



# Risk assessment case study

*Upper Mnyameni, South Africa*

# TECHNEAU

## *Risk assessment case study – Upper Mnyameni, South Africa*



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**Title**

Risk assessment case study - Upper Mnyameni,  
South Africa

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# Summary

Within Work Area 4 (WA4) *Risk Assessment and Risk Management*, in the TECHNEAU project, six risk assessment case studies were carried out at different drinking water systems during 2007-2008. This report presents a risk assessment of the drinking water system in Upper Mnyameni, South Africa. Upper and Lower Mnyameni are two rural villages in the Eastern Cape province, about 80 kilometers from the south east coast. The villages are supplied with drinking water by a water treatment plant that takes its water from the Mnyameni dam. Altogether the water treatment plant supplies approximately 2 500 people with water. These communities are very rural and no major industries or other commercial activities are supplied with water from the Upper Mnyameni water treatment plant.

The objectives of this case study were to identify hazards in the drinking water supply system (from “source-to-tap”), estimate and evaluate the risks to humans and the development of the society, and evaluate the risk assessment methods that were used. Two types of risk analysis were performed. The first risk analysis was performed by risk ranking of likelihood and consequences and presentation of risks with risk matrices (coarse risk analysis (CRA)). The second risk analysis was performed by using South African Risk Evaluation Guidelines.

The TECHNEAU Hazard Data Base (THDB) was used to facilitate hazard identification for both methods. Eleven hazardous events were identified from the assessment and subsequent brainstorming sessions. The hazards were rated (by experts at Amatola Water) by likelihood and consequence of occurrence. There were two consequence ratings, one focused on human health and one on number of people affected.

The major risks were found at the water taps (most households do not have taps), and from insufficient storage of water, inadequate hygiene due to lack of easily accessible taps and for the lack of power-supply. Suggested risk reduction options were found to reduce the risks significantly.

Of the two estimation methods the risk matrices were found to be most useful for Upper Mnyameni water treatment plant. The South African Evaluation Guidelines were found to be less useful, mainly due to the lack of detail when ranking the risk for the raw water source. We would also recommend that another category, one at the end of the supply system (at the consumer), would be added to not forget this important aspect.



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# 1 Introduction

## 1.1 Background

Within Work Area 4 (WA4) *Risk Assessment and Risk Management*, in the TECHNEAU project, six risk assessment case studies were carried out at different drinking water systems during 2007-2008. The aim of the case studies was to apply and evaluate the applicability of different methods for risk analysis (i.e. hazard identification and risk estimation) and to some extent risk evaluation of drinking water supplies, see Figure 1. The case studies provide a number of different examples on how risks in drinking water systems can be analysed and evaluated. The drinking water supplies in the following six locations constitute the case study sites where risk assessments were performed in WA4:

- a) Göteborg, Sweden
- b) Bergen, Norway
- c) Amsterdam, the Netherlands
- d) Freiburg-Ebnet, Germany
- e) Březnice, Czech Republic
- f) Upper Nyameni, Eastern Cape, South Africa

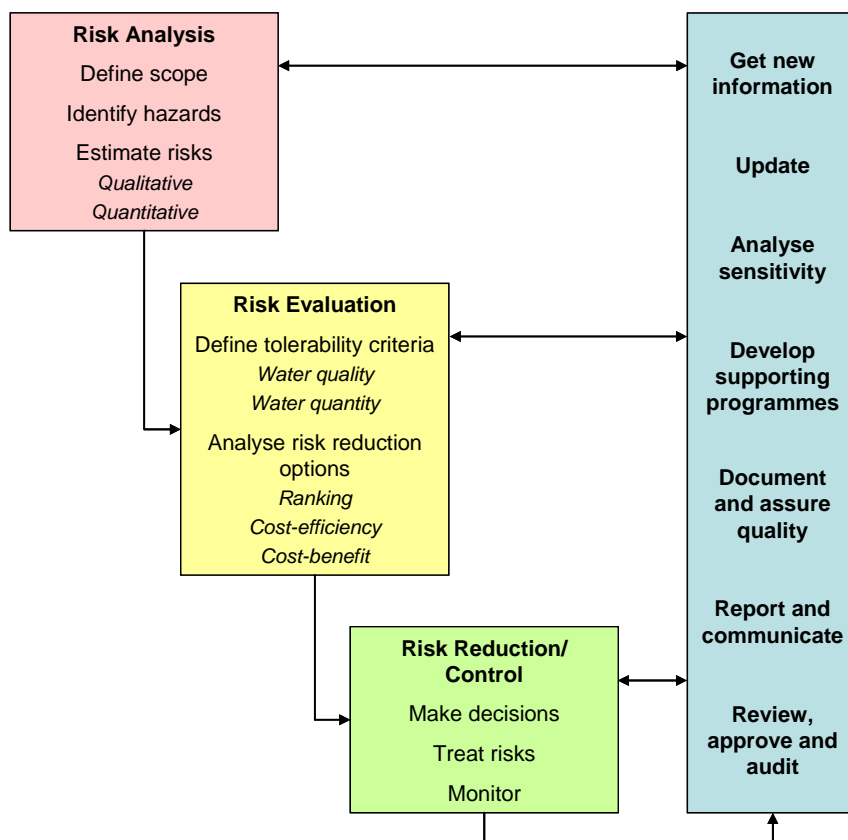


Figure 1. Main components of the TECHNEAU generic framework for integrated risk management in water safety plans (Rosén et al., 2007).

This report presents a risk assessment of the drinking water system in Upper Mnyameni, Eastern Cape, South Africa. This case study was conducted in collaboration with Amatola Water, the local water utility.

## 1.2 Objectives and scope

One aim for this case study will be to identify and evaluate hazards by applying risk evaluation methods.

The objectives of the risk assessment study at Upper Mnyameni are:

- Identifying risks in drinking water systems.
- Investigation of risks for water supply failures and risks for insufficient water quality.
- Overall evaluation of risks and the consequences for humans and the development of the society.
- Evaluation of the risk assessment methods that will be used.

## 1.3 Method

To cover the whole water supply system a “source-to-tap” approach has been used. A system description was made after discussion with Amatola Water, gathering of data and by site visits. Hazards were identified by both using TECHNEAU Hazard Database (Beuken *et al.*, 2007) and by discussion with Amatola Water. Two different methods has been performed. The first method for risk assessment was by ranking likelihood and consequences and by presenting the risks with risk matrices with ALARP zones according to Generic Framework. Rating of likelihood and consequences for the risk matrix were made in collaboration with experts at Amatola Water. The second risk assessment method was performed by using South African Risk Evaluation Guidelines.

## 1.4 Limitations

The whole drinking water system is included in the risk assessment. There is lack of information about parts of the system. There was no available information of the dam’s depth and volume and limited information about the piping system.

## 2 System description

### 2.1 Overview

#### 2.1.1 Local conditions

South Africa has a huge variety in water resources and water quality depending on local conditions. The coastal and eastern regions are mainly high precipitation areas, while the inland and western parts are low in precipitation. Because of the limited rainfall raw water is usually collected in dams.

South Africa has large number of small water treatment plants; 51 % produce less than 0.5 M l/day. (Figure 2) The daily drinking water production at Upper Mnyameni water treatment plant is approximately 0.24 M l/day. The aim in South Africa is to centralize water supply facilities because of high operational costs at smaller WTPs.

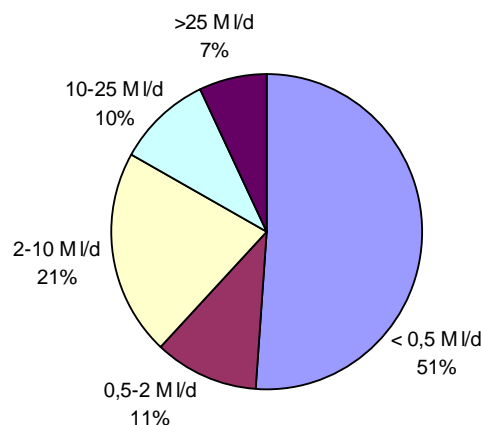


Figure 2. Distribution in percentage of South African water treatment plants.

Upper Mnyameni water treatment plant is situated in a rural area in the Amatola Mountains in the province Eastern Cape (Figure 3). The small villages Upper and Lower Mnyameni are low income communities with a very high unemployment rate (approximately 80 percent). The major industry in the villages is forestry. There is also some non-formalized low scale farming activities such as roaming cattle in the villages.

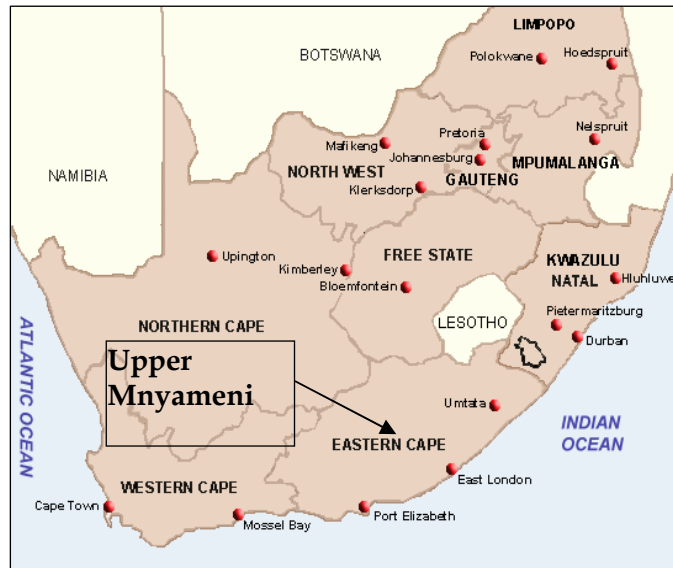


Figure 3. Location of Upper Mnyameni.

Amatola Water Board is the local drinking water supplier for Amahlati Municipality, to which Upper and Lower Mnyameni belongs. It is one of totally 20 water boards and utilities in South Africa. Amatola Water Board belongs to South African Association of Water Utilities and has the mandate from the South African government to supply municipalities and other consumers with water.

### 2.1.2 South African drinking water requirements

The South African National Standard – Drinking Water (SANS 241:2005) specifies quality criteria for acceptable drinking water. The standard includes quality control of microbiological, physical, organoleptic and chemical parameters. Drinking water is divided into two classes, class I and class II:

- Class I: Acceptable quality for lifetime
- Class II: Acceptable quality for limited period

South African National Standard recommends that a community with a population of less than 2 500 persons, sampling should be carried out at minimum one time per month. Sampling should be performed more often during the rainy season. **Fel! Hittar inte referenskölla.** and **Fel! Hittar inte referenskölla.** describe a selection of the sampling parameters.

Table 1. Microbiological safety requirements for drinking water according to the South African National Standard – Drinking Water.

1	2	3	4	5
Determinant (parameter)	Unit	Allowable compliance contributor		
		95 % of samples, min.	4 % of samples, max.	1 % of samples, max.
		Upper limits		
E. coli or Thermotolerant (faecal) coliform bacteria	Count/100 ml	Not detected	Not detected	1-10
	Count/100 ml	Not detected	- 1	

Table 2. Physical, organoleptic and chemical requirement water according to South African National Standard – Drinking Water.

Determinant (parameter)	Unit	Class I (recommended operational limit)	Class II (max. allowable for limited duration)	Class II water consumption period, a max.
pH value at 25 (aesthetic/operational)	pH units	5.0 - 9.5	4.0 - 10.0	No limit <sup>c</sup>
Turbidity (aesthetic/operational/indirect health)	NTU	< 1	1-5	No limit <sup>d</sup>
Chloride as Cl <sup>-</sup> (aesthetic)	mg/L	< 200	200-600	7 years

### 2.1.3 *The system in Upper Mnyameni*

Upper and Lower Mnyameni are two rural villages (Figure 4) in the Eastern Cape province in South Africa, about 80 kilometers from the south east coast. The villages are supplied with drinking water by a water treatment plant that takes its water from the Mnyameni dam. Altogether the water treatment plant supplies approximately 2 500 people with water. These communities are very rural and no major industries or other commercial activities are supplied with water from the Upper Mnyameni water treatment plant.



Figure 4. *Upper Mnyameni Village.*

## 2.2 Source water

The raw water source is the Mnyameni Dam (Figure 5) which is situated approximately 1 kilometer from the Upper Mnyameni village. The outflow from this dam is the source of the Keiskamma River which has its outflow to the Indian Ocean close to the village Hamburg, South Africa. The dam is surrounded by precipitous mountains and the incoming water comes from rain and snow melting, but also from groundwater flow into the dam. The fact that the dam is partly supplied by groundwater makes the supply of raw water stable for long periods with dry weather. The flow of water into the dam is much higher than the demand from the two water treatment plants.



Figure 5. The Upper Mnyameni Dam.

The dam was originally used for water supply for large scale farming, but is today only used to supply raw water for the treatment plants in Upper Mnyameni and Masincedane. The raw water is characterized by moderate turbidity levels, usually around 10 NTU, but this level can increase drastically as a result of heavy rains. High turbidity negatively affects the aesthetic quality of the water and, more importantly, decreases the effectiveness of the disinfection process. There are neither roads nor industrial activity in the area around the dam and therefore there is no risk that oil or other chemical substances will contaminate the water source. The dam is also protected from farming activities because it is located in a natural reserve where such activities are forbidden.

## 2.3 Treatment

The water gravitates from the dam, at 912 meter above the sea level, to the treatment plant which is located approximately 70 meters lower. Figure 6 shows a schematic flow diagram of the water supply in Upper and Lower Mnyameni. The raw water to the WTPs in Upper Mnyameni and Masincedane is first transported in the same pipe. There is a cross connection to this pipe just below Upper Mnyameni. The flow into to the Upper Mnyameni WTP can be controlled manually at this point. The water then

flows by gravity to a balancing chamber located just outside the treatment plant. In the balancing tank pre-chlorination takes place, but the main purpose of the tank is to have a flow into the WTP with static head. Chlorination is not effective at this stage because the turbidity is too high for successful disinfection to be achieved. From the balancing tank the water gravitates down to the filter house. Before the water reaches the filter house, a coagulant (polymer blend, Zetachem 553) is pumped into the pipe (Figure 7). Inside the filter house there are two parallel flocculation tanks and six parallel pressure sand filters. The function of the flocculation tanks is to increase the time for the flocculation process to inhibit flocs forming after the water has passed through the filters. There are no peddle wheels or other equipment for mechanical mixing inside the tanks. Flocs form inside the flocculation tanks and the majority of the flocs are trapped in an upper layer of the sand filters (400 mm anthracite media filter). Remaining flocs are then filtered out in the lower sand layer of the filter. A booster pump then carries the water to the Clean Water Reservoir (CWR) at the plant. Inside the CWR chlorination takes place through chlorine tablets.

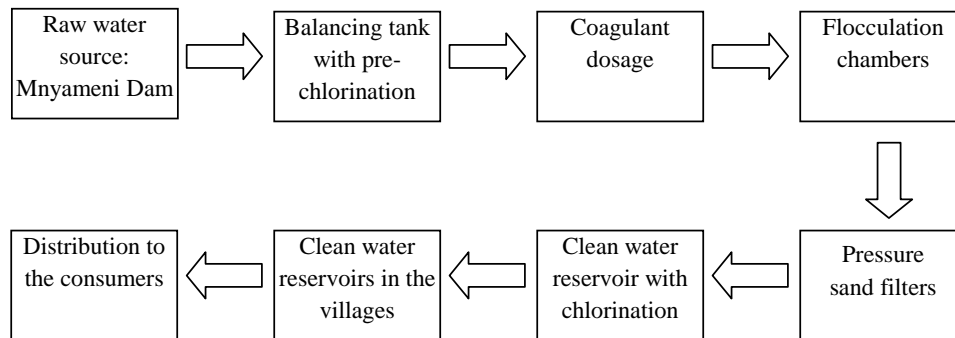


Figure 6. Flow diagram of the water supply in Upper and Lower Mnyameni.



Figure 7. Polymer dosage at Upper Mnyameni WTP.



## 2.4 Distribution

Chlorinated water is pumped from the WTP to a high altitude reservoir in the upper part of Upper Mnyameni (Figure 8). From this reservoir parts of the water gravitates to a smaller reservoir in the middle of the village and parts of the water is directly distributed to consumers. Lower Mnyameni has a similar distribution system but there are three reservoirs. Also here the water gravitates between the reservoirs and to the consumers. That means there are no pump stations on the pipe network. There are two electrical pumps at the



*Figure 8. The high altitude reservoir in Upper Mnyameni.*

treatment plant, one that pumps to each village. Both pumps have the possibility to pump to the other village if necessary. There is no back-up power supply for the pumps in case of power failures. The main distribution pipes, called bulk pipes, are managed by Amatola Water. From the bulk pipes smaller pipes distribute water to the taps. Both bulk pipes and taps are managed by Amahlati Municipality. Most taps are outside and there is approximately one tap per 20 houses. Villagers usually have some kind of container that they fill up with water. Some of the households have water inside the houses, of which some are illegal (Generally there are 5-20 households per tap in the rural villages of the Amatola Mountains). When this study took place there was no test made for retention time in reservoirs and pipes. Experts at Amatola Water estimated the retention time to not more than 3 hours during the day-time, but longer during the night-time as demands drops. The total drinking water production is approximately 240 m<sup>3</sup>/day.

## 2.5 Operation

The plant works 24 hours a day all year around, but it is only manned during office hours. During this time samples of water are taken and analyzed every hour. The analysis includes turbidity and pH-value in the raw water and for the treated water analysis includes turbidity, pH-value and amount of residual chlorine. The raw water samples are taken from the pipe between the balancing tank and the flocculation tanks and the clear water sample is taken in the CWR (Figure 9). The sand filters are backwashed in the morning and in the afternoon. At weekends, the plant is manned for shorter periods of time and at least one backwashing of the sand filters is done. The levels in two of the reservoirs on the distribution system, one in Upper Mnyameni and one in Lower Mnyameni are monitored in the operator's office at the plant. The water level in the CWR at the plant is also measured. This information is also available in the control room at the water treatment plant in Sandile, which is manned 24 hours a day. If there is a pump failure at the Upper Mnyameni

treatment plant this can also be noticed in Sandile. The pumps can not be controlled from Sandile, only monitored. In case of a break down of one of the two pumps the other pump can alternate between the villages, but it can only be done manually at the WTP in Upper Mnyameni.

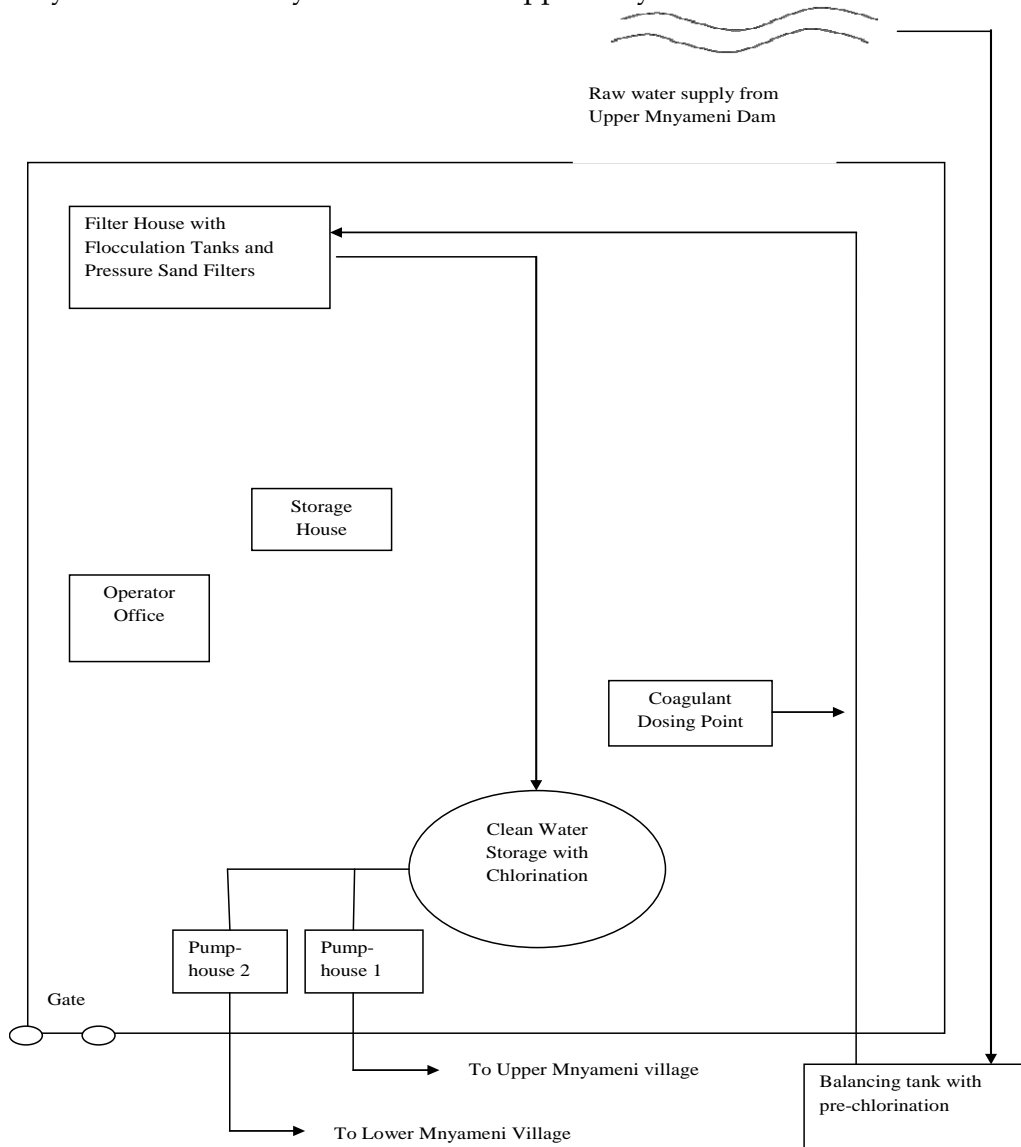


Figure 9. Layout of Upper Mnyameni water treatment plant.

## 2.6 Earlier incidents and problems

The end-user reported that problems were experienced with water shortages in the community during periods of high demand, and also incidents of poor water quality due to ineffective flocculation and filtration when increasing the flow rate through the plant in an attempt to meet high water demand.

## 2.7 Improvements of the treatment process

During the past year, the water treatment plant in Upper Mnyameni has been upgraded and the quality of the drinking water has increased because of this. Four measures were taken to improve the water treatment process:

### **Cleaning of the reservoir**

A lot of sludge is gathered in the clean water reservoir and occasionally this sludge used to flow out in the system and affected the turbidity in the drinking water. The reservoir was emptied and then all sludge cleaned out. This should be done on regular basis, but had not been done for many years, perhaps never. After the cleaning of the reservoir the water quality improved significantly.

### **Change in dosage system for the coagulant**

The coagulant was dosed and transported by gravitation into the pipe between the balancing tank and the sand filters. A dosage pump was installed and that made it possible to adjust the dosage of polymer blend according to the turbidity in the raw water.

### **Change of coagulant**

Aluminium hydroxide was earlier used as coagulant and successful use of Aluminium hydroxide as coagulant depends on the pH-value. To achieve a high pH, lime was also dosed to the water at the same point as the coagulant. The Aluminium hydroxide is now replaced with a polymer blend (Zetachem 553), which performance is not dependent on pH.

### **Installation of new pressure sand filters**

The four pressure sand filters at the WTP were often overloaded, i.e. too high water flow of the system and as a consequence of that, the flocculation process took place after the water had passed the sand filters and flocs were created in the clean water reservoir. To solve the problem with overloading, two more pressure sand filters were installed. Previously the water gravitated from the filters up to the clean water reservoir but this did not work very well after the two new filters were installed. The speed in the pipe up to the CWR was too low, which lead to shortage of water. This problem was solved with an installation of a booster pump, which pumps the water from the filter house up to the CWR.



## 3 Risk analysis

Hazard identification for 11 scenarios follows below. Each scenario is presented under hazardous events part. Risk matrices are presented in the end of the risk estimation section.

### 3.1 Hazard identification

The following eleven risk scenarios have been identified by brainstorming and by using the TECHNEAU Hazard Database:

1. High turbidity causing ineffective chlorination.
2. Contaminated taps due to animals leaning/scratching against them.
3. Inadequate hygiene due to low water availability at homes.
4. Contaminated groundwater leaking into pipes.
5. Poor storage of water.
6. Lack of treated water leading to use untreated water.
7. High turbidity when the WTP is unmanned causing high bacterial amount.
8. Ineffective mixing of chlorine leading to high bacterial amount.
9. Sabotage at any part of the system.
10. Incorrect actions due to lack of enough operational skills.
11. Pump failure when the plant is unmanned.

The eleven possible risk scenarios that can affect the drinking water have been rated by experts at Amatola Water which is the utility organisation responsible for water supply to Upper Mnyameni and Lower Mnyameni. The risk scenarios are rated by likelihood and consequence of occurrence. There are two consequence ratings, one focuses on health and one on number of people affected.

#### **Scenario 1: High Turbidity due to heavy rainfall, leading to ineffective chlorination. Resulting in high bacterial count in drinking water.**

High turbidity can affect the effectiveness of the chlorination process, which may lead to high counts of bacteria in the drinking water. This may cause diseases, for example gastroenteritis. The highest turbidity that has been measured in the raw water is around 50 NTU (Figure 10). For treated water, turbidity has never been higher than 4.5 NTU in the past year. Even if this turbidity affects the treatment process, the effects of this scenario is limited because the water is not very contaminated with bacteria, such as e-coli. It will be possible to drink non-disinfected water for shorter periods without any negative health effects. The values for the turbidity should be considered a bit unreliable since the turbidity levels sometimes change drastically without any obvious reason as shown in Figure 10.

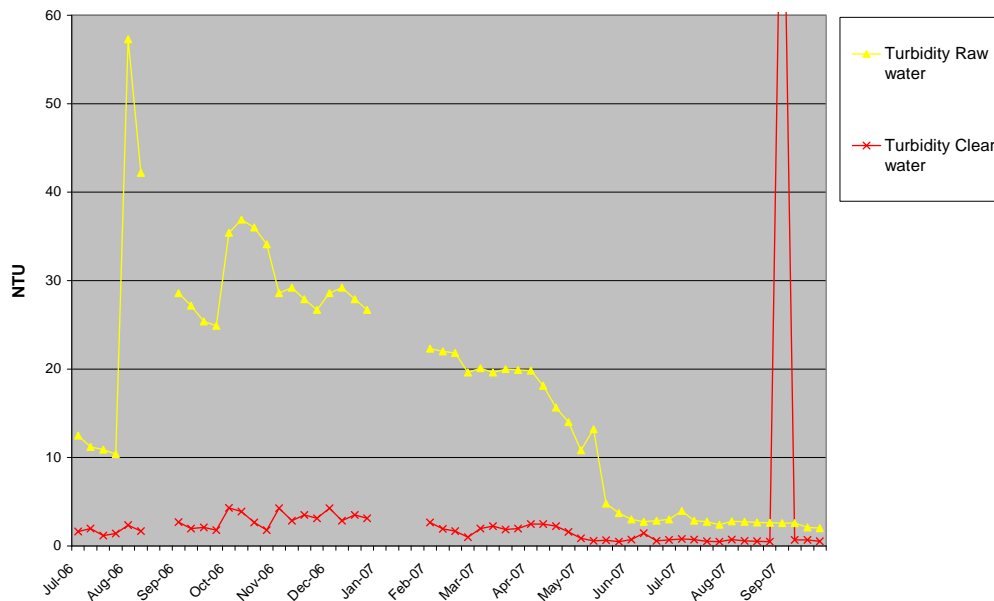


Figure 10. : Average turbidity in raw- and clear water July 2006 – September 2007.

**Scenario 2: Contaminated taps caused by animals leaning against them. Contamination may spread when people, especially children drink from taps.**

It happens regularly that animals (cattle or dogs) lick or lean against taps, which might cause bacterial spread from animals to humans via taps. Taps are not covered or protected from animals in any way. Nor do people cleanse the taps before tapping up their water or drinking directly from the taps (however, most water is boiled within the home environment). This is obviously not a problem for those having pipe connections inside their houses, which is relatively unusual and not the norm. There are no records of individuals being affected due to contaminated taps during the past few years, but it is very likely that this could have happened. Water analyses performed by Amatola Water have not shown any high counts of bacteria in the water. This is probably the greatest risk regarding the water quality due to its high frequency and severe effects (diseases for the consumers).

**Scenario 3: Few taps make water accessibility low (one tap per 5 up to 20 houses and distances up to 200 meter to the nearest tap), which might lead to inadequate hygiene. For example: improper washing after using latrines which might cause bacterial spreading.**

Local health clinics in the region have made major efforts to educate the local people as to the importance of proper hygiene. The households without household connections often keep water in their homes which also promotes poor hygiene caused by lack of water.

**Scenario 4: Groundwater, contaminated by latrines, leaking into pipes. This can lead to high bacteriological count in drinking water.**

There is no sewage system in the villages and the wastewater runs either to a septic tank or directly into the soil. If the pipe system is leaking this may

result in leakage of wastewater into the drinking water pipes. This risk is considered very low in the Mnyameni villages because most of the houses are situated below the most critical parts of the piping system, so the wastewater will not be able to gravitate into the pipes. Nor are there major problems with contamination from garbage as the disposal and treatment of garbage is formalised in the area. The number of pipe bursts in the water delivery system is also very low. Bursts are much more common at the parts of the distribution system that are situated above the ground, i.e. standing pipes, the tap itself and junctions between standing pipes and taps.

**Scenario 5: Poor storage of water. For example storage in open buckets or dirty bottles.**

While there are a small amount of household connections in the area, many people store large amounts of water inside or outside their homes. There is a large risk for contamination both inside and outside houses if water is stored in an open bucket. Long time storage of water also results in low levels of chlorine at the time the water is consumed. This risk will obviously be minimized if all the people living in the village would get household connections. Most people are at least aware of the risk and many boil the water before using it.

**Scenario 6: Long-time power failure or other incident leading to lack of water. People might use the untreated water at Mnyameni River instead (quality related problem).**

If there is no supply of water for a longer time, people will have to get their water directly from the river or the dam. This could mean that they use polluted water or water that is very muddy because of heavy rain falls. The combination of power-failure and water of high turbidity can be common because both are often caused by thunderstorms. Both villages are situated close downstream from the Mnyameni Dam, which is the source of the river, therefore the water is unlikely to be polluted or muddy even after heavy rain at the point it passes the villages. Highly turbid river water is a larger problem downstream in the river where the water is often much muddier and have a turbidity of up to 4000 NTU.

**Scenario 7: High turbidity during periods when the treatment plant is unmanned. Dosage of polymer blend is not controlled effectively during such periods. High bacterial count might cause illness for consumers.**

The water treatment plant is only manned during office hours and in short periods over the weekends. If the level of turbidity changes drastically during night, the dosing amount of chlorine and Polymer blend might not have adjusted before the next morning. Meanwhile the treatment plant may be producing water with too high turbidity and too high bacteria count.

Major changes in turbidity during short periods of time are rare in Mnyameni Dam. Changes in turbidity level are seasonal, i.e. changes take place over a long period of time rather than hourly or daily. According to Amatola Water the plant can be left unmanned for a period of up to one week without any major impact on the turbidity or chlorine level in the drinking water – this is

true under circumstances where enough chlorine is dosed before the treatment plant is abandoned.

**Scenario 8: Ineffective disinfection due to poor mixing between chlorine and water in the reservoir. This might lead to high bacterial amount in drinking water.**

The chlorine level in the clean water reservoir is measured hourly and the dosage of chlorine is increased as necessary. Chlorine level is not measured at night, but more chlorine tablets than required are dosed in the reservoir. If the chlorination should fail for some unforeseen reason, it will not lead to any catastrophic consequences since the bacterial count in the raw water is so low that it could be consumed untreated without any negative effects to people’s health. According to South African National Standards the residual chlorine should be at least 0.5 mg/l in the water that is pumped out from the plant. As shown Figure 11 this limit has been achieved during the whole period. The values in the diagram are average values per week, not the lowest measured value during the period\*.

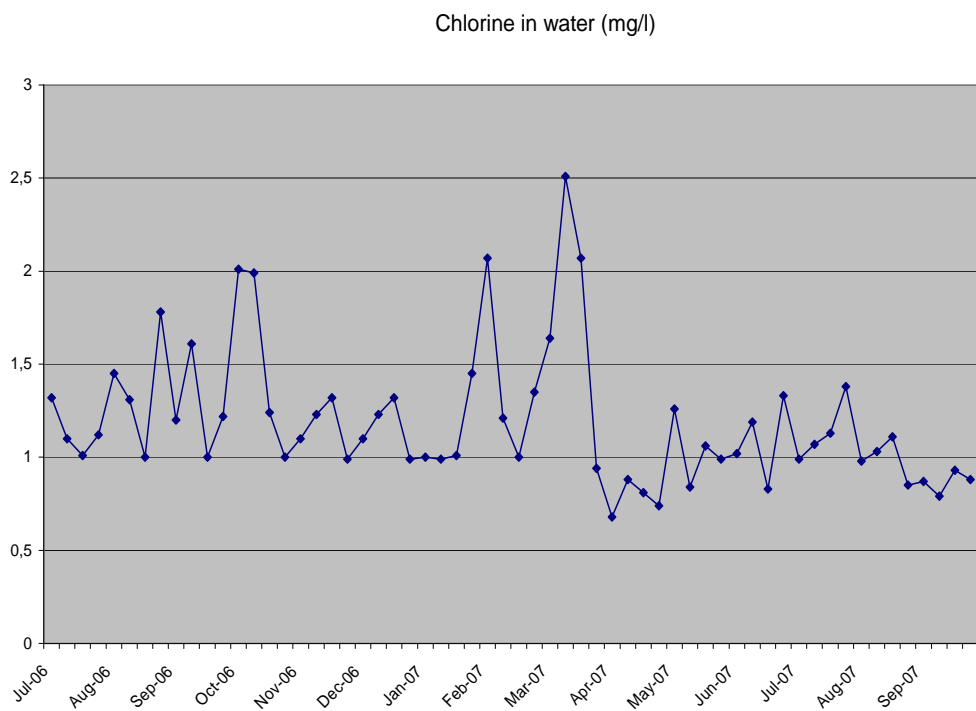


Figure 11. Residual chlorine in the clean water reservoir, July 2006 – September 2007.



**Scenario 9: Sabotage of water supply (e.g. purposeful contamination of raw or clear water, damage to pumps, filters etc. or theft of vital equipment.)**

There are no known cases of sabotage against or theft to the water supply system in Upper or Lower Mnyameni, but sabotage is common in other areas where Amatola Water is responsible for the water supply. The water treatment plant is surrounded by a fence, while the reservoirs and the balancing tank are secured by a padlock. The reason why no sabotage has taken place is probably that the people in the villages have been informed of the importance of the facilities and the relative inaccessibility of villages.

**Scenario 10: Correct operational actions are not taken due to lack of adequate operator skills at WTP. This may result in non-potable water.**

No failures caused by incorrect operational actions have occurred for at least seven years in Upper or Lower Mnyameni. Operators have the possibility to contact personnel at the larger Sandile water treatment plant over radio if necessary. The consequence of this scenario would be that people would consume untreated water, i.e. water of the same quality as in the dam, which is possible to drink for a limited period of time without any health effects.

**Scenario 11: Pump failure when personnel have left the plant leading to water delivery failure.**

If the distribution pumps fail to work when reservoirs are full, and demand is high, there will be a lack of water in the villages in less than three hours. Should the booster pump break (it pumps water from the sand filters to the clean water reservoir), water can gravitate up to the reservoir, but the inflow to the reservoir will not be sufficient for the demand of water. The distribution pumps deliver water from the CWR to Upper Mnyameni reservoir and Lower Mnyameni reservoir. If the pump that supplies Upper Mnyameni's reservoir should fail, then the pump that supplies Lower Mnyameni can be switched to pump to Upper Mnyameni and vice versa. Amatola Water tries to use identical pumps in their treatment plants to make it easy to replace a broken pump if necessary. If the pumps break during periods when the treatment plant is unmanned, it can be observed from the control room at the Sandile water treatment plant. But they can only see if the pumps are out of order, and not switch a pump to deliver water for another village. This can only be made manually at the treatment plant in Upper Mnyameni.

### **3.2 Risk estimation and presentation of risks with risk matrices**

The possibility that the different risk scenarios will occur and the consequence of the scenarios have been ranked on a scale from one to five by experts at Amatola Water. The consequences of the scenarios have been ranked with respect to health consequences (*Risk Matrix 1*, Figure 12) and number of people affected (*Risk Matrix 2*, Figure 13). The two risk matrices have been weighed and merged to a total risk matrix (*Risk Matrix 3*, Figure 14).

The matrices are divided into three zones. The green field shows risks that are considered to be acceptable and the red field indicates that the risks are unacceptable and could not be tolerated, i.e. must be reduced immediately. The yellow field indicates the ALARP (As Low As Reasonably Practicable) Region. That means that the risk can be accepted if it is economically and technically unreasonable to reduce it.

Risk estimation has also been performed using the South African Evaluation Guidelines. The evaluation guidelines divide the drinking water supply into risk evaluation into five different categories. Each category is ranked into three different risk fields and from these a weighting is performed to get the total risk of the system.

### 3.2.1 Risk Matrix 1 - Health effects

The matrix (Figure 12) shows that the most serious problem for water quality is at the taps and the handling of the water. The risk scenarios that concern the water treatment processes are considered fairly low. The reason for this is that the raw water is fairly clean and could be used untreated. There are no known major problems with the treatment process, but the risk of problems with for example poor working filters or dosage of chemicals must be calculated for periods when the plant is unmanned for long time. In terms of quantity, the major risks have to do with the pumps. While both pumps are electrical and no back-up power supply is available, longer power failures always lead to lack of water for the consumers. The following scenarios fall into the yellow or red zone:

- Scenario 2: Contaminated taps due to animals scratching against them.
- Scenario 3: Inadequate hygiene due to low water availability at homes.
- Scenario 5: Poor storage of water.
- Scenario 6: Lack of water leading to use of untreated water.

	Little or no health risk	Minor health risk	Considerable health risk	Potential for major health risk	Major health risk (severe illness and death)
Frequent			2, 5		
Occasional		6			
Possible					
Rare				3	
Has not occurred	1, 4, 9	7, 8, 10	11		

Figure 12. Risk Matrix 1. Risk matrix for the water supply in Upper and Lower Mnyameni with health consequences.

### 3.2.2 Risk Matrix 2 - Number of people affected

The possible hazardous events have also been arranged in matrix regarding the number of people affected by a certain hazardous event (Figure 13). That matrix shows the possibility of the event occurring compared to how many people that would be affected. This matrix is also divided in to three zones in the same way as for the quality risk matrix but the zones look a bit different. For example, the red zone only includes three fields. The reason for this is that the population is too small to make the risks unacceptably high just by quantity matter. Generally the hazardous event will affect the whole population in the villages, approximately 2500 people. The scenarios that fall into the yellow or red zones are the same as in Risk Matrix 1 (Figure 12). The green field in risk matrix has been extended for the likelihood scales of the categories *Has not occurred* and *Rare*. The decision to enlarge the green field was made by reasoning that an event that never has occurred is more severe if it is classified as *major health risk* than an event of low severity that affects a large number of people. How the fields of the risk matrix are chosen may vary.

	1-9 People affected	10-29 people affected	30-249 People affected	250-1250 People affected	1250 < People affected
Frequent	5	2			
Occasional					6
Possible					
Rare					3
Has not occurred				11	1, 4, 7, 8, 9, 10

Figure 13. Risk Matrix 2 for the water supply in Upper and Lower Mnyamemi with number of people affected.

### 3.2.3 Risk Matrix 3 - Total risk matrix

In order to combine the two factors *health* and *number of people affected* of the two different matrices the two factors have been weighted (Table 3) in order to create a third “total” risk matrix (Figure 14). Decision was taken to make the health aspect more important than the number of people affected. The health consequences are weighted as three times as important as the number of people affected by an incident. It is reasonable to think that severe health consequences for a few people result in larger consequences than a minor discomfort for many people. The consequence classes are numbered from 1-5 and the weighting was carried out according to the formula below (Table 3).

$$\text{Total consequence} = [ (\text{Health effects} \times 3) + (\text{Number of people} \times 1) ] / 4$$

Table 3. Scenario weighting.

Scenario	Health effects	Number of people	Total
1	0.75*1 = 0.75	0.25*5 = 1.25	2.00
2	0.75*3 = 2.25	0.25*2 = 0.50	2.75
3	0.75*4 = 3.00	0.25*5 = 1.25	4.25
4	0.75*1 = 0.75	0.25*5 = 1.25	2.00
5	0.75*3 = 2.25	0.25*1 = 0.25	2.50
6	0.75*2 = 1.50	0.25*5 = 1.25	2.75
7	0.75*2 = 1.50	0.25*5 = 1.25	2.75
8	0.75*2 = 1.50	0.25*5 = 1.25	2.75
9	0.75*1 = 0.75	0.25*5 = 1.25	2.00
10	0.75*2 = 1.50	0.25*5 = 1.25	2.75
11	0.75*3 = 2.25	0.25*4 = 1.00	3.25

	Little or no consequence	Minor consequence	Considerable consequence	Major consequence	Catastrophic consequence
Frequent			2,5		
Occasional		6			
Possible					
Rare				3	
Has not occurred		1,4,9	7,8,10, 11		

Figure 14. Risk matrix 3 estimates risks for water supply in Upper and Lower Mnyameni.

### 3.3 Risk estimation with South African Risk Evaluation Guidelines

A risk evaluation guideline has been made for water and wastewater systems in South Africa. The purpose of the guideline is to come up with a nationally consistent method for risk evaluation in South Africa (Water Research Commission, 2007).

It is emphasized in the risk evaluation guidelines that it is only a *guideline* and therefore it does not cover every single situation. If needed the risk level can be modified/adapted due to circumstances at the particular system.

In the guidelines it is recommended that the first a rapid assessment based on the material available takes place. After the rapid assessment a more detailed assessment shall take place to determine the potential risk of the system, which results in a risk level. Whenever the system changes or there is additional information the guideline should be consulted again and the risk level be revised.

A national evaluation is to take place annually to control the progress of increased water safety. The regional capital manager is responsible for the risk evaluation, but the actual risk evaluation is carried out by a regional technical expert who might collaborate with other experts.

The outcome of the total risk, or overall risk, will be one of the three *levels* : low, medium or high. When performing the risk ranking the system is divided into five subsystems, or *categories*, each ranked from 1-10 individually. The categories are:

- a) Water source
- b) Design
- c) Operation
- d) Reporting
- e) Operator

After ranking of each risk all categories are weighted according to the assessment of its importance to give the overall risk:

- a) Water source 10 %
- b) Design 30 %
- c) Operation 30 %
- d) Reporting 10 %
- e) Operator 20 %

*Overall risk* = (0.1 x Water source risk) + (0.3 x Design risk) + (0.3 x Operation risk) + (0.1 x Reporting risk) + (0.2 x Operator risk)

*The low risk level (1-4)* is systems with minor deficiencies and the water quality mainly meet the requirements of SA quality drinking water guidelines.

*The Medium Risk level (5-7)* does not require immediate action, but measures should to avoid future problems.

*The high risk level (8-10)* needs immediate attention and corrective actions should be taken. In this risk level region it is a combination of major deficiencies that threatens safe drinking water.

Risks are ranked on the following pages.

**Category One: Water Source**

The risk evaluation guidelines assess both quantity and quality of the raw water source. When weighting the different categories the raw water source has been given a fairly light impact on the total risk. The reason is that if the system is designed to remove the risk from the source the risk for the whole treatment system is considered to be low. If the total value is greater than 10 it should be set to 10.

*Table 4. Water source risk ranking.*

CRITERIA	REASONING	RISK RANKING
Starting value	Surface water source should be given the value 5.	5
1. Availability of Water	There is no lack of water.	0
2. Vulnerability	Minor or low risk probabilities of contamination.	1
3. Deterioration/Variability of water quality	Quality of source water has not deteriorated during the last years.	0
4. Source Water/Watershead/Wellhead protection plan	The community has no such plan.	2
<b>Summarized value</b>		<b>8</b>

**Comment:** The total value cannot exceed 10 the summarized value 8 for the table above is high. This part of the whole would be classified as *high risk*. Giving a starting value of 5 for the Upper Mnyameni Dam is a high value and somewhat unfair. As described above the dam is relatively isolated and should perhaps be given a lower starting value. Due to the weighting of the categories (10% for raw water source) the high number makes a smaller impact on the total value. For a raw water source that is isolated and considered as safe the Upper Mnyameni Dam it would be more satisfying to have a lower starting value than 5.

#### Category Two: *Design Risk*

The category *Design Risk* is about how well the system works if it is operated and maintained perfectly. It covers facility, equipment, treatment processes and distribution/collection system. If the total value is greater than 10 it should be set to 10.

Table 5. Design risk ranking.

CRITERIA	REASONING	RISK RANKING
Starting value	All systems start with the value 1.	1
1. Applicable water quality guidelines	The water meets the guidelines and legislation.	0
2. Applicable Building/System Design Standards	System meets standards.	0
3. Multiple Treatment Processes Appropriate for Source Water Quality	The system has multiple treatment steps that meet quality demands.	0
4. Waste Management	There is no management of waste created by the treatment process taking into consideration in the design.	1
5. Capacity	The system has exceeded 75% of its capacity.	1
6. Flexibility	The system is assessed to be flexible.	0
7. System reliability	There is no extra power supply.	3
<b>Summarized value</b>		<b>6</b>

**Comment:** The waste/sludge from the backwashing of the pressure filters is let out at the WTP. The waste from the treatment plant is very small. There is no waste management for the latrines at homes; the impact of this is not known, experts at Amatola Water says this has no impact on the water quality at the end-user. The summarized value 6 falls under the category *medium risk*.

Category Three: *Operation Risk*

The category *Operation Risk* deals with the procedures, plans and maintenance of the WTP and not the operator's level of education/certification.



Table 6. Operation risk ranking.

CRITERIA	REASONING	RISK RANKING
Starting value	All systems start with the value 1.	1
1. Applicable Legislation/ Guidelines	The treated water meets the guidelines.	0
2. Operation and Maintenance Procedures	An approved O & M manual is being used.	0
3. Emergency Response Plan	At the time of the case study the ERP was not yet implemented	2
4. General maintenance	Maintenance is being well performed.	0
<b>Summarized value</b>		<b>3</b>

**Comment:** The operation risk would be classified as a *low risk*. The only lack of the operation risk is that there exists no Emergency Response Plan (ERP). An ERP will be implemented. There is no information in the Risk Evaluation Guidelines about what an ERP contains. The overall operation risk is low according to the risk estimation for this part and it is considered to be a reasonable estimation.

#### Category Four: Reporting Risk

The *Reporting Risk* chapter evaluates how data is recorded and if required reports are provided. The adequacy and the number of reports should be compared to legislation and standards.

Table 7. Reporting risk ranking.

CRITERIA	REASONING	RISK RANKING
Starting value	The starting value in this category is zero.	0
1. Consistent records	Operator has consistently taken appropriate records and provided appropriate reports as required throughout the year.	1 (1-4)
2. Inconsistent records	-	(5-7)
3. Improper records	-	(8-10)
<b>Summarized value</b>		<b>1</b>

**Comment:** Records of chlorine, pH and turbidity has consistently been measured. Other physical, chemical and microbiological parameters are measured less frequently. The figures in the parenthesis are the possible risk ranking numbers. The reporting has been complete and the reporting risk has been ranked as low as possible.

### Category Five: *Operator Risk*

The category *Operator Risk* deals with the level of training and certification of the operator. How the WTP is actually managed has already been evaluated by *Operation Risk* and *Reporting Risk* category.

Table 8. *Operator risk ranking.*

CRITERIA	REASONING	RISK RANKING
Starting value	The starting value in this category is zero.	0
1. Fully certified	Primary operator certified to level of system	(2)
2. Certified-1 level	Primary operator certified but to one level below of system	4
3. Certified-2 levels	Primary operator certified but to two levels below of system	(6)
4. Certified-3 levels	Primary operator certified but to three levels below of system	(7)
5. Trained 2+ years	Systems primary operator is uncertified but trained and has 2 years experience.	(7)
6. Trained 2- years	Systems primary operator is uncertified but trained and has less than 2 years experience.	(8)
7. Trained 5+ years	Systems primary operator is uncertified but trained and has 5 years experience.	(9)
8. Trained 5- years	Systems primary operator is uncertified and untrained and has less than 5 years experience	(10)
9. Supervision (Additional)	Primary operator is supervised or otherwise has access to an operator fully trained to level of system	(-1)
10. Back-up operator (Additional)	1. Operator is certified	(-2)
	2. Uncertified back-up operator	-1
	3. Operator is untrained or if there is no back-up operator	(0)
4. Enrolled in training (Additional)		(1)
<b>Summarized value</b>		<b>3</b>

**Comment:** The primary operator is certified-1 level and there is an uncertified back-up operator, which makes the operator risk low risk (4-1=3). The figures in the parenthesis are the possible ranking numbers. To give the operator risk a low risk value seems reasonable due to the relatively high education of the operator and that there is a back-up operator. It is also possible for the operators to contact staff at another plant if problem should occur at Upper Mnyameni WTP, which is an extra safety, though it is not considered in the South African Evaluation Guidelines.

### The overall risk

The five categories are weighted and presented in Table 9.

Table 9. Summarize of the five categories to the total risk.

Category	Value	Weighting factor	Weighted value
Water Source	8	0.10	0.80
Design	6	0.30	1.80
Operation	3	0.30	0.90
Reporting	1	0.10	0.10
Operator	3	0.20	0.60
<b>Total</b>			<b>4.20</b>

The overall risk number is 4.20, as shown in Table 9. If the value is rounded off to 4 the overall risk would be categorized as a low risk, on the edge to be a medium risk. The highest scores come from water source and design risk.

As mentioned above, the high risk for the water source does not reflect the risk compared with a large number of surface water sources. It would be reasonable to make the possible range of starting value for different surface waters. For the design risk the lack of extra power supply makes the higher risk in this scenario more justified. A category that would be suitable to add is the condition at the consumer, i.e. if there are taps in all households.

### 3.4 Sensitivity analysis

There are several uncertainties for the input information. Upper Mnyameni is a small village in an underdeveloped country and the information about the system is limited. The lack of information, e.g. pipe information, number of taps, and number of people in the villages leads to more reliability on the experts. For a system that is not very well documented it also requires a more thorough field study, though a lot of information will still be missing. Likelihood, health effects and number of people affected by a certain scenario will always be difficult to estimate. The experts at Amatola Water had long experience in the field of water engineering and thorough knowledge about small drinking water systems in rural areas, which make the reliability of the experts' estimations greater. Communication with local people can also lead to uncertainties due to lack of language skills or misunderstanding in other ways.



# 4 Risk evaluation

## 4.1 Risk tolerability

There is no single way that the zones of the risk matrix must be put and it is important to consider and motivate how the fields are chosen. The fields of the risk matrices were chosen differently depending on what the different consequences were. Health effects for one individual, presented in *Risk Matrix 1*, were considered most severe and therefore the red field is largest in this matrix. *Risk Matrix 2* considered the possible number of people being affected by an event and was given larger green zone and smaller red zone. The total risk matrix, *Risk Matrix 3*, was given the same zones as the risk matrix that considers health effects.

Other factors that could affect the way the zones are chosen could be if the system studied is a low or high income community or the size of the community. A poor rural village might not have the same possibility to take the same safety measure as a rich large city, even though the goal should be to provide safe drinking water to all individuals. A low income society is more likely to also consider about other measures that can improve the life quality of the society.

## 4.2 Risk reduction options

This section describes what measures can be taken to decrease the risk of the different scenarios. The risk matrix in Figure 15 shows how the risks move in the matrix when measures are taken. The scenarios that fall under the green field does not need any measures and will thus not be described in this section.

	Little or no consequence	Minor consequence	Considerable consequence	Major consequence	Catastrophic consequence
Frequent			2 5		
Occasional		6			
Possible					
Rare			2	3	
Extremely unlikely with proper measures		6	5	3	

Figure 15. Risk matrix that shows how the hazardous events move after risk reduction measures have taken place.

**Scenario 2: Contaminated taps caused by animals leaning against the taps. Contamination may spread when people, especially children drink from taps.**

This hazardous event is in the red field in Risk Matrix 3 with ALARP zones. That means the risk is not acceptable and should be reduced as soon as possible. The best thing would be to make household connections for all the households in the villages. This is a long term ambition and will be an extensive project that will require large investments. It must also be taken into consideration that household connections probably will increase the water demand. A more simple measure would be to add some protection for the taps, e.g. fences, etc to prohibit that animals can come in contact with the taps.

**Scenario 3: Few taps make water accessibility low (one tap per 5 up to 20 houses and distances up to 200 meter to the nearest tap), which might lead to inadequate hygiene. For example: improper washing after using latrines which might cause bacterial spreading.**

This risk scenario falls into the yellow zone in Risk Matrix 3 and should then be prevented if it is reasonable. This risk will be minimized if all the villagers get household connections, which is the long term ambition for the water supply in South Africa.

**Scenario 5: Poor storage of water. For example storage in open buckets or dirty bottles.**

This risk scenario falls into the red zone in Risk Matrix 3 and needs to be prevented. This risk will be minimized if all the villagers get household connections, which is the long term ambition in South Africa. It can also be

reduced if people get information on how to handle and store their water in a hygienic way.

**Scenario 6: Long-time power failure or other incident leading to lack of water. People might use the untreated water at Mnyameni River instead (quality related problem).**

This risk scenario falls into the yellow zone in Risk Matrix 3 and should therefore be prevented if measures are reasonable. As it would need major upgrades at the power supply system to prevent the occurrence of long time power failures it would take major large scale actions and it would fall outside feasible measures for this study. It is also difficult to reduce the time it takes to restore power back as these failures are often a result of storms which also affect access to the villages. A power generator at the WTP is the only reasonable short-term option in order to ensure enough drinking water.





# 5 Discussion and conclusions

## 5.1 Method evaluation

Two types of risk analysis have been performed. The first risk analysis was performed by risk ranking of likelihood and consequences and presentation of risks with risk matrices. The second risk analysis was performed by using South African Risk Evaluation Guidelines. TECHNEAU Hazard Data Base was used as hazard identification for both methods.

The hazardous events that are analysed in the case study are developed from the examples in the TECHNEAU Hazard Data Base. Even though THDB is developed primarily for urban communities in developed areas, it is also applicable in rural communities such as Upper and Lower Mnyameni. THDB was found to be a useful and extensive tool for identifying hazards.

Ranking consequences can be difficult due to that a consequence can be hard to define. It can e.g. include the number of people affected and the severity of a certain event for one individual. The risk matrices were found to be a useful tool for presentation of risks.

When using South African Evaluation Guidelines the outcome might be misleading. An example is the assessment gave a high risk of the water source. If some adjustments are made in the South African Risk Evaluation Guidelines it might become a useful and efficient tool for risk assessment.

A method evaluation is presented in Table 10.

Table 10. Summary of the method evaluation by means of general criteria.

Criteria	Low	Medium	High
<b>Resources needed</b>			
Required level of expertise needed		X	
Time required for analysis		X	
Required level of data details needed		X	
<b>Method properties</b>			
Ability to consider a source-to-tap approach			X
Ability to include water quantity aspects	X		
Ability to consider water quality aspects		X	
Ability to consider interactions between events, i.e. chains of events	X		
Ability to acknowledge system structure/design		X	
Ability to consider uncertainties of e.g. probabilities	X		
Ability to consider/model risk reduction options			X
Ability to be integrated in the water company management/maintenance routines		X	
Updating possibilities, i.e. update when new information becomes available		X	
<b>Results</b>			
Ability to provide understandable results to the specific end-user			X
Ability to provide input data to be used in further studies, e.g. more detailed risk analysis		X	

## 5.2 Lessons learned

The importance of the following cannot be underestimated:

- Gathering of as much system data as possible to be able to identify risks.
- Taking notes while meeting with experts and not only write down a risk ranking number. This will simplify the further work if something needs to be revised and further discussed with experts.
- It is likely that there are no set of rules how to choose the different zones in risk matrices or the categories on the risk matrix axis. It is important to discuss and reflect on what is reasonable and to motivate the choices made.

## 5.3 Conclusion

Risk estimation with risk matrices is a useful and efficient tool. It is easy to understand and present data. When choosing what consequences are of importance it is vital to think it through thoroughly. For this report it was chosen to use *health* and *number of people affected* by a certain hazardous event as consequence factors.

The major risks were found at the water taps (most households do not have taps), and from insufficient storage of water, inadequate hygiene due to lack of easily accessible taps and for the lack of power-supply. Suggested risk reduction options were found to reduce the risks significantly.

Of the two estimation methods the risk matrices were found to be most useful for Upper Mnyameni water treatment plant. The South African Evaluation Guidelines were found to be less useful, mainly due to the lack of detail when ranking the risk for the raw water source. We would also recommend that another category, one at the end of the supply system (at the consumer), would be added to not forget this important aspect.

## 6 References

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