DEW Point
DEVELOPMENT RESOURCE CENTRE
ENVIRONMENT – WATER – SANITATION

DFID Department for International Development

# Water quality standards and microbiological contamination

## DEW Point Enquiry No. A0408

## February 2011

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| Title: | Water quality standards and microbiological contamination | |
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| Client contract No: | 06 7037 | |
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| Amendment record: | Version: | Date: |
| | Draft Final Report | 28/02/2011 |
| | Final Report | |
| Reference: | | |
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[1] Consortium comprises Harewelle International Limited, NR International, Practical Action Consulting, Cranfield University and AEA Energy and Environment

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## 1. Description of enquiry

**Introduction**

WaterAid has organizational guidelines outlining its commitments to water safety and water quality assurance in its programmes. Each WaterAid Country Programme uses these guidelines as a basis for drafting a national water quality policy which is tailored to take account of national water quality standards. The organizational guidelines state the following in relation to microbiological contamination:

*"Thermotolerant faecal coliform (TTC) bacteria occur in large quantities in human faeces and are used to indicate the presence of animal and human faecal matter in drinking-water. Where faecal matter is present there is a high-risk that pathogenic organisms, viruses and parasites will also be evident. The risk of contamination increases with the number of thermotolerant bacteria colonies detected. Thermotolerant faecal coliforms are not in themselves dangerous to health but serve as markers that faecal matter and therefore dangerous pathogens MAY be present.*

*As a general principle, projects relying on ground water extracted through tubewells via hand or mechanical pumps, or piped supplies based on protected springs, should aim for the microbiological standards set by national government. Current WHO guidelines stipulate a count of zero TTC bacteria for ingested water, but this is widely regarded as impractical for un-chlorinated community supplies in developing countries. Many people in rural areas of Europe drink water containing up to 100 TTC/100ml without ill effect. Some national standards quote a limit of 10 TTC/100ml. If the national standard is impractical, a limit of less than 10 TTC/100 ml may be attainable but, if necessary, up to 100 TTC/100ml may be tolerable."*

***Table 1 Example of risk indicated by increasing numbers of TTC bacteria per 100ml*** *[Source: Valiente & Pedley, (1 July 1997) Waterlines, Vol 16, No 1, p7]*

| *Thermotolerant coliform count per 100ml* | *Disease risk classification* |
|---|---|
| *0* | *No risk* |
| *1 – 4* | *Low risk* |
| *5 – 100* | *Intermediate risk* |
| *101 – 1000* | *High-risk* |
| *>1000* | *Very high-risk* |

*Table 1 shows an interpretation of relative disease risk levels associated with increasing numbers of TTC indicator bacteria. The South African government gives a slightly more stringent interpretation of disease risk in their national water quality guidelines (Table 2).*

***Table 2: Disease risk indicated by the presence of faecal coliform bacteria*** *[extracted from the South African Government Water Quality Guidelines 1996, 2nd edition]*

| *Faecal coliform count/100ml* | *Effects* |
|---|---|
| *Target water quality range 0* | *Negligible risk of microbial infection* |
| *0 – 10* | *Slight risk of microbial infection with continuous exposure; slight risk with occasional exposure* |
| *10 – 20* | *Risk of infectious disease transmission with continuous exposure; slight risk with occasional exposure* |

| | |
|---|---|
| *> 20* | *Significant and increasing risk of infectious disease transmission. As faecal coliform levels increase, the amount of ingested water required to cause infection decreases* |

*These tables can be used as a guide for setting microbiological standards.*

*Where hand-dug wells with windlasses and buckets are used or surface water sources have to be relied on, standards may be relaxed if it is impractical to do anything else and so long as the projects are likely to result in health benefits because they significantly increase volumes of water used for personal hygiene purposes. In such cases, the over-riding principle should be that the water quality of the 'improved' source is at least as good as, and preferably better than, the source originally used before the project was carried out.*

*Authoritative in-country advice should be sought, if it exists, and consultation with communities and partners should form a part of the process to decide on an appropriate microbiological quality standard for a particular project."*

WaterAid country programme water quality policies generally recommend adherence to national standards. There are occasions when WaterAid recommends a deviation from the national standard. The governments of some countries such as India, Burkina Faso and Bangladesh specify 0 faecal coliforms/100ml as the national standard for water supplies. They do not distinguish between treated and untreated community supplies. Where the government standard is listed as 0/100ml, most WaterAid Country Programme policies recommend a deviation to between 0 and 10 faecal coliforms /100ml. The justification for this deviation is that the WHO guidelines for drinking water quality "*recognize that in the great majority of rural water supplies, especially in developing countries, faecal contamination is widespread. Under these conditions, medium-term targets for the progressive improvement of water supplies should be set*". WEDC also make a similar recommendation.

**Questions to be answered by the consultant**

WaterAid's Internal Audit Team have asked the following questions about the risks associated with deviation from national standards:

1. *Do we have any reasonably robust way of estimating the probability of harm to service users from a 10 faecal coliforms/100 ml count? Or indeed any count between 0 and 10. (For Malawi, we would pose the same question at 50 per 100 ml and 10-50 per 100 ml).*
2. *Do we have any study linking the performance on microbiological tests on commissioning a water source to microbiological results at given periods after that date?*
3. *If we were to wish to, are we able link health outcome data to microbiological results? (The same question could be asked of non-microbiological contaminants).*
4. *We are interested in any risk exposure we incur by adopting standards on individual contaminants which are more lax than the national government's. We understand why we may wish to use different standards, and perhaps advocate for their adoption, but perhaps where we do, the compliance risk should be assessed and documented.*

We would like the consultant to address the questions above by drawing on their own knowledge of the subject and up to date supporting literature. We are seeking an external opinion on these questions so that we may obtain external validation of the position outlined in our organizational guidelines (detailed above).

For any points of clarification, the consultant should speak with Vincent Casey or Richard Carter at WaterAid.

## 2. Response on water quality standards and microbiological contamination

Four questions were posed by WaterAid to be answered by a consultant. Each is dealt with in turn.

1. *Do we have any reasonably robust way of estimating the probability of harm to service users from a 10 faecal coliforms/100 ml count? Or indeed any count between 0 and 10. (For Malawi, we would pose the same question at 50 per 100 ml and 10-50 per 100 ml).*

WaterAid's organizational guidelines for water quality testing (2008) (referred to hereafter as the Organisational Guidelines) state the following in relation to microbiological contamination:

*"Thermotolerant faecal coliform (TTC) bacteria occur in large quantities in human faeces and are used to indicate the presence of animal and human faecal matter in drinking-water. Where faecal matter is present there is a high-risk that pathogenic organisms, viruses and parasites will also be evident. The risk of contamination increases with the number of thermotolerant bacteria colonies detected. Thermotolerant faecal coliforms are not in themselves dangerous to health but serve as markers that faecal matter and therefore dangerous pathogens MAY be present.*

This statement is consistent with the rationale for the standard approach taken for water quality testing worldwide. Thermotolerant coliforms (or faecal coliforms) are one of a number of groups of faecal indicator bacteria that may be used in the microbiological testing of water. Faecal indicator bacteria (FIB) are used for water quality testing rather than specific pathogens because it is currently impractical to test for the full range of possible pathogens of faecal origin.

The numbers of thermotolerant coliforms in a water source could be related to the number of people becoming infected as a result of exposure to faecal pathogens in drinking water under certain very specific conditions. Hypothetically, if we were to take a sample of sewage from a community in which cholera is endemic, create a dilution series with sterile water (e.g. a series of bottles in which the first bottle is undiluted sewage, the second is 50% sewage, the third is 25% sewage, and so on) and then measure the numbers of thermotolerant coliforms and the numbers of cholera bacteria in each of the bottles then we could reasonably expect there to be a direct relationship between the indicator bacteria and the pathogens (assuming the bacteria are equally dispersed in the diluted samples). Logically, if we were then to expose a number of equally healthy / susceptible people to the faecal pathogens contained in our dilution series then we might expect there to be a relationship between the numbers of thermotolerant coliforms (and therefore the number of cholera bacteria) in each bottle and the probability of infection.

However, it would be unsafe to attempt to relate a probability of harm to the TTC concentration. The principal reason for this advice is that the ratio of the TTC concentration to the concentration of faecal pathogens is not fixed. Whilst the number of TTC in a gram of fresh faeces from any individual may be relatively predictable, the number and type of pathogens on a gram of faeces is not. I am not infected with cholera. Therefore there is no risk of cholera associated with my faeces – although each gram of my faeces will contain hundreds of millions of TTC. The extent of infectious gastrointestinal disease in a given community will determine the relationship between TTC concentration and pathogen concentration in that community's faeces / wastewater. So, one might expect that if one glass of drinking water was contaminated with sufficient fresh faeces (e.g. sewage) from a village in UK (where the inhabitants don't travel to low income countries) to bring the TTC concentration to say 100 cfu / 100 ml and another glass was contaminated to the same level with sewage from Nairobi, the concentration and "diversity" of gastrointestinal pathogens in the glass of water contaminated with Nairobi sewage would be much greater. Each community, neighbourhood or family group may, therefore, have its own specific relationship between the numbers of TTC bacteria and the number of faecal pathogens in its faeces / sewage. In theory if these situation-specific relationships were characterised predictions of harm would be possible using tools such as quantitative microbial risk assessment (Howard *et al*., 2006). In practice, such relationships would be very difficult to quantify due to the scientific challenges involved in generating such data experimentally and in controlling confounding factors such as other sources of faecal ingestion other than drinking water and differences in host-specific vulnerability from one community to another. I am familiar with one example of a FIB-gastro-intestinal disease relationship which was developed for assessing the risks of gastrointestinal (GI) infection associated with bathing water contaminated with faecal pollution (Kay, *et al*., (2004)). Attempts have also been made to relate the risk of disease to the TTC concentration in wastewater used for irrigating fresh produce (Blumenthal *et al.*, 2000). Nevertheless, in the absence of a such a TTC-disease relationship for each city/neighbourhood/family group it is not possible to predict the probability of harm associated with any TTC concentration.

The ratio of the concentration of TTC to the concentration of faecal pathogens may also change following the faecal contamination of a water source. Such changes further complicate any attempt to relate TTC to the probability of harm. Ideally such changes would not occur – the perfect faecal indicator would not change in respect of its numerical relationship with faecal pathogens. TTCs are not perfect in this respect. There is growing evidence that changes in the TTC:pathogen ratio can occur in certain circumstances (Field and Samadpour, 2007). One example of this phenomenon is the situation in which faecal indicator bacteria (such as TTCs) and faecal pathogens are subject to a stressor that affects the FIB more than the pathogens. This could lead to a situation in which no FIBs are detectable in a water sample (suggesting safe water) when the pathogens are still present. Rose *et al*., (1988) for example found that the faecal pathogen Cryptosporidium was not well correlated with faecal indicator bacteria (Cryptosporidium survives in the environment in the form of oocysts which allow enhanced survival against various stressors including chlorine when compared to TTC bacteria). For this reason the assumption that 0 TTC / 100 ml equates to no risk (as inferred in the Valiente and Pedley (1997) reference) may not hold true in all circumstances.

Situations also exist in which the TTC concentration may increase relative to the pathogen concentration. This phenomenon is referred to as regrowth. As previously mentioned, ideally, the ratio of FIBs to pathogens would remain constant in a water sample. Under such circumstances we would be confident that high concentrations of TTCs represent high levels of faecal contamination and therefore a greater probability of the presence of faecal pathogens and vice versa. It is now established, however, that thermotolerant coliforms may grow in water supplies under circumstances – typically where water temperatures are high (i.e. in warmer climates) and where nutrients are plentiful. Under these circumstances TTCs may grow whilst the pathogens do not. In such a situation, the quality of drinking water may appear to be worse than it actually is. Regrowth has been reported in piped water systems and in household storage vessels (WHO, 2004). Therefore there are circumstances where the statement in the Organisational Guidelines that "*the risk of* [faecal] *contamination increases with the number of thermotolerant bacteria colonies detected"* would be incorrect. TTCs are imperfect faecal indicators.

In conclusion, whilst it is theoretically possible to relate a specific concentration of TTC in a water sample to a probability of harm, in practice the situation-specific dose-response data needed to permit prediction of harm do not exist (and are not realistically likely to exist in the near future). Furthermore, there is a growing recognition of the limitations of TTCs under certain circumstances which further reduce our confidence in their significance as indicators of probability of harm.

2. *Do we have any study linking the performance on microbiological tests on commissioning a water source to microbiological results at given periods after that date?*

The sampling and testing of a source at the commissioning stage of a new water supply is to be encouraged. It seems inappropriate to provide a new source of water and not check that its quality is of an acceptable quality for that source type. Under most circumstances, and for microbiological contaminants in particular, it is not reasonable, however, to infer future water quality from measurements made at the commissioning stage. Source water quality may change with time. Depending upon the hydrogeological conditions and the characteristics of the water source engineering, groundwater is subject to temporal variability due to rainfall events. It is well established that the water quality of shallow groundwater supplies can deteriorate following heavy rainfall (Richardson *et al*., 2009). One hypothesis for this is that faecal matter on the ground surface (human faeces where open defecation occurs or animal faeces) may be washed into the water source. Water sources are expected to be vulnerable where short flow paths are available as a result of a lack of source protection (Howard *et al*., 2003). Any water supply, groundwater or surface water, may be subject to temporal variability due to the short term effects of rainfall events and the longer term effects of catchment change (e.g. changes in land use, changes in agrochemical use, changes in livestock density). Water quality in a water supply may change with time due to the development of biofilms. One-off sampling at the commissioning stage provides virtually no information about how the system will respond to weather. Repeated sampling which ensures samples are taken in dry and rainy periods is more likely to provide a better characterisation of system response to rainfall. Characterisation of longer term water quality change resulting from catchment changes, deterioration of source protection structures, and biofilm growth requires regular, long term monitoring.

3. *If we were to wish to, are we able link health outcome data to microbiological results? (The same question could be asked of non-microbiological contaminants).*

It would be highly desirable to be able to link health outcome data to the results of microbiological water quality testing data. For example it would be interesting to know if communities served with untreated but well protected water where the TTC counts are about 10 cfu / 100 ml were more prone to GI disease than communities supplied from a treated source according to the WHO guideline value of 0 TTC / 100 ml. Any attempt to relate faecal indicator bacteria data to health outcome data is likely to be thwarted however by confounding factors.

For example, if a WaterAid supported project supplies water which consistently meets the WHO guideline values for TTC to a community which previously had a water supply which suffered from significant faecal pollution there would be an understandable expectation of a positive health impact. The provision of a water supply that has no, or a very low level of, faecal contamination is a prerequisite step towards the reduction of the occurrence of GI disease in a community to an acceptable level but it not sufficient *per se*. Clean water is just one of several steps on the road towards reducing the unacceptable toll of death and ill-health experienced by low income communities around the world as a result of diarrhoeal disease. Drinking water is just one of the routes by which faecal pathogens may be transmitted to vulnerable individuals – the simple model of which is represented by the well-known F diagram. Arguably, in some circumstances, and for some members of a community, drinking water may not be the most significant route for exposure to faecal pathogens. For example in situations in which open defecation is common and hand hygiene is poor, young children are likely to be exposed to very significant amounts of faecal matter through the hand to mouth route. In such circumstances improved water quality may have little impact on exposure for these individuals.

The relative importance of different faecal-oral transmission routes has been the subject of academic debate in recent years driven, in part, by a desire to identify priority interventions which can be targeted (i.e. identification of cost effective interventions)(Curtis et al., 2000; Curtis and Cairncross, 2003; Fewtrell *et al*., 2005). It is apparent from this work that water quality interventions on their own can make a significant reduction in diarrhoeal incidence but that other improvements in peoples' environments are needed to further reduce diarrhoeal disease incidence to an acceptable level. It seems that the reductions in diarrhoeal incidence attributable to each intervention are not additive. The reasons for this do not seem to have been fully elucidated. It is likely that unless high risk practices like open defecation and failure to wash hands after defecation are eradicated, significant faecal contamination of the living and working environment, and therefore unacceptably high levels of GI disease, will persist.

In my opinion it may be more feasible to make a link between water quality data and health outcomes with chemical toxins in water, under specific circumstances. Where water is the single most important source of the toxin, as may be the case with arsenic in Bangladesh, then in theory, one would expect there to be a relationship between the mass consumed in water and the community response to that dose.

4. *We are interested in any risk exposure we incur by adopting standards on individual contaminants which are more lax than the national government's. We understand why we may wish to use different standards, and perhaps advocate for their adoption, but perhaps where we do, the compliance risk should be assessed and documented.*

Further elaboration of the concerns underlying question 4 was provided by Jon Elford of WaterAid in his email of 4th February, the key paragraphs of which are re-presented below:

***Compliance Risk***
*This is the risk that WaterAid may be deemed to be non-compliant with National law. This could be in the form of punitive or restrictive action by government bodies against WaterAid, public prosecution, or possibly a risk to WaterAid's credibility to advocate within a state where we are seen to be failing to abide by national laws. E.g. is there a risk of appearing arrogant to some audiences if we are perceived to be disregarding the decisions of a national government in favour of our own judgement?*
*Given that this risk relates to a failure to comply with standards, regardless of any evidence of harm to service users, I see this as a risk which could arise purely from the information that we have adopted a given standard. However, any detected harm to service users or, say, a contamination event, could draw attention to any failure to comply with national standards.*

***Reputational Risk***
*This is the risk that WaterAid's reputation could suffer from adopting more lenient than national standards. We run the risk of reputational damage in the UK, in other member countries, at national and regional levels in CP states. Even at the level of service delivery, we might find our work suffers if we lose the confidence of service users Again, I would have thought risks of this nature would be elevated in the instance of a contamination event, or evidence of harm to users.*

***Risk of Prosecution by Injured Parties***
*This is the risk that those harmed, who believe they have been harmed, or are acting on the behalf of others, pursue a claim in tort against us. As noted above, there could easily be non-financial impacts of such a case. And even a successful defence could be costly. I'm interested in how deviations from national standards might relate to the likelihood of being prosecuted, and the likelihood of prosecutions being successful. It would surprise me if a private prosecution could be initiated, or be successful solely on the grounds that we deviated from national standards. But if harm was believed to have been caused by our work, the relationship between our chosen standards, and national standards may well be relevant. I can see arguments about the relative benefits of larger quantities of water of a somewhat lower quality compared to smaller quantities of high quality water having a bearing here.*

As I have no legal credentials, I cannot provide meaningful advice relating to the law. Notwithstanding this, I hope the following comments in relation to question 4 and the Organisational Guidelines may be useful.

i. WaterAid should consider taking legal advice on the issue of the relationship between national standards and WaterAid standards where they are different.
ii. The wording of the Organisational Guidelines on the relationship between national standards and WaterAid "standards" might be reviewed. There might be merit in considering drawing a clearer distinction between WaterAid "standards" and national standards should they differ. One might argue that the achievement of WHO guidelines for drinking water quality should be the ultimate aim for all water supplies. Presumably, WaterAid would argue that their role in facilitating the provision of a new, untreated rainwater harvesting supply is an important step in the right direction but that such a supply cannot be realistically expected to achieve the WHO standards. Further incremental steps in water supply provision are needed for that. WaterAid's commitment seems to be a step on that road. Perhaps you should consider avoiding any inference that you are relaxing national standards or adopting lax standards.

Maybe the word "standard" should not be used? Perhaps you should refer to internal/organisational operational water quality "targets" that are interim steps on the road to meeting national standards / WHO guideline values? This is a somewhat semantic argument but you might be careful about appearing to usurp national standards.

iii. With regards to reputational risk there may be a case for defining WaterAid's policy on the provision of "safe" water supplies. Presumably WaterAid's philosophy is that it is better to provide substantial quantities of water of reasonable quality to communities at an affordable price than to meet the WHO guideline values for a smaller number of people. If all water that WaterAid was responsible for providing met WHO standards consistently then you would only improve the lives of a fraction of those you currently support. There's a trade-off between quality and quantity/convenience/affordability that is defendable. Maybe this defence should be explicitly stated in one of your higher level policy documents – then WaterAid cannot be accused of selling the idea of "clean" water to its supporters in a misleading way.

iv. An argument that WaterAid could consider using to protect itself from reputational risk would be to explicitly promote (and be able to defend) the fact that its approach to the funding/support/facilitation of appropriate water supplies in low income countries represents international best practice. This may provide a defence to claims that you have cut corners or relaxed standards. I assume that WaterAid would aspire to being at the forefront of international best practice when working with local delivery organisations to specify new water supplies in low income countries. The ability to defend such a claim through a demonstration of your organisations standard operating procedures and monitoring and verification measures would seem to be a sensible precaution.

v. WaterAid might consider adding a little more detail to the statement beneath Table 2 on page 21 of the Organisational Guidelines: *"These tables can be used as a guide for setting microbiological standards"*. I wonder how country programme staff interpret these tables. At first glance they seem quite different: the South African classification goes up to >20 TTC cfu/100ml whereas the Valiente and Pedley table goes up to >1000 TTC. What is the rationale for this? My interpretation, based on my reading of Lloyd and Helmer's work (1991), is that the classification systems have been adapted pragmatically to the prevailing conditions of specific water supplies.

vi. In Table 1 of the Organisational Guidelines (source: Valiente and Pedley, 1997), a concentration of 0 TTC /100ml is equated to "no risk". For the reasons stated in the response to question 1 this is not true in all circumstances. The wording of Table 2 is more appropriate. This is a minor/pedantic point but worth noting.

vii. The Organisational Guidelines refer to target water quality at the point of supply. I assume that a significant percentage of the water supplies that WaterAid country programmes facilitate are not piped to the home with a chlorine residual. It is known that water quality deteriorates between the point of supply (e.g. a community water point such as a handpump or tapstand) and the point of consumption in the home (Wright *et al.,* 2004). This deterioration is probably due to contact between the stored water and faecally-contaminated hands. There may also be a contribution from naturalised TTC which are harboured in surface biofilms and which may multiply in the storage vessel. The health significance of such post-supply contamination has been debated in the past although there seems to be a growing consensus that it is potentially significant. The Organisational Guidelines could refer to this phenomenon and emphasise the need for high standards of safe storage and possibly household water treatment. If ignored there is a risk that the good work done in protecting water sources may be, in part, negated by post source contamination.

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