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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Framework for Drinking-Water Safety in Saint Lucia Health Based Targets

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This paper is part of a larger project in the Caribbean looking at the drinking-water supply provision for a community in Saint Lucia using the Water Safety Plan approach. Quantitative Microbial Risk Assessment (QMRA) was used to assess waterborne pathogen exposure in the community of Micoud and the potential for reduction of exposure by implementation of the Water Safety Plan approach. The QMRA for Micoud illustrates that the Water Safety Plan has the potential to significantly reduce the burden of disease within five years. This provisional QMRA was based solely on hazard assessment and review of available literature and is the first step in a cycle of setting goals and identifying gaps in data to feed back into the model increasing its accuracy in order that it may used as a tool for decision making and prioritisation of improvements for sustainable drinking-water supply.

Introduction

This paper is part of a larger project in the Caribbean looking at drinking-water supply provision for a community in Saint Lucia using the Water Safety Plan approach (McKie A et al., 2006). Quantitative Microbial Risk Assessment (QMRA) was used to assess waterborne pathogen exposure to the community of Micoud. QMRA is a science-based and transparent tool (Medema G and Smeets P, 2004) to prioritise risks and set health based targets as recommended in the drinking-water framework in the new Guidelines for Drinking-water Quality (WHO, 2004). In order to objectively compare different water-related hazards and their different health outcomes, DALYs (Disability-adjusted life-years) have been used extensively to evaluate public health priorities and to assess the disease burden associated with environmental exposures (WHO, 2004). Much of the work described here for Saint Lucia is theoretical as there is little data necessitating assumptions about pathogen exposure and reduction based on the literature available and the system assessment described elsewhere (McKie A et al., 2006). QMRA was used to establish provisional health based targets for the water safety plan.

Methodology

Data and information collection methods are devised elsewhere (McKie A et al., 2006). The system assessment was evaluated using published data on pathogen reduction and water treatment (WHO, 2004) to give preliminary quantification of risk from waterborne pathogen exposure. The simplified QMRA was based on Campylobacter as the reference pathogen which has been used extensively in previous DALYs assessments (Black R et al., 1988; Medema et al., 1996) providing data of Campylobacter exposure and infectivity for further work carried out here. Transmission pathways were identified from the system assessment as were treatment barriers. Baseline and maximum removal for each specific treatment process was extracted from the guidelines (WHO, 2004) and estimates used to assess the operational performance of the water supply system. The Beta-Poisson model was used to assess the dose-response relationship of Campylobacter and to recognise that the community may be frequently exposed to multiple sources of the pathogen; a risk of infection going to illness has been reduced to 10%. For a healthy population in North America (Black R et al., 1988) risk of illness resulting from infection with Campylobacter was 22%. The level of exposure to Campylobacter in Saint Lucia is likely to be much higher resulting in greater immunity hence the lower risk value of 10% has been used. To assess potential burden of disease benefits from implementation of the Water Safety Plan approach, pathogen concentrations were adjusted for each improvement in treatment efficiency. A similar methodology conducted for viruses and parasites (but not conducted here) would ensure that the burden of disease as a result of drinking-water does not shift away from waterborne bacteria to predominantly viruses and parasites if they have not been accounted for in the scaling-up of treatment facilities.

Calculation of DALYs

1. Estimated concentration of *Campylobacter* in raw water.
2. Calculation of % pathogen removal/deactivation.
3. Concentration of organisms per litre after treatment
4. Dose-response (r) relationship based on the Beta-Poisson model: $r = (1 + dose/B)^{-a}$
   where B = 7.59 and a = 0.145 (constants as per (Medema et al., 1996)) (1)

5. Risk of Infection per day: $P\neg_{inf,d} = 1 - r$ (2)
6. Risk of infection per year: $P_{inf,y} = P\neg_{inf,d} \times 365$ (3)
7. Risk of illness given infection: 0.1 (constant)
8. Risk of illness: $P_{ill} = P_{inf,y} \times 0.1$ (4)
9. Disease burden per case (db):
   DALYs per case 4.6×10^{-3} for *Campylobacter* (constant as per (WHO, 2004))
10. Disease burden per population (DB):
   DALYs per year $P_{ill} \times db$ (5)

Results
Health and surveillance
Health surveillance data for Saint Lucia is limited. The Country Health Profile for Saint Lucia (PAHO, 2001) concluded 'major health problems in children include diarrhoeal disease with 8.7% of adult deaths attributable to disease of the digestive system.' Diarrhoeal infection epidemics occur every two years, with children under 5 accounting for 50% of cases. There is some public health surveillance conducted in Saint Lucia however lack of resources at the Department of health (Gabriel W, 2005) mean that only a proportion of non-communicable diseases are recorded. In 2003 water related diseases in Saint Lucia were 72% of the total communicable diseases recorded (1.89% of the total population for Saint Lucia were affected) of which 94% was gastroenteritis, over a third of cases being children under 5 (Saint Lucia Government Statistics Department, 2006). The nurse (Duplessi, 2005) responsible for health care in Micoud confirmed that there are regular outbreaks of eye infections and also Trichuris Trichiura, which is transmitted through a faecal-oral route (Narain K et al., 2000).

Assessment and assumptions of environmental exposure
Water is abstracted, treated and distributed by the Water & Sewerage Corporation (WASCO). The source water for Micoud is the River Mahaut, which is located on a private estate and therefore not accessible for survey. Saint Lucia is a tropical island and subject to heavy and regular rainfall for approximately six months of every year. There is human and animal activity in the catchment (Martia J, 2005) although it is not known to what extent. Two raw water samples (out of two) carried out by WASCO tested positive for faecal coliforms, total coliforms and faecal streptococci (WASCO, 2004). The WHO guidelines (WHO, 2004) list impacted rivers and streams as carrying an enteric pathogen load of 90 to 2500 organisms per litre. The potential hazard from high concentrations of pathogens, was indicated by high raw water turbidity exceeding 500NTU (Martia J, 2005) and surface run-off is likely to deposit any waste in the catchment area into the river. This risk is heightened by the absence of an operator outside of working hours to turn off pumps and divert highly contaminated water so it does not enter the treatment works. River use upstream of the intake is unknown so other sources of microbial contamination other than during rainfall are unknown.

Barriers to hazards at the Micoud treatment works include; settlement in tanks which is reported as achieving a baseline pathogen removal of 30% (WHO, 2004). However this is with the addition of a coagulant to assist settlement (LeChavallier M and Au K, 2004) and in the absence of a chemical coagulant removal of microbes is low because sedimentation velocities are low (Medema G et al., 1998). The settlement tank is small (approximately 1.5 m x 0.4m), there are no cleaning procedures in place and no baffles are present suggesting a likelihood of short-circuiting (Fisher, 1997) so a very low removal reduction percentage of 5% has been estimated.

The slow sand filters (SSF) do not contain sand and have not done so for some time (Martia J, 2005) thus it is presumed that turbidity removal is negligible. Chlorination is effective by inactivating most of bacteria and viruses (WHO, 2004) however high turbidity during and after rainfall can exert high chlorine demand and protect pathogens from the effects of disinfectant. Increased resistance to disinfection may result from attachment or association of microorganisms to various particulate surfaces (LeChavallier M and Au K, 2004), including particles that cause turbidity (LeChavallier M et al., 1981) (Ridgway H and Olson B, 1982). Studies carried out in America (LeChavallier M et al., 1981) show that in water of 13NTU pathogen concentration was reduced to only 20% of the initial count by disinfection. Given that this paper indicates that the relationship between turbidity and chlorination disinfection efficiency is negative and linear, it may be estimated that there is a 1.67% decrease in efficiency with an increase in turbidity of 1NTU. Based on this reasoning if disinfection is close to 100% efficient in water qualities of less than 1NTU, disinfection efficiency in a water quality of 50NTU may only be 16.5%. However, water quality of 50NTU is unlikely to be persistent in all seasons and is more likely to be around 10NTU in the dry season, where disinfection efficiency is estimated to be approximately 83%. Given the evidence of water quality and efficiency of disinfection it has been estimated that in the worst case scenario of >50NTU disinfection will only be approximately 15% efficient. Chlorine is dosed to have 1.5mg/l residual as the treated water leaves the plant (Martia J, 2005) but often arrives at the tap with little or no residual chlorine content indicating that there may be organic matter and biofilms within the network. However the majority of chlorine contact time is outside the treatment plant in the storage tank so without further testing is it not possible to establish if the decay in chlorine residual is due to insufficient preliminary dosing or the poorly maintained distribution system.

The extensive nature of the distribution system, with many kilometres of pipe, cross-connections, storage tanks and the potential for tampering and vandalism provides many opportunities for contamination (LeChavallier M and Au K, 2004). Studies conducted globally show that between 11 and 37% of reported waterborne disease outbreaks were attributable to contamination of the distribution system

(Craun GF, 1986); (Craun GF and Calderon RL, 1999); (Hunter P, 1997); (Stenstrom T, 1994). The likelihood of recontamination and an environment conducive to bacterial growth is dependent on a number of factors. Lack of appropriate treatment resulting in poor removal and deactivation of pathogens that may be the source of an important level of endemic disease in the population (Payment P, 1999). Poor removal of organic material that provide nutrients for the multiplication of bacteria (Payment P and Robertson W, 2004) and temperatures that facilitate growth. Biofilms, sediments and corrosion products may also harbour pathogenic microorganisms introduced through inefficient treatment or breaches of the integrity of the distribution system, these could be released during repairs and cleaning operations, or by erosion caused by sudden changes in flow patterns. (LeChavallier M and Au K, 2004; LeChavallier M et al, 1999). Lack of hygiene and safe sanitation facilities in the community, particularly in areas where faecal material builds up close to the pipe and where surface or soil water would be likely to become contaminated (Payment P and Robertson W, 2004) providing the opportunity for pathogens to enter the network. A poorly maintained, leaking network with intermittent supply allowing ingress of pathogens and organic materials (Kirmeyer G, 2001) during periods of negative pressure. The network in Micoud is subject to all four of the factors above creating an ideal environment for recontamination, multiplication of bacteria and therefore a it has been assumed that pathogen concentrations may increase by up to 10% in the WASCO network.

Household distribution systems will encounter similar problems however the extent of exposure will be dependent on the length of pipe exposed i.e. the opportunity for ingress, the maintenance of the pipe and the proximity to sources of contamination. Given that household distribution pipes will be shorter but that consumers may have little knowledge and ability to maintain them appropriately and that most household sewage is in the form of localised soak-away pits, the likelihood of recontamination may be as much as for the WASCO distribution network, so a further 10% increase in pathogen concentration has been assumed.

Although the treatment facilities to some extent reduce exposure to Campylobacter and other pathogens, water use practices and community beliefs in addition to pricing policy means that the river is used by some people as an alternative to water supply which results in higher exposure to pathogens over a longer time period.

Assumptions for treatment efficiency with implementation of the Water Safety action plan.

The following assumptions are made as an example of the possible improvement that could be achieved by adopting a basic water safety plan.

Short term actions by the operator.

These include regular clearing of intake, abstraction management, hygienic cleaning and maintenance of works. Sanitary surveys may identify other actions to reduce microbial contamination. Other responsibilities at this stage include the development of monitoring and recording procedures in addition to planning for other organizational changes and communication mechanisms in order that appropriate sustainable scaling-up decisions can be made in the future.

Abstraction management to prevent highly turbid raw water entering the works may reduce the initial pathogen concentration assuming that microbial contamination is a result of surface run-off and arising in the catchment as opposed to direct contamination to the source water. However, it is essential that sufficient quantity of water is available otherwise alternative highly contaminated water sources will be used, so it is likely that abstraction will have to continue when there is potentially high-risk to water quality but the frequency of these times may reduce, for these reasons, although source water quality abstracted may improve, the highest pathogen concentration of 2500 organisms per litre has been assumed to take account of water use during high risk events.

Appropriately maintained and cleaned settlement tanks may improve settlement but without the addition of a coagulant to assist settlement and the likely stream-lining, pathogen removal has been estimated to be approximately 10%.

Table 3.1.1: Estimated pathogen exposure of *Campylobacter* from the existing drinking-water supply at Micoud.

Process	Contamination/ Removal or Deactivation	
	Change in path. concentration (%)	Pathogen Concentration (organisms/litre)
Abstraction		2500
Settlement	-5%	2375
SSF	0%	2375
Disinfection	-15%	2019
WASCO Distrib	+10%	2221
Hsehld Distrib	+10%	2243

Table 3.3.1: Estimated pathogen exposure of *Campylobacter* from the Micoud drinking-water supply with implementation of the short-term action plan.

Process	Contamination/ Removal or Deactivation	
	Change in path. concentration (%)	Pathogen Concentration (organisms/litre)
Abstraction		2500
Settlement	-10%	2250
SSF	0%	2375
Disinfection	-75%	594
WASCO Distrib	+10%	650
Hsehld Distrib	+10%	715

Abstraction management may reduce raw water turbidity improving disinfection efficiency. In the short-term if raw water entering the treatment works is not higher than 20NTU, after settlement, disinfection may be up to 75% efficient at deactivating pathogens however current dosing procedures may result in an insufficient chlorination for given water qualities.

At this stage there have been no planned improvements in the WASCO and household distribution networks so a 10% recontamination has been maintained respectively.

Medium term actions by water supply management

Medium term actions include developing raw water storage and the introduction of Standard Operating Procedures and inspection programs for new installations, operations, maintenance, leak detection and pipe flushing to prevent recontamination of treated water. Other responsibilities to be carried out at this stage relate to long term actions.

Raw water storage will prevent high turbidity water from entering the treatment works resulting in lower pathogen concentrations therefore initial concentration of pathogens has been assumed to be a lower figure of 1500 organisms per litre. Improved raw water quality in addition to some settlement may result in a water quality of approximately 5 to 10 NTU which will greatly improve disinfection efficiency (LeChavallier M et al., 1981) with deactivation of pathogens estimated to be more than 80% of the initial loading. Standard operating procedures for the distribution system have the potential to significantly reduce the risk of recontamination and the introduction of raw water storage may reduce the problem of intermittent supply causing negative pressure in the system. However totally preventing recontamination in the system and complete control is difficult to achieve (LeChavallier M and Au K, 2004) so assuming the development of procedures and inspection are 50% effective the increase in pathogen concentration through recontamination was set at 5% as opposed to 10% in the WASCO distribution system. Household plumbing is unlikely to be improved in the medium term so the assumption of 10% recontamination has remained unchanged.

The effect of behavior change programs are difficult to assess. It was found that there was a 28% reduction in diarrhoea from the integration of hygiene education in water projects (Fewtrell L et al., 2005) however the majority of the studies where for communities without household connections and the health assessment in most cases was conducted on children under five. As hygiene and behaviour in Micoud where not assessed as part of this study it is not evident to what extent hygiene and handling may recontaminate the drinking-water supply and it is therefore difficult to estimate the effect of interventions for the community. It is likely that hygiene and behaviour change programs will have a positive affect given the evidence to date (Fewtrell L et al., 2005) however due to a lack of any sort of data for Micoud the success of these interventions cannot be estimated.

Table 3.3.2: Estimated pathogen exposure of *Campylobacter* from the Micoud drinking-water supply with implementation of the medium-term action plan.

Process	Contamination/ Removal or Deactivation	
	Change in path. concentration (%)	Pathogen Concentration (organisms/litre)
Abstraction		1500
Settlement	-10%	1350
SSF	0%	1350
Disinfection	-80%	270
WASCO Distrib	+5%	284
Hsehld Distrib	+10%	312

Long-term institutional actions

Long term actions include improving organisational and institutional structures and the introduction of legislation and mechanisms to improve catchment protection and prevent of recontamination at household level, as well as the installation of appropriate treatment based on the analysis of records collected through the short and medium term action plan. Is has been assumed that treatment processes will be 99% efficient with the implementation of treatment upgrade to reduce turbidity to below 1NTU which will greatly improve disinfection also (99%).

The introduction of plumbing guidelines, inspection and licensing may reduce household recontamination so a 5% recontamination has been assumed however this is likely to benefit only new installations at first with existing plumbing in households being upgraded over a longer time period. It would be very difficult to assess all the sources of contamination at this stage as there are many potential routes, so it would be reasonable to address the obvious routes first and then move progressively to addressing other contamination sources.

### Quantitative microbial risk assessment

Based on the assumptions described above, the estimated pathogen exposure levels were calculated for the existing water supply arrangements and for each of the sequential improvements (short, medium and long term action plans).

Table 3.3.3: Estimated pathogen exposure of *Campylobacter* from the Micoud drinking-water supply with implementation of the long-term action plan.

Process	Contamination/ Removal or Deactivation	
	Change in path. concentration (%)	Pathogen Concentration (organisms/litre)
Abstraction		500
New Treatment	-99%	5
Disinfection	-99%	0.05
WASCO Distrib	+5%	0.053
Hsehld Distrib	+5%	0.06

Table 3.4.1: DALYs (per population per year) for *Campylobacter* due to drinking-water, before and after the implementation of the Water Safety Action Plan in Micoud.

		River water	Existing treat	Short-term	Medium-term	Long-term
Raw water quality	organisms per litre	2500	2500	2500	1500	500
reduction from treatment	percent reduction	0	2	73	79	<100
drinking water quality	organisms per litre	2500	2443	680	310	0.06
consumption of unheated drinking water	litres per day	1	1	1	1	1
exposure by drinking water	organisms per day	2500	2443	680	310	0.06
risk of infection	per day	0.568736	0.5672961	0.4797378	0.419079	0.00114
risk of infection	per year	207.5888	207.06308	175.1043	152.5987	0.4165
risk of (diarrhoeal) illness given infection		0.1	0.1	0.1	0.1	0.1
risk of (diarrhoeal) illness	per year	20.75888	20.706308	17.51043	15.25987	0.04165
disease burden (db) per case of *Campylobacter*	DALYs per case	0.0046	0.0046	0.0046	0.0046	0.0046
susceptible fraction	% of pop	100	100	100	100	100
disease burden (DB) per population	DALYs per year	0,095491	0.0952449	0.080548	0.070195	0.00019

Graph 3.4.1: DALYs (per population per year) for waterborne *Campylobacter* before and after the implementation of the Water Safety Action Plan in Micoud.

Water Safety Action Plan
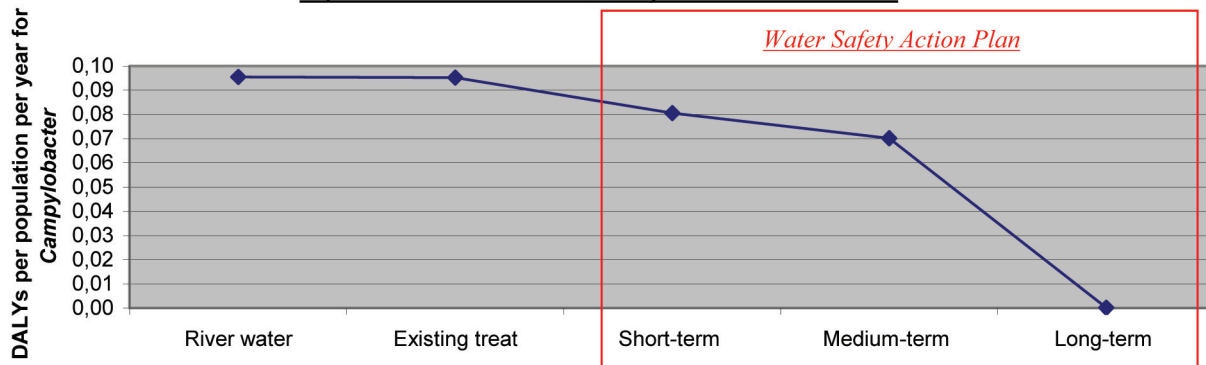
Water Quality with implementation of Water Safety Action Plan

The resultant QMRA in terms of DALYs is given in Table 3.4.1.

Discussion

The existing drinking-water management structure for Micoud results in a high risk of waterborne pathogen exposure. The Water Safety Action Plan addresses aspects of improvements for the whole management structure from catchment to consumer and identifies sequential improvement steps, some capable of implementation immediately, others requiring prior acquisition of knowledge and resources to enable development of improved infrastructure and institutional arrangements in the longer term. Short-term actions should result in immediate benefits with existing resources reducing burden of disease for Campylobacter in Micoud

from 9.5 healthy life years lost to 7.1 healthy life years lost in a population of 100 over one year which represents a 15% reduction in the overall burden of disease attributable to Campylobacter from drinking-water sources. Medium term actions build on these improvements and should be achievable within two years reducing burden of disease to 7.0 healthy life years lost in a population of 100, representing a 26% reduction in the overall burden of disease attributable to Campylobacter. However it is in the long term that major benefits will be seen. Actions taken in the short and medium-term that are not immediately measurable lay the foundations for significant reduction in disease burden. The burden of the disease for Campylobacter in the long term may be as low as 0.019 as opposed to the 9.5 healthy life years lost in a population of 100 with the existing management structure,

representing a 99.8% reduction in overall burden of disease attributable to Campylobacter. The reference level of risk used by the WHO is 1 x 10-6 (WHO, 2004) that is a tolerable loss of one healthy life year due to a specific illness in a population of a million over a year. Whilst this is certainly attainable for Saint Lucia it is not a realistic health target at this point but should be achievable with the progressive assessment and improvement methodology outlined by the WSP approach.

The existing burden of disease for Campylobacter due to piped drinking-water in Micoud has been assessed as 9.5 healthy life years lost per year in a population of 100. Based on the evidence available and taking into consideration that there is very little public health surveillance in Saint Lucia, 9.5 healthy life years lost per year in a population of 100 is estimated to be a significant proportion of the total diarrhoeal disease burden. Studies conducted in the Netherlands (Havelaar A, 2004) assessed average exposure of the Dutch population for major sources of Campylobacter. Water, including recreational water for the Netherlands but which is the same source as drinking-water in some cases for Micoud, was found to be 1% of the total average exposure as opposed to 67% from direct contact, normally from animals. These percentages are unlikely to be exactly the same in Micoud however are useful for the estimation of improvements due to specific interventions in the overall public health context. Given that exposure to Campylobacter from water is 1% it can be estimated that the total burden of disease for Campylobacter from all sources is approximately 32.8 healthy life years lost in a population of 100 in a year. As a result of this actual diarrhoeal illness due to Campylobacter from water is estimated to be 27% of the total diarrhoeal illness due to Campylobacter from all sources.

Campylobacter is a major cause of diarrhoeal illness and is generally regarded as the most common bacterial cause of gastroenteritis worldwide (WHO, 2004). It is difficult to estimate the total burden of disease due to diarrhoeal illness in Micoud with the data available but based on the knowledge of incidence of Campylobacter it is likely to be a major contributor to diarrhoeal illness of which drinking-water is a significant source.

The implementation of the Water Safety Plan approach has the potential to significantly reduce incidence of diarrhoeal illness due to Campylobacter. Over the longer term which has been estimated to be approximately five years, the Water Safety Action Plan may reduce burden of disease for Micoud to an assessed 0.019 healthy life years lost in a population of a 100. Based on available evidence this constitutes an appropriate initial health target.

This case example shows that the lack of accurate specific data for QMRA should not be used as an excuse not to formulate an assessment. An assessment based on available evidence formulates a starting point in a cycle of setting goals and identifying gaps in data that need collecting in order to feed back into the model and increase its accuracy. Clearly stating assumptions indicates the accuracy and usefulness of

Table 4.1: Total DALYs (per pop per year) in Micoud due to *Campylobacter* as estimated by average exposure to sources in the Netherlands.

Source	Expo sure (cfu) *	Expo sure (%)	Exist Path Conc	DALYs per pop per year
Drinking Water	0.0015	1%	2443[†]	0,095249
Food	0.050	37%	90391	0.1248431
Direct contact	0.084	62%	163681	0.1283949
Total DALYs due to Campylobacter				0.3484871

Source: (Havelaar A, 2004)
[†]*Exposure from existing treatment of drinking-water*

the tool in decision making. Table 4.2 below gives an indication of the different levels of accuracy of the QMRA model with the ideal scenario reliable for decision making and the minimum needed useful for identifying gaps in data.

The QMRA carried out for Micoud in this paper is based on minimum data needed. Accuracy of the QMRA would be improved with the collection of more detailed data however initial calculations are useful to illustrate the potential value of applying the water safety plan approach. Monitoring water quality at four points along the system, namely source water, after treatment, at the end of the distribution lines and at the tap would give valuable information to enable the refinement of the water safety plan.

Water quality samples in Saint Lucia all comply with WHO guidelines however, samples are not collected during high risk events such as after and during rainfall. Gastroenteritis in the community is common and treatment facilities are inadequate so it is likely that a more comprehensive monitoring program would find that microbial water quality falls outside of these guidelines. The water safety plan approach takes into account that zero risk to drinking-water safety is a theoretical ideal for most water supplies and instead identifies incremental improvement steps. The QMRA used in conjunction with the system assessment outlined in the Water Safety Plan approach assesses all hazards holistically source to tap. It enables decision-makers to assess how interventions at different points in the water supply chain will deliver benefits and contribute to the over-arching goal of a safe drinking-water framework.

Conclusions

Over approximately five years, the Water Safety Action Plan may reduce burden of disease for Micoud from 9.5 healthy life years lost in to an assessed 0.019 healthy life years lost in a population of 100 which reduces the overall burden of disease due to incidence of Campylobacter from an approximated 34.8 to 25.3 healthy life years lost in a population of 100, a 27% improvement from a major source of diarrhoeal illness. Based on available evidence this appears to be an appropriate initial health target achievable through specified drinking-water interventions that may be revised annually

Table 4.2: Scenarios for the availability of data to use for QMRA

Framework	Data and information used for a Quantitative Microbial Risk Assessment.		
	Ideal	**Pragmatic**	**Minimum Needed**
Catchment	– Detailed hazard assessment of catchment, based on documented data, surveys of the source, intake and the surrounding catchment, (accounting for seasonal variations) and with detailed interviews with appropriate stakeholders. – Raw water quality monitoring – Testing and assessment of types and concentration pathogen exposure – QMRA based on known pathogen concentrations	– Detailed hazard assessment of catchment, based on documented data, surveys of the source, intake and the surrounding catchment, (accounting for seasonal variations) and with detailed interviews with appropriate stakeholders. – QMRA based on assumptions of types and concentrations of pathogens from available literature.	– Hazard assessment of catchment based on available data through documentation, interviews or surveys. – QMRA based on assumptions of types and concentrations of pathogens from available literature.
Treatment	– Detailed hazard assessment of treatment works and operational procedures through surveys, interviews with appropriate stakeholders and review of available operational performance documentation. – Water quality monitoring at key points in treatment processes – Testing and assessment of reduction in pathogen concentration for specific treatment processes. – QMRA based on known reduction of pathogen concentration.	– Detailed hazard assessment of treatment works and operational procedures through surveys, interviews with appropriate stakeholders and review of available operational performance documentation. – Water quality monitoring at end of treatment – QMRA based on assumptions of the reduction of pathogens for specific treatment processes from available literature.	– Hazard assessment of treatment works and operational procedures based on available data through documentation, interviews or surveys. – QMRA based on assumptions of the reduction of pathogens for specific treatment processes from available literature.
Distribution	– Detailed hazard assessment of distribution network, maintenance and procedures based on surveys, interviews and review of available performance documentation. – Water quality monitoring at end of water suppliers distribution lines. – Testing and assessment of pathogen exposure in the distribution network. – QMRA based on known exposure to pathogens.	– Detailed hazard assessment of distribution network, maintenance and procedures based on surveys, interviews and review of available performance documentation. – Water quality monitoring at the tap – QMRA based on assumptions of recontamination in distribution due to pathogen exposure.	– Hazard assessment of distribution network, maintenance and procedures based on available data through documentation, interviews or surveys. – QMRA based on assumptions of recontamination in distribution due to pathogen exposure.
Consumer	– Detailed hazard assessment of household distribution systems based on surveys, interviews and review of available performance documentation. – Detailed hazard assessment of drinking-water handling based on interviews and observations. – Detailed hazard assessment of water sources uses based on interviews and observations. – Water quality monitoring at tap and other water sources used. – Testing and assessment of pathogen exposure from household distribution systems, handling and alternative water sources used. – Assessment of selected indicator pathogen dose-response and risk of illness given infection relationship for the community – QMRA based on known pathogen exposure. – DALYS assessment based on known dose-response relationship and likelihood of illness given infection for the community.	– Detailed hazard assessment of household distribution systems based on surveys, interviews and review of available performance documentation. – Detailed hazard assessment of drinking-water handling based on interviews and observations. – Detailed hazard assessment of water sources uses based on interviews and observations. – Water quality monitoring at tap and other water sources used. – QMRA based on assumptions of recontamination in household distribution systems, handling and use of water sources. – DALYS assessment based on assumptions of dose-response relationship and risk of illness given infection in available literature.	– Hazard assessment of household distribution systems based on available data through documentation, interviews or surveys. – Hazard assessment of drinking-water handling based on available data. – Hazard assessment of water sources uses based on available data. – QMRA based on assumptions of recontamination in household distribution systems, handling and use of water sources. – DALYS assessment based on assumptions of dose-response relationship and risk of illness given infection in available literature.

with analysis of newly available data.

A QMRA based on the minimum data needed is the first step in a cycle of setting goals and identifying gaps in data needed in order to feed back into the model and increase its accuracy for decision making. A more accurate QMRA would give very valuable information to improve targeting of interventions in the medium term and to justify significant changes in the institutional arrangements and investment in upgraded infrastructure.

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