens, so the potential benefits of piped water for domestic agricultural use might have been underestimated in this area. The general trend is for B higher than A, possibly because Village B's participants had no experiences with a supply system and hence they had higher expectation what they could use it for – with a food garden possibly on the cards and as yet no policy guiding this.

Focus group discussion in A confirmed that accessibility-related benefits such as time saving and reduced physical burden were valid benefits from using tap water. However, there were hidden factors that restricted the extent of the benefits experienced by the people in Village A. Limited pumping capacity in A caused the water supply to be cut off between 16:00 and 08:00 the next day to allow for reservoir refilling. Working adults and school-attending children who did not return before the cut-off time could not collect water during the weekdays. Instead, people resolved to increase filling over weekends to store up water for the following week, imposing additional physical burden. Many of the A households were thus compelled to spend extra time on weekends to increase their weekly stored water stocks.

Those in Village A who could collect water during weekdays before the cut-off time experienced the benefits of time saving and reduced physical burden. Furthermore, those households not living in the vicinity of taps still experienced excessive physical burden. In the A focus groups, the participants reported that they still experienced chronic back/neck pain and headaches from water collection despite the system intervention. Several mothers in the A focus groups also reported painful caesarean lesions when they lifted and carried water containers. However, the general levels of physical burden were reduced since the intervention.

3.2.1.2 Subjective Norm

Strong correlations were observed between social pressure from family, neighbours and the community ($r_s = 0.81, 0.83, 0.83$), which indicated that in Village A, social pressure was a stronger motivation to use tap water compared to B ($r_s = 0.76, 0.72, 0.72$). Associating this with the finding that health benefits was one of the strong motivations for using tap water, the participant might be motivated specifically because of the health benefits for their family members.

3.2.1.3 Perceived Controls

Distance was perceived to be the strongest barrier to collect water at taps compared to other perceived difficulties such as queuing for water, low pressure and stolen container for Village A participants ($r_s = 0.53$) although less so for B ($r_s = 0.62$). Similar to what was found in attitude, higher correlations were found with B reflecting the difference between the A) people who had experienced access of using a supply water system and B) people who did not.

3.2.2 Application

The scores for attitude, subjective norm were again close to the maximum score (Table 12) while the scores on perceived control this time were not negative as with acquisition but were still equally low – showing that community members expected as well as experienced the variables we measured for “loss of control” as things they would also find an impeding factor but with moderately more of a tendency to see these as challenging in the motivational sense.

Table 12: Total scores for attitude, subjective norm and perceived control for *Application*

	Village A (with taps)			Village B (about to receive taps)		
	Attitude	Subjective Norm	Perceived control	Attitude	Subjective Norm	Perceived control
Total scores	37	56	7	40	59	9
Possible range for total score	±42	±63	±42	±42	±63	±42

Note: Refer to Table 6 for calculation of scores.

The intention to use and maintain taps in a responsible manner was very strong for both groups. This was confirmed in the focus groups in both Village A and Village B that the participants from both villages saw that looking after the taps of the system was their responsibility while the service provider's responsibility was to provide the infrastructure and fix major problems. Both groups showed positive attitudes and subjective norm to look after the taps. The low positive perceived control total scores for both groups suggested a low level of difficulty to overcome the problems (i.e. taps not inside house, a hypothetical fine imposed by the community leader).

3.2.2.1 Attitude, subjective norm and perceived control

For Village A, social pressure from family, neighbours and community was found to have weaker associations with the intent to comply compared to other beliefs (Table 13) ($r_s = 0.45, 0.42, 0.45$). For Village B, the social pressure was also a bit stronger compared to the other correlations but still weak ($r_s = 0.54, 0.54, 0.54$). Beliefs that involve financial payment such as avoid paying a fine for water wastage ($r_s = 0.58$) and fines imposed by community leader for not looking after taps ($r_s = 0.40$) were not motivations for B probably they did not yet have the experience.

Table 13: Attitude/Subjective Norm/Perceived Control as measured by the TpB model for Application

	Village A (with taps)						Village B (about to receive taps)					
	Belief strength (b)		Outcome evaluation (e)		Total score	r _s of b _i e _i	Belief strength (b)		Outcome evaluation (e)		Total score	r _s of b _i e _i
	Mean	Stdv	Mean	Stdv			Mean	Stdv	Mean	Stdv		
Attitudes – Behavioural beliefs												
I will help reduce water wastage	6.86	0.38	2.67	1.28	18.32	0.42	6.84	0.37	2.94	0.25	20.11	0.26
I will avoid paying for water wastage	6.67	0.95	2.68	1.28	17.88	0.35	6.81	0.48	2.97	0.18	20.23	0.58
36						40						
Subjective Norm – Normative beliefs												
My family	6.90	0.30	2.84	0.77	19.60	0.45	6.94	0.25	2.77	1.09	19.22	0.54
My neighbour	6.88	0.32	2.71	1.14	18.64	0.42	6.74	1.09	2.77	1.09	18.67	0.54
The community	6.88	0.32	2.65	1.28	18.23	0.45	6.74	1.09	2.77	1.09	18.67	0.54
56						57						
Perceived control – Control beliefs												
It is difficult to look after the tap if it is not inside my yard	4.60	2.80	0.35	2.73	1.61	-0.01	4.45	2.99	0.55	2.92	2.45	0.22
The community will fine me If I do not look after the tap	4.35	2.82	0.60	2.85	2.61	0.14	4.68	2.74	0.68	2.87	3.18	0.40
4						6						

In the A focus groups, the inability of some households to contribute money for maintenance was reported as one of main barriers. In the B focus group, it came out that the participants had not yet considered what actions to take in the case of broken taps/pipes but they expressed willingness to contribute financially for maintenance.

4 CONCLUSION

4.1 Can this tool measure the social effect of an intervention?

This tool was intended to be a robust and simple instrument to measure the effect of a water supply intervention at the social level. To answer the question on whether this tool worked in its pilot application, one has to consider two sub questions elements; 1) did the “before” and “after” data shift from expected scenarios to experienced scenarios, i.e. were there higher levels of positive experience than expectations and 2) were these shifts significant? Table 14 summarises a robust analyses of the data based on these two questions and shows the various scores and results for testing whether these shifts were significant.

Table 14: Receptivity results

	Max score	Village A (with system)		Village B (to receive system)		ANOVA Paired T-test	Interpretation
		Average score	Average in %	Average score	Average in %		
Awareness	6	4.6	85%	3.2	46%	P=0.012	Significantly greater <i>awareness</i> in the <u>after</u> (experienced) group
Association	4	3.8	94%	3.3	83%	P=0.083	Differences in <i>association</i> not significant
Acquisition	273	186	68%	162	59%	P=0.497	Differences in <i>acquisition</i> not significant
Application	147	97	66%	103	70%	P=0.047	Significantly greater <i>application</i> anticipated by the <u>before</u> (expectation) group
Overall receptivity		79%		66%		P=0.250	No overall significant differences

While shifts can be noticed, these were insignificant for two of the indicators (association and acquisition). The power at which each of these two tests was conducted was quite low, which means that a significant difference might have existed but the paired T-test would not be sufficiently sensitive to detect such difference. This could be corrected by an increase in the sample size.

If we assume that the proxy approach will have given data of the same quality one would have expected had we been in a position to evaluate a community before an intervention and again the same community after, then the following conclusions are made:

- The tool as it is now configured, failed to detect an impact or;
- There were simply no effects to be measured because the communities in waiting were at the same level of anticipation as the experience of communities that use systems. If this is the case, then two more questions arise:
 - o Could it be that the tool was quite effective in detecting that expectations were met to a large extent?
 - o Can the exact same variables could be applied in a before and after scenario;

As this is work in progress, these questions will be further explored as the tool development continues.

4.2 Impeding and motivational factors

While the tool as such showed that more thinking and work would be required, the data showed interesting driving forces in the receptivity of a system by communities in waiting as well as communities that use systems. These are summarised in Table 15.

Table 15: Summary of findings for Village A and Village B

	Village A (with taps)	Village B (about to receive taps)
Reduction of waterborne disease	▪ This was the strongest motivator to optimally use a system.	▪ This would be the strongest driver of expectations for communities in waiting.
Improved access (time saving and reduced physical burden)	▪ These were also strong motivators but because of the unreliable supply, these benefits were not experienced by all participants and at all times.	▪ These would be also strong predictors to use taps but their anticipation for these benefits was not high.
Gain in productive activity	▪ Use tap water for, e.g. growing food garden was not a common practice for A.	▪ This would not be a strong predictor for effective use of a system.

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