RISK-BASED SITE-SPECIFIC RECREATIONAL WATER QUALITY GUIDELINES

B Genthe, M Claassen and M Steyn

VOLUME 1 – DESCRIPTION OF THE DECISION SUPPORT SYSTEM

WATER RESEARCH COMMISSION

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RISK-BASED SITE-SPECIFIC FRESHWATER RECREATIONAL WATER QUALITY GUIDELINES

VOLUME 1 – DESCRIPTION OF THE DECISION SUPPORT SYSTEM

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

The South African Water Quality Guidelines of 1996 are one of the most widely-used tools in water quality management in South Africa. A Department of Water and Sanitation (then Department of Water Affairs) initiative looking at a needs assessment developed a general philosophy with general specifications recommended for a decision-support system for revised water quality guidelines for South Africa. Guidelines should no longer be used simply as trigger values above which something needs to be done and below which water quality can be ignored. While the 2008 Department of Water Affairs initiative looking at a needs assessment identified the need for revision of all the 1996 South African Water Quality Guidelines and the alignment with the 1998 National Water Act, this report focuses on updating the approach to the 1996 South African Recreational Water Quality Guidelines. The 1996 guidelines were based to some extent on a risk philosophy; the updated guidelines proposed follow a risk-based approach. While the scope of the guidelines remains applicable to any inland water used for recreational purposes, an important improvement of the revised guidelines is the site-specific and user-specific nature of the guidelines, allowing greater input and management of water use. In addition, they are available primarily in a software-based decision support system.

AIMS

The general aim of this project was to develop a software-based decision support system (DSS) able to provide both generic and site-specific risk-based recreational water quality guidelines for South Africa. Specific aims were:

i. To develop an intermediate 'technology demonstrator' that demonstrates the most important features.
ii. To engage with stakeholders to elicit comment and recommendations.
iii. To maximise synergy with parallel projects on the development of water quality guidelines for other water uses.
iv. To develop a fully-functioning DSS for recreational water use.

METHODOLOGY

The project assessed advances in guideline determination, both international and local, to ensure that the guidelines were based on the latest and most appropriate science and practice. The review of the recreational water quality guidelines took into account how suitable water is for recreational water use, and expanded on the 1996 guidelines to address site and user specificity. Water quality guidelines are intended to be protective however, they may be over-protective or under-protective at sites with unique conditions. A four-class classification system based on the current Department of Water and Sanitation (DWS) practice is used to depict water quality for recreational use.

Fitness-for-use Class	Description
Ideal	A water quality that would not normally impair the fitness of the water for its intended use
Acceptable	A water quality that would exhibit only limited impairment to the fitness of the water for its intended use
Tolerable	A water quality that would exhibit increasingly unacceptable impairment to the fitness of the water for its intended use
Unacceptable	A water quality that would exhibit unacceptable impairment to the fitness of the water for its intended use

This classification system harmonised water quality with a risk-based assessment to determine fitness for use. The “Ideal” fitness for use class for recreational water use, for example, describes a class where water quality would not impair the fitness of water for its intended purpose. Both the fitness-for-use classification and the risk-based water quality assessment are represented in the DSS output screens depicting an assessment of water quality. The same colour scheme is used to depict the different fitness-for-use classes.

The Development Platform

One of the important design criteria stipulated in the project Terms of Reference, is that the Decision Support System (DSS) should make use of open source software. The DSS was created in an Excel based format using VBA macros.

Defining Risk

According to the World Health Organisation (2017), risk is the likelihood of identified hazards causing harm in exposed populations in a specified time frame, including the magnitude of that harm and their consequences. Two important characteristics of hazards are the health impacts (severity) associated with the substance and the likelihood of significant occurrence (exposure). Combined, these elements determine the risk associated with a particular hazard. Describing risk consists of answers to three questions:

i. What can happen? (i.e. what can go wrong or hazard identification?)
ii. How likely is it that that will happen?
iii. If it does happen, what are the consequences?

Decisions about defining acceptable risk and tolerable burdens of disease are complex and need to take account of the probability and severity of impact in addition to the environmental, social, cultural, economic and political dimensions that play important roles in decision-making. Despite the complexity, definitions of tolerable burdens of disease and reference levels of risk are required to provide a baseline for the development of health-based targets. Risk is an expression of the likelihood that an undesired effect may occur. The risk is dependent on an agent causing the effect (the hazard), and the subject experiencing the effect (the response).

The calculation of risk is a technical/scientific process. Mathematically, it is the product (multiplication) of the likelihood of the subject being exposed to the hazard, and the likelihood that the effect will be expressed if the subject is exposed to the hazard. However, the decision of whether a particular level of risk is acceptable or unacceptable and if it warrants an action, is a value-based decision, which belongs in the policy and management domains. This report specifically deals with the DSS. A technology demonstrator was developed while engaging with project team members of the two parallel water use projects developing guidelines for irrigation and domestic use. The general aim to develop a fully functional software-based DSS able to provide both generic and user- and site-specific risk-based recreational water quality guidelines for South Africa, was completed and is described in this report.

The DSS is a user-friendly self-contained system based on Excel macros with a manual and supporting information required to run the DSS. While the main report/manual focuses on the background information and the understanding of risk as well as the different options and how the tool look, the report provides user information to optimally run the DSS tool in Excel.

CONCLUSIONS AND RECOMMENDATIONS

Establishing the concepts to design the DSS was a large undertaking. As was experienced with the two parallel projects for domestic and irrigation use, it is anticipated that further refinement is needed for features identified during the duration of the project. To ensure uptake by water quality managers, training sessions will be needed, with additional modifications expected to be identified.

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Name	Affiliation
Dr N Kalebaila	Water Research Commission (Chairperson)
Dr J Molwantwa	Water Research Commission (former WRC Research Manager)
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Mr Pieter Viljoen	Water Resource Planning Systems, DWS
Mr Geert Grobler	Water Resource Planning Systems, DWS

Many additional international names to be included who have agreed to review the DSS:

Jamie Bartram	Editor of WHO water quality guidelines and health risk assessment guidelines
Al Dufour	US EPA and principle researcher and investigator of US recreational water quality guidelines and ingestion volumes

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CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

This Manual (Report) provides instructions on how to use the Decision Support System (DSS) developed for both generic and user- and site-specific risk-based recreational water quality guidelines for South Africa. The report/manual describes the main functions of the DSS.

The term *recreational water*, as used in these guidelines, refers to all inland fresh water resources used for recreational purposes (excluding swimming pools which are under the jurisdiction of the Department of Health)). As *recreational water* is used for a wide variety of activities, the type of quality requirements for such water represents a combination of the needs for various activities, and the variety of problems that might be encountered where water does not meet requirements.

The Decision Support System (DSS) provides potential users with a tool to evaluate water quality for different types of recreational activities. The current definition of recreational use is terms of DWS policy now extends beyond sport, leisure and tourism and includes uses such as personal or commercial activities as well as activities which contribute to the general health, well-being and skills development of individuals and society. This therefore includes social, cultural and religious uses of water resources.

1.1.1 Sources of Water

Water used for recreational purposes can originate from impoundments such as dams, from rivers and streams, or from ground water via boreholes. Recreational water in South Africa spans a wide range, including water of high quality to more polluted surface water. Both water quantity and quality may be affected by seasonal droughts or floods.

1.1.2 Water Quality Problems

Recreational water users may experience a range of impacts as a result of changes in water quality. These have been categorised as follows:

1.1.2.1 *Health impacts*

Water-borne diseases (gastroenteric diseases); skin and ear infections; carcinogenic risk

1.1.2.2 *Human safety*

Poor visibility; profuse plant growth; benthic microbial and/or algal growth

1.1.2.3 *Aesthetic impacts*

Changes in water taste, odour or colour; discolouration and staining; objectionable floating matter; nuisance plants

1.1.3 Constituents

The water quality problems and issues listed are often recognised in association with the constituents that cause them. Constituents that affect the recreational use of water are microbial, physical and chemical quality with the following parameters included:

- Microbial contamination – *E. coli*, and human pathogenic microorganisms
- Algae – *chlorophyll-a* and cyanotoxins
- pH
- Odour
- Floating matter and refuse
- Nuisance plants
- Clarity
- Chemical irritants
- Bilharzia

1.2 DETERMINING ACCEPTABLE RISK

1.2.1 What is risk?

According to the World Health Organisation (2017), risk is the likelihood of identified hazards causing harm in exposed populations in a specified time frame, including the magnitude of that harm and their consequences. Two important characteristics of hazards are the health impacts (severity) associated with the substance and the likelihood of significant occurrence (exposure). Combined, these elements determine the risk associated with a particular hazard. Describing risk consists of answers to three questions:

iv. What can happen? (i.e. what can go wrong, or hazard identification?)
v. How likely is it that it will happen?
vi. If it does happen, what are the consequences?

Decisions about defining acceptable risk and tolerable burdens of disease are complex and need to take account of the probability and severity of impact in addition to the environmental, social, cultural, economic and political dimensions that play important roles in decision-making. Despite the complexity, definitions of tolerable burdens of disease and reference levels of risk are required to provide a baseline for the development of health-based targets.

Risk is an expression of the likelihood that an undesired effect may occur. The risk is dependent on an agent causing the effect (the hazard), and the subject experiencing the effect (the response). The need to consider risk arises because of our uncertainty about exposure to the stressor and uncertainty about the subject's response to the stressor. We can use the expression of likelihood (probability) to inform our decisions. Our uncertainty can arise either through inadequate information, or because of the variable nature of the phenomena. An example of inadequate information is when it is not known if a disease vector is present in a particular area. An example of variability is the difference in susceptibility of individuals or populations to a pathogen. Both factors contribute to the uncertainty about the effect that an individual may experience.

The calculation of risk is a technical/scientific process. Mathematically, it is the product (multiplication) of the likelihood of the subject being exposed to the hazard, and the likelihood that the effect will be expressed if the subject is exposed to the hazard. However, the decision of whether a particular level of risk is acceptable or unacceptable and if it warrants an action, is a value-based decision, which belongs in the policy and management domains.

1.2.2 What is meant by 'acceptable risk'?

Risk is generally taken to be the probability of injury, disease, or death under specific circumstances (WHO, 2001). In the course of deriving risk-based guidelines, different risks are presented for different users. The subject of what constitutes an acceptable risk is an extremely complex issue and must be handled from a policy perspective. Descriptions of tolerable burdens of disease relating to water are typically expressed in terms of specific health outcomes such as maximum frequencies of diarrhoeal disease or cancer incidence. However, these descriptions do not consider the severity of the outcomes. The various hazards that may be present in water are associated with very diverse health outcomes with different impacts ranging from mild diarrhoea to potentially severe outcomes such as typhoid, paralysis or cancer. A common "metric" can be used to quantify and compare the burden of disease associated with different water-related hazards, taking into account varying probabilities, severities and duration of effects.

The metric used by the WHO to evaluate public health priorities and to assess the disease burden associated with environmental exposures is the disability-adjusted life year, or DALY. The World Health Organization has used DALYs to be able to aggregate different impacts on the quality and quantity of life and to be able to focus on outcomes and not only potential risks. DALYs can be used to define tolerable burden of disease and the related reference level of risk and therefore support public health priority setting.

Some international practices are presented in the next section. Acceptable risk is very location-specific and for this reason it plays an important role in adapting guidelines to suit local circumstances, where local stakeholder involvement is vital. This is relevant and comes into play with the Tier III guidelines.

A 10^{-5} risk of developing cancer represents 1 chance in 100,000 associated with environmental contaminants and has evolved into a target risk (Cotruvo, 1988) and is in line with WHO guidelines for drinking water quality. It is generally thought that where practical, an excess lifetime cancer risk of 10^{-5} for carcinogenic risks over a lifetime is acceptable (WHO, 1993). Similar approaches have been adopted elsewhere and for other risks.

In the UK, for example, the Health and Safety Executive (HSE) adopted levels of (un)acceptable risk based on the probability of an individual dying in any one year:

- 1 in 1000 as the 'just about tolerable risk' for any substantial category of workers for any large part of a working life.
- 1 in 10,000 as the 'maximum tolerable risk' for members of the public from any single non-nuclear plant.
- 1 in 100,000 as the 'maximum tolerable risk' for members of the public from any new nuclear power station.
- 1 in 1,000,000 as the level of 'acceptable risk' at which no further improvements in safety need to be made.

Putting the burden of chemical contamination into context, in South Africa, our current risk of developing cancer is approximately 1 in 4 (or 0.25) with international estimates of background levels of environmental contaminants contributing between 1 in 1000 and 1 in 100 of this risk (Kelly & Cardon, 1991). Even with data that is not up-to-date, a perspective of relative risk contributions is provided. Risks resulting from exposure to microbial pathogens cannot be dealt with in the same way as risks resulting from exposure to chemicals. Microbial infections may occur if people are exposed to pathogens, which may result in illness. The US EPA use Giardia as a reference organism for drinking water guidelines and require the microbial risk to be less than 1 infection per 10,000 people per year. However, the illness rates associated with their Recreational Water Quality Criteria are 32 and 36 gastro-intestinal illnesses per 1,000 primary contact users, or an average of 3.4 gastro-intestinal illnesses per 100 users (U.S. EPA, 2012). For recreational water the EU bathing water directive prescribed an acceptable risk of illness associated with bathing in surface water of 3-5%, which are similar to the US EPA (2012) recreational water quality guidelines.

1.2.3 Disability-adjusted life years (DALY) as a measure of acceptable risk

The concept of tolerable disease burden (acceptable risk) was set out in the fourth edition of the Guidelines for Drinking Water Quality or GDWQ (WHO, 2011). The guidelines defined the tolerable burden of disease as an upper limit of 10^{-6} disability-adjusted life year (DALY) per person per year. One DALY per million people a year roughly equates to one cancer death per 100 000 in a 70-year lifetime and was the benchmark often used in chemical risk assessments (WHO, 2004). This level of health burden is equivalent to a mild illness such as watery diarrhoea with a low fatality at an approximately 1 in 1000 annual risk of disease to an individual, which is equivalent to a 1 in 10 risks over a lifetime (WHO, 1996; Havelaar & Melse, 2003[i]). Although many waterborne pathogens may lead to gastroenteric symptoms, the duration and severity of illness and likelihood of long-term sequelae[1] vary between pathogens. Pathogens that lead to the greatest burden of disease should be given priority when managing water safety. Disability Adjusted Life Years (DALYs) is as a system of measurement used by the WHO to translate the disease burden to a general health burden per case of illness. It combines the burden of mortality and morbidity (non-fatal health problems) into a single number. The DALY accounts for the years lived with a disability (YLD) plus the years of life lost (YLL) due to the hazard.

The disability severity is assigned a weight ranging from zero, representing perfect health or no disability, to one, representing the most severe disability, or death. A “tolerable” risk of 10^{-6} DALY per person per year allows for the loss of 365 healthy days in a population of one million over the course of one year which is the DALY limit one excess case of cancer per 100 000 people ingesting treated drinking-water over a 70-year period. The DALY measurement system is described in greater detail in the GDWQ (WHO, 2011 & 2017). Using the same limit, in terms of DALY, but milder outcome of self-limiting diarrhoea is equal to 1 excess case of diarrhoea per 1000 population per year (1 in 1000). The DALY is calculated as the product of the probability of each illness outcome with a severity factor and the duration (years). Calculation of the DALY contribution per infection is made using the formula:

$$DALY = YLL + YLD$$

Where:
YLL = years life lost;
YLD = years lived with a disability standardised with a severity weight. YLD = number of cases, multiplied by the average duration of the disease and the weight factor that reflects the severity of the disease on a scale from 0 to 1.

1.2.4 Tolerable burden of waterborne disease

According to the WHO (2017) a tolerable burden of waterborne disease from drinking water is suggested as 10^{-6} DALY per person per year. The estimated disease burden associated with mild diarrhoea at an annual risk of 1 in 1000 or 0.1% is approximately equal to 10^{-6} DALY per person per year. This high level of protection is needed for drinking water but it may not be seen as applicable to recreational exposure to water.

A discussion paper by Mara et al. (2010) suggests a lower DALY such as 10^{-5} or 10^{-4} DALY pppy as “more realistic, yet still consistent with the goal of providing high-quality, safer water and encouraging incremental improvement of water quality”, and it is lower than the current diarrhoeal disease incidence of 0.7 pppy.

[1] Sequela can be described as an after effect of a disease, or disease arising from a pre-existing disease.

1.3 SETTING TOLERABLE RISKS FOR RECREATIONAL WATER QUALITY

1.3.1 Overview

According to Hunter and Fewtrell (2001)[ii] a risk can be acceptable if it falls below a level that is already tolerated. For recreational water the EU bathing water directive prescribed an acceptable risk of illness associated with bathing in surface water of 3-5%, similar to the US EPA (2012) recreational water quality guidelines which historically allow a risk of illness of 3.6%. The US EPA sets a tolerable risk of less than 1 in 10 000 people per year (a 10^{-4} risk) from drinking-water (Regli et al., 1991[iii]) however it has been argued that based on background rates of gastrointestinal disease in the general population, that even a risk of 10^{-3} of infection per person per year would be too low (Haas et al., 1991). Global health data, presented by WHO (2006), shows that adults overall experienced 0.2 episodes of diarrhoea per year compared to young children in developing countries who experienced an average 4.7 diarrhoeal episodes per year (equal to a 4.7 yearly risk).

1.3.2 Hypothetical Disease Burden estimates for different water-borne pathogens

Examples presented by the WHO (2016) of the DALYs for different waterborne pathogens are provided in Table 1-1. Similar DALYs per 1000 cases could be anticipated as a result of Norovirus infections with later sections showing calculations. It is important to include the variability (natural dispersion in a system, such as pathogen concentrations in a river) and uncertainty (lack of understanding and/or inability to measure) in all steps of the risk characterization. The DALY concept provides a tool to evaluate and compare health risks from a specific environment for a specific population and behaviour and for comparing with other health risks of daily life. Both person- and pathogen-specific variations in the course of gastroenteritis may lead to different health outcomes.

Table 1-1: Example of Hypothetical Disease Burden estimates for different water-borne pathogens (Source: WHO, 2016)

Pathogen	Disease burden per 1 000 cases		
	YLD	YLL	DALY
Cryptosporidium	1.34	0.13	1.47
Campylobacter	3.2	1.4	4.6
Shiga-toxin producing E coli	13.8	40.9	54.7
Rotavirus			
High income countries	2.0	12	14
Low income countries	2.2	480	482
Hepatitis A virus			
High income countries	5	250	255
Low income countries	3	74	77

1.4 DEVELOPING RISK-BASED AND SITE-SPECIFIC RECREATIONAL WATER QUALITY GUIDELINES

1.4.1 What are risk-based water quality guidelines?

The 1996 Water Quality Guidelines are based on available dose-response data. The distribution was interpreted to determine the values at which the desired level's protection ("Target Water Quality Range") would be ensured at a high level of confidence, whereas descriptors of effects at other levels were also provided. Although the 1996 Guidelines were easy to implement, the uncertainty in the cause-effect data was not explicitly included in the guideline values. They also did not explicitly provide for different levels of protection, nor did they facilitate assessments at different levels of confidence. Although the 1996 Water Quality Guidelines used a distribution of data representing dose-response, the guideline levels were not expressed in risk terms.

The current Guidelines consider the likelihood of exposure through considering exposure distributions and also consider the likelihood of an effect through dose-response distributions. The resultant risk is then expressed as a probability between 0 and 1 (or as a percentage), that the specified effect will be expressed, given a certain distribution of exposure.

Internationally, recreational water exposure is generally associated with an increased risk of acute gastroenteritis. Review of epidemiological studies of illness rates concluded that the rate of symptom groups was significantly related to the count of faecal index bacteria in recreational water, with gastrointestinal symptoms the most frequent health outcome and less often, respiratory illness (Prüss, 1998). Most of the 22 studies reviewed by Prüss (1998) also suggested that symptom rates were higher in lower age groups. Based on the guideline values used at the time of the epidemiological studies, it was found that generally the recommended indicator of faecal contamination corresponded to a seasonal gastrointestinal illness rate of 1-2% (10-20 illnesses per 1000 swimmers). This is illustrated in the regression analyses shown in Figures 1-1 AND 1-2 showing illness rates and water quality with corresponding 95th confidence intervals.

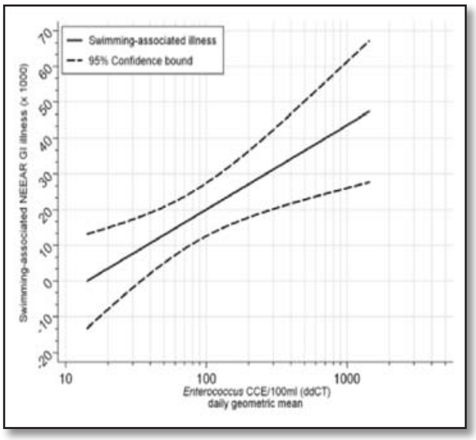


Figure 1-1: Dose response between gastro-intestinal illness and faecal indicator (Source: Fleisher, 2010)

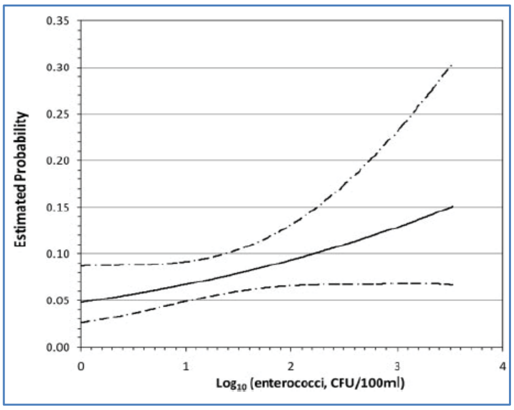


Figure 1-2: Dose response between skin symptoms and indicator organism (Source: Fleisher, 2010)

A basic risk-based approach was first adopted by WHO as the Stockholm Framework, providing a conceptual approach to assess water quality hazards and managing the risks associated with these (Bartram et al., 2001[iv]). The US's EPA and CDC study, the "National Epidemiological and Environmental Assessment of Recreational Water" or NEEAR, concluded that combining routine *E. coli* monitoring alongside actions, procedures and tools to collectively reduce the risk of swimmer exposure to faecal contamination in the recreational water environment represents the most effective approach to protecting the health of recreational water users (US EPA, 2012).

Therefore, *E. coli* is used as the indicator of faecal contamination in the South African Water Quality Guidelines for recreational use and the accompanying DSS as an indicator of microbial pathogens, recognizing that levels of *E. coli* are usually higher than those of microbial pathogens

1.4.2 Site specificity – the three-tiered approach

In line with the original terms of reference, three tiers are presented for recreational water quality guidelines.

1.4.2.1 *Tier 1*

The water quality guidelines are generic and applicable in the absence of site-specific information. These guidelines are similar to the 1996 water quality guidelines. A water safety planning process is followed for identifying the hazards, and risk calculations will be made with generic risk assumptions. The following information is included (based on domestic water quality guidelines):

- A full description of the hazard
- The guideline range (may be more than one depending on exposure assessment)
- The basis of the guideline derivation (data used, its quality, reliability of method, safety factors, etc.)
- Guidelines in other countries (literature comparison)
- References

1.4.2.2 *Tier 2*

The water quality guidelines in this tier incorporate site and scenario specific considerations that influence the fitness for use of a particular water quality constituent. The calculations for site/scenario specific considerations include one or combinations of the following:

- Refined exposure parameters – higher or lower exposure or dose situations based on recreational activity which includes cultural or social practices and may differ from that described in Tier 1
- Acclimatization of users to extended or high volumes of a constituent which can include whether users have knowledge of a water body that might be classified with a high risk as a result of clarity, or if natural water bodies have low pH values such as many rivers in the Western Cape.
- Sensitive sub-populations, for example informal communities and high HIV-infection areas are taken into consideration in tier 1 values in most instances, but with some exceptions, as it is not possible to examine water for all possible opportunistic pathogens. Some pathogens that may be naturally present in the environment may be able to cause disease in vulnerable subpopulations. If water used by such persons for recreational purposes contains sufficient numbers of these organisms, they can produce various infections of the skin and the mucous membranes of the eye, ear, nose and throat. These organisms are not pathogenic for healthy individuals but can easily infect individuals with decreased immunity. Examples of such agents are *Pseudomonas aeruginosa* and species of *Flavobacterium*, *Acinetobacter*, *Klebsiella*, *Serratia*, *Aeromonas* and certain non-tuberculous mycobacteria (WHO, 2017).

- Location from point source water quality impacts – for example wastewater treatment works or mining activities
- User density
- Recreational use during or after large rainfall or flood events.

1.4.2.3 *Tier 3*

The final tier refers to site and scenario specificity not catered for in the previous tiers.
Collected date, site and scenario specific information and sophisticated models will be needed to determine the fitness for use water quality constituents in very specific cases. The third tier will not be provided for in the envisaged DSS, but it will allow for assessment and objective setting. This tier requires specialist input and data interpretation.

1.4.3 Fitness for use classification

A four-class classification system based on the current Department of Water and Sanitation (DWS) practice is used to depict water quality for recreational use (Table 1-2). This classification system harmonised water quality with a risk-based assessment to determine fitness for use. The “Ideal” fitness for use class for recreational water use for example describes a class where water quality would not impair the fitness of water for its intended purpose. Both the fitness-for-use classification and the risk-based water quality assessment are represented in the DSS output screens depicting an assessment of water quality. The same colour scheme is also used to depict the different fitness-for-use classes. The DSS can be used to evaluate the fitness for use as well as to set water quality objectives for specific sites.

Table 1-2: A generic description of the DWS fitness-for-use classification of water used to determine management class

Fitness-for-use Class	Description
Ideal	A water quality that would not normally impair the fitness of the water for its intended use
Acceptable	A water quality that would exhibit only limited impairment to the fitness of the water for its intended use
Tolerable	A water quality that would exhibit increasingly unacceptable impairment to the fitness of the water for its intended use
Unacceptable	A water quality that would exhibit unacceptable impairment to the fitness of the water for its intended use

CHAPTER 2: OVERVIEW OF THE DECISION SUPPORT SYSTEM (DSS)

2.1 INTRODUCTION

The DSS is a risk-based software tool developed with a human health risk understanding of the different exposure scenarios and likely levels of contact (e.g. full-contact, intermediate contact and non-contact recreation) and likely exposure to different volumes of water (e.g. ingestion, skin contact, inhalation) reported in international literature and likely associations with health impacts. The Desktop DSS Tool to determine risk-based water quality guidelines for recreational water use is in Excel 2013 (version 15) format. The desktop tool to determine risk for recreational water use contains a landing (or welcome) page followed by an "Activities" page where recreational activities and specific exposure scenarios are selected (Figure 2-1 and 2-2).

Figure 2-1: Decision Support System startup page

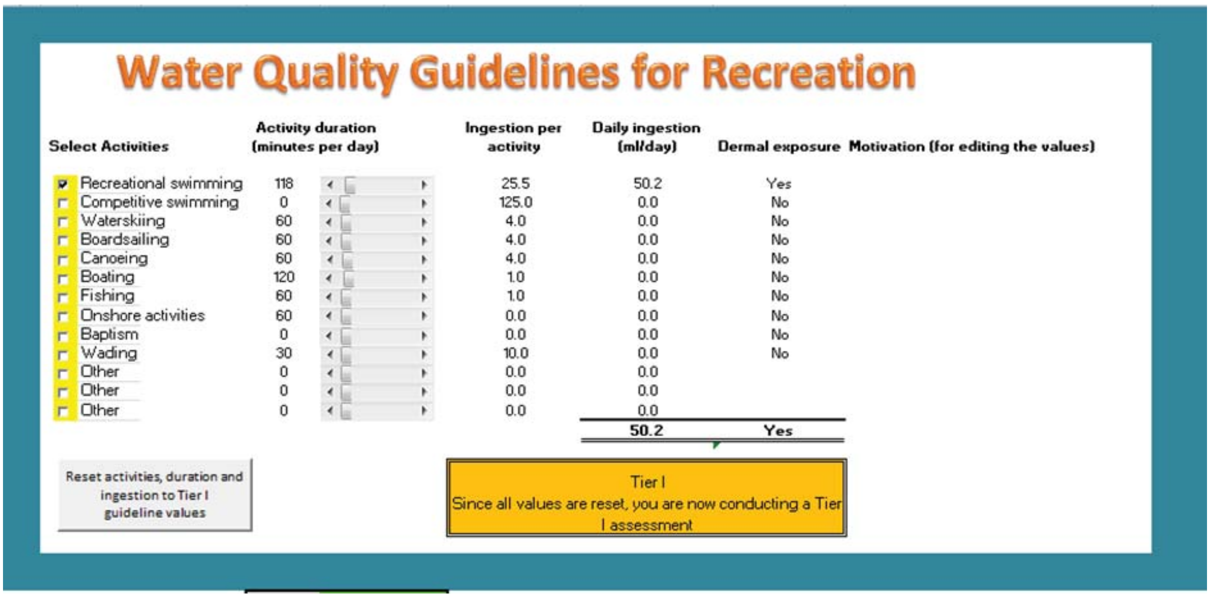


Figure 2-2: Decision Support System Activities Page

The DSS Tool contains a screen where recreational activities are selected and exposure scenarios can be edited. The next pages are for each of the parameters used to assess water quality for recreational purposes on separate "pages" or worksheets. Each of these pages contains:

- The reference dose/response data;
- The user-defined exposure data or also referred to as "Your data"
- A numeric expression of the risk;
- A table that indicates the risk ranges in relation to management classes; and
- A table that provides exposure scenarios (Selected exposure conditions) for a Tier 1 assessment is based on national and international data and makes use of data predicting volumes of water ingested during different types of activities.

2.2 GENERAL GUIDANCE ON INSTALLING AND USING THE DSS

The sections below describe the recommended settings to use the DDS tool in Excel. Following these instructions will allow the user to optimise the screen layout and computational functionality.

2.2.1 Recommended Excel settings

Although the Tool will run under default Excel 2013 settings, the following changes are recommended to optimise the screen layout and computational efficiency. In each case, the instructions to change the settings are provided on a blue background and the instructions to restore the setting are provided in the box with the green background. The instructions are for Excel 2013, but the same functionality is available for earlier versions.

2.2.2 Allow Macros

Allow

When you open the file, Excel will display a message to state that Macros have been disabled. You have to select "Enable Content" for the Tool to work.

Restore to default

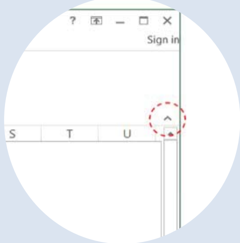
The acceptance on opening the file does not cause a change to your settings and therefore does not require a restore action.

2.2.3 Minimise Menu bars

The tool displays a lot of information on each tab and you do not need the menus to use the tool, therefore hiding them increases the screen area available for displaying information.

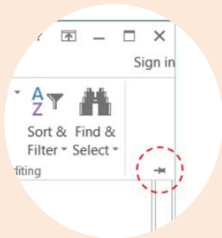
Minimise menus

Click on the "^" in the right-hand side of the menu bar



Restore menus

Click on "HOME" or any other top menu item. Click on the pin in the right-hand side of the menu bar that apeared.

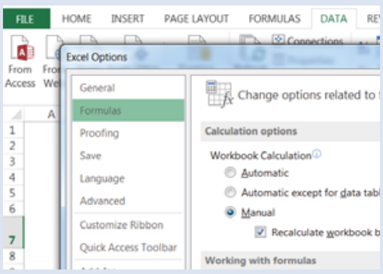


2.2.4 Set recalculations on manual update

The Tool contains a lot of calculations, which will update every time you enter any data. This will slow down the computer significantly. By setting recalculations to manual, the Tool will run very fast. Each time that you entered data and you want to update the calculations; you can just press "**F9**".

Set recalculate to manual

Click on "File" from the top menu, then "Options" from the drop-down menu. Select "Formulas" in the side menu of the new window. Under "Calculation options" select "Manual" and "OK"



Restore to default

Follow the instructions for setting recalculate to manual (described in the adjacent box), but choose "Automatic" rather than "Manual"

2.2.5 Zoom

Depending on your screen resolution, you may have to adjust the "Zoom" to display more or less on the screen.

Zoom to appropriate scale

There is a Zoom bar in the bottom right-hand corner of the screen. The Zoom ratio can be changed by clicking "-" or "+" or by moving the slider.

Restore to default

Adjust the slider back to the preferred ratio.

2.2.6 Activities Tab

The Activities Tab lists a number of common recreational activities that could cause contact with, or ingestion of, water. For a Tier I assessment (default), only recreational swimming is selected. The swimming duration and the ingestion rate is set to result in a water ingestion of 50 ml/day. Swimming is specified as to also result in dermal exposure.

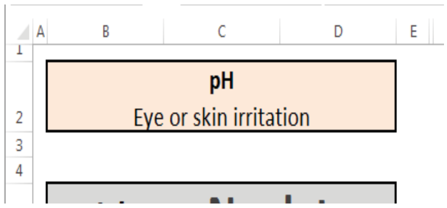
For a Tier II and Tier III assessment, different activities can be selected and their duration and ingestion rate can be changed. The "Activity duration" can be changed by either over-typing the value or with the slider bar. The default setting for activities, duration and ingestion can be reset by clicking on the reset buttons below each column. Provision is made for "Other" activities. The user can overtype the text "Other" with a specific activity and also specify the appropriate duration and ingestion. Lastly, for "Other" activities, the user also needs to specify if the activity will result in "Dermal exposure". In order to do this, click on the relevant cell and select "Yes" or "No" from the drop-down menu.

Whenever any of the values are changed, the user must provide a justification for the change under the "Motivation" column. References to sources of data should also be provided whenever possible. The text does not "wrap", but the full text can be displayed by selecting the cell and pressing "F2".

2.2.7 Variables Tabs

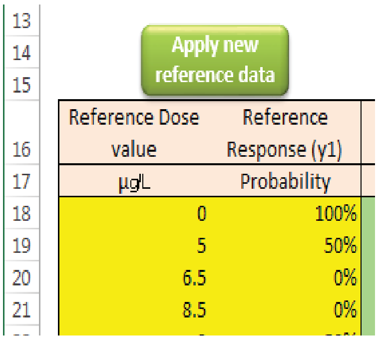
The content of all the tabs for the different variables are laid out in exactly the same way, therefore the following description applies to all of the variable tabs. To select a Tab, click on the name of the variable at the bottom of the screen.

2.2.8 Endpoint description



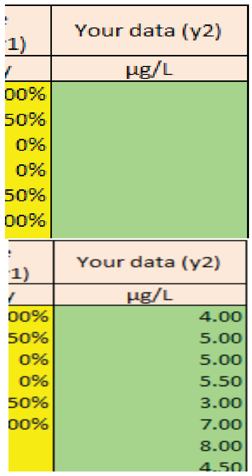
The top-left of the screen shows the variable name and a description of the "Endpoint" for which the risk is determined (in a light orange box). The example for pH denotes that the calculations on the page evaluates "*the probability that the target population will experience eye or skin irritation, given the specified levels of exposure*".

2.2.9 Dose-response data



The bottom-left of the screen shows the dose-response data for the variable (in the light-yellow box). Importantly, the relationship is specified for the reference oral ingestion of 50 ml/day. These values can be adjusted for a Tier III assessment, however a motivation for the adjusted values should be provided in the light-text box to the right. The modified "Reference Dose" should be in the units provided and cover the full range for which you want to calculate a risk. The modified "Reference Response" is expressed as a percentage, thus "*the probability that the specified endpoint will be expressed, given the corresponding level of exposure*". When new Dose-Response data has been added, you should click on the "Apply new reference data" to recalculate the dose response curve.

2.2.10 Environmental water quality



The risk-based water quality guidelines are calculated in relation to a distribution of data. This can either be an existing dataset for a retrospective assessment, or a hypothetical (or expected future) dataset for a prospective assessment. This data is entered in the green box adjacent to the Dose-Response data. The box allows for up to 1000 data points. You can either type the data in, or copy it from another Excel file. If you copy the data, it is best to use “Paste special” and select the “Values only” option, to prevent unwanted formatting of the cells in the tool. If your dataset contains more than 1000 data points, you can simulate the distribution by calculating percentiles of the data in 0.1-unit increments. Whichever option you use to enter data into the “Your data” field, the data does not need to be ordered. Once the data has been entered, you can press “F9” to calculate the risk.

2.2.11 The Risk

The answer to the risk assessment is displayed in the box with large black text. The colour of the box will change according to the management class within which the risk falls (see description hereunder). The value will always be between 0% and 100%. This value signifies “*the probability that the endpoint will be expressed, given the dose-response function and the environmental water quality*”. The answer is accurate to ±1%.

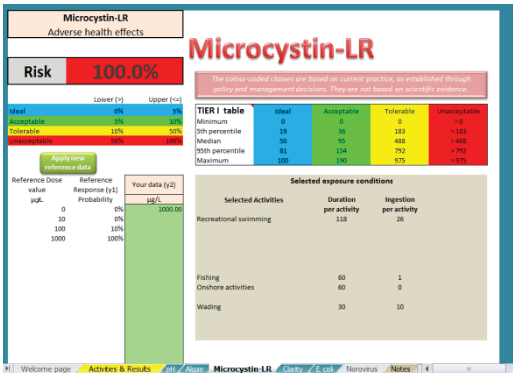
2.2.12 Relation to Management Classes

The above risk value can be interpreted by comparing it to the Management Class table below the risk calculation. The table provides the lower and upper risk boundaries for the four management classes. Although the calculated risk value is based on scientific evidence the boundaries of what is ideal, acceptable, tolerable and unacceptable is a management decision.

	Lower (>)	Upper (<=)
Ideal	0%	5%
Acceptable	5%	10%
Tolerable	10%	50%
Unacceptable	50%	100%

2.2.13 Graphic display

The Dose-Response, Environmental data (“Your data”) and the resultant risk is highlighted. In the adjacent hypothetical example, the water quality data is entered in the “your data” column and a colour coded risk is calculated based on the activities selected in the ‘activities” worksheet.



CHAPTER 3: PROCEDURE FOR PERFORMING CALCULATIONS IN THE DECISION SUPPORT SYSTEM

3.1 INTRODUCTION

The DSS can be used to evaluate the fitness for use as well to set water quality objectives for specific sites. This data is built into the DSS to allow water resource managers to assess likely risks or fitness for use at specific sites based on different recreational activities.

3.2 GENERAL APPROACH AND CALCULATION PROCEDURES

3.2.1 Input requirements

Depending on the option the user wishes to perform, specific input data will be required.

3.2.2 Tiers of risk assessments

A more refined risk assessment (Tier II and III) which is more site and exposure specific reduces the level of uncertainty.

3.2.2.1 *Tier I*

The Tier I assessment is the simplest approach with the least inputs required. For a Tier I assessment, the activities for which the water quality guidelines are provided is set at 118 minutes of recreational swimming per day, which translates to an ingestion of 50 ml of water per day. Furthermore, the dose-response data is fixed at the input values provided in the tool. The user can either draw on the Tier I guideline values provided as examples for each parameter, or enter data (“Your data”), against which the risk and associated category can be determined. The Tier I assessment will not be site-specific or endpoint-specific and could thus be over-protective in many cases, or under-protective for specific situations.

3.2.2.2 *Tier II*

The Tier II assessment uses the same baseline as the Tier I assessment, but the user can change the exposure conditions by selecting different activities, activity durations and ingestion rate per activity. This will result in more site-specific or condition-specific water quality guidelines.

3.2.2.3 *Tier III*

In addition to the user inputs for Tier II, the user can also change the dose-response data for a Tier III assessment. Such changes will have to be motivated in the provided text box and will generally require specialist skills. The Tier III assessment provides for differences in end-point susceptibility, thus differences in sensitivity of individuals or communities that embark on recreational water use.

3.2.3 How to use the outputs of the tool

In all cases (regardless of the Tier), the values in the "Your data" column that produces a risk value that is compliant to the management category becomes the guidelines. Thus, if a single value is specified and the corresponding risk is within the selected category boundaries, then the single value can be applied as a guideline. However, the risk-based approach will be much more beneficial if a data set is provided under "Your data". A data set representing a distribution of data (real world conditions) will allow for more practical management options. Whereas the "old fashioned" specification of a single value has been viewed as easy to implement, it often limited development opportunities.

3.3 VOLUMES OF WATER INGESTED DURING SPECIFIC RECREATIONAL WATER ACTIVITIES

3.3.1 Overview

Most illnesses resulting from contaminated recreational water result from the accidental ingestion of the water. Table 3-1 provides a summary of the volumes of water reported in international literature associated with specific recreational activities. These range depending on the type of contact, from full contact swimming to canoeing, fishing, playing, wading, etc., but also making provision for competitive swimming (e.g. Midmar mile, Iron Man competition, Triton X Trail run series). Aspects such as vulnerable sub-populations are able to be included in the DSS at a tier III level if new data becomes available relating to area specific susceptibilities of the population.

Table 3-1: Volumes of water ingested in association with specific recreational activities according to exposure studies

Activity	Volume ingested	Reference
Canoeing	4 mL/h	Sunger and Haas, 2015
Boating	1 mL/h	
Fishing	1 mL/h	
Wading	10 mL/h	
Playing	12 mL/h	
Swimming	25 mL/h	
Swimming – men	27-34 mL/event	Schets et al., 2011
Swimming – women	18-23 mL/event	
Children	31-51 mL/event	
Swimming – children	47 mL/event	Evan's et al., 2006
Swimming males	30 mL/event	
Swimming females	19 mL/event	
Limited contact	3-4 mL	Dorevitch et al., 2011
Swimming	10-15 mL	
Children	37 mL	Dufour et al., 2006, 2017
Adults	16 mL	
Competitive swimmers	125 mL	
Wading	10 mL/h	US-EPA, 2000

Estimates of water ingestion are based on international studies that have attempted to measure this, using a combination of approaches. Dufour et al. (2006) determined the amount of water swallowed during swimming activity by measuring the amount of ingested cyanuric acid in pools disinfected with chloroisocyanurates. The chloroisocyanurates decomposes slowly to release chlorine and cyanuric acid. Cyanuric acid passes through the body un-metabolised. Fifty-three recreational active swimmers participated in the study. Their urine was collected for the next 24 hours. Cyanuric acid was measured in pool water and urine samples to calculate the volume of pool water ingested while swimming. Results of the study indicate that adults ingest about half as much water as children during swimming activity. The average amount of water swallowed by children and adults was 37 mL and 16 mL, respectively. This study allowed the measurement of the actual volumes of water swallowed during swimming activity.

Estimates of water ingestion for common restricted exposure recreational activities such as canoeing, fishing, kayaking, motor boating and rowing are limited. Dorevitch et al. (2011) assessed the water ingestion for these activities making use of self-reporting estimates in combination with cyanuric acid measurements in pool and urine samples. The results obtained from the combined tests were used to derive translation factors to quantify self-reported estimates in open water environments. Mean estimates of water ingestion during limited contact recreation was 3-4 mL. Only a limited number of studies have looked at assessing limited contact exposures. Dorevitch et al. (2011) found swimmers ingested water more frequently and in larger average volumes than canoers and kayakers, who in turn ingested water more frequently and in larger volumes than those who wade/splash or fish.

Canoers and kayakers who do not capsize ingest water as often and in similar amounts to those who fish or wade/splash. Canoers and kayakers who do capsize swallow less frequently and in reduced volumes compared to swimmers. Schets et al. (2011) also made use of a combined approach of self-reporting and measurements of volumes of mouthfuls to transform categorical data to numerical data of swallowed volumes of water. Sunger and Haas (2015) made use of a number of studies reported in the literature to estimate low contact exposure events using the method of maximum likelihood estimation (MLE). Using site-specific water quality data and a QMRA model to look at variability from all input parameters, including non-swimming (low contact) exposure scenarios to predict total health risks, they found that activities contributing most to the risk of gastro-intestinal illness at creeks were wading and playing (81%), while fishing was the potential risk contributor (65%) at rivers.

Time spent exposed to water differs according to the type of recreational activity. Time spent swimming is typically reported as minutes/month. The amount of time was based on 2 key studies reported in the US EPA Exposure Factors Handbook (US EPA, 2011).

3.4 QUANTITATIVE MICROBIAL RISK ASSESSMENT (QMRA) IN THE DSS

3.4.1 Overview

In addition to the epidemiological studies providing the correlation to faecal indicators, Quantitative Microbial Risk Assessment (QMRA) can be used to characterise risks associated with a particular pathogen to calculate a concentration of a specific pathogen that would correspond to a pre-specified level of risk, or to evaluate the relative ranking of pathogen/exposure combinations. Figure 3-1 below illustrates the process as described by Sunger and Haas (2006) that can be used to calculate risk of illnesses per 1000 users per day at a site and the total risk of illnesses per day. The process using QMRA to develop water quality guidelines is described in detail in the Technical Report and is summarised here. The concept of tolerable disease burden (equated to acceptable risk) was set out in the fourth edition of the WHO Guidelines for Drinking Water Quality or GDWQ (WHO, 2011). The guidelines defined the tolerable burden of disease as an upper limit of 10^{-6} disability-adjusted life year (DALY) per person per year.

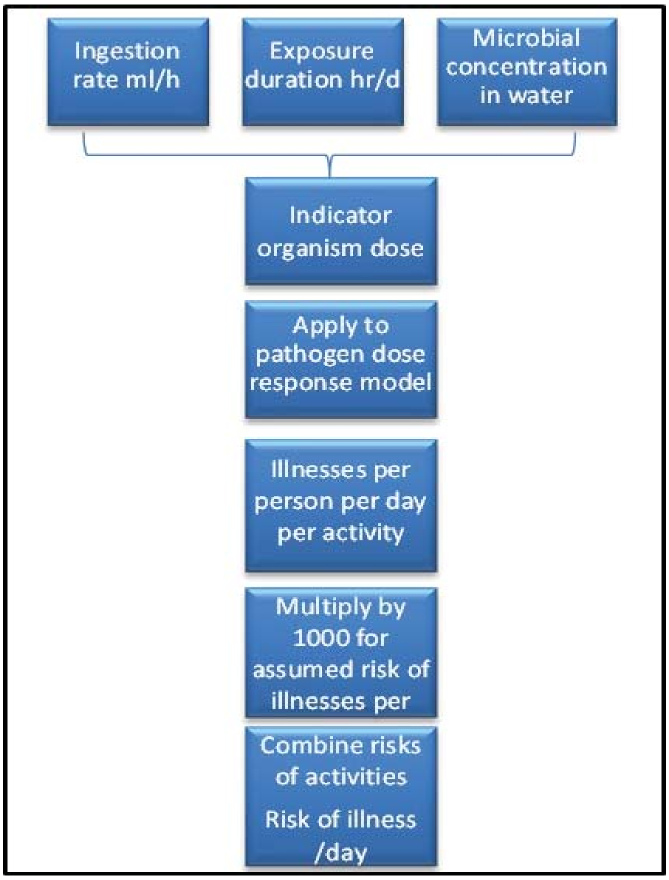


Figure 3-1: Flow chart calculating total risk of illnesses per day and illnesses per 1000 users per day at each site. (Source: Sunger and Haas, 2006)

One DALY per million people a year roughly equates to one cancer death per 100 000 in a 70-year lifetime and was the benchmark often used in chemical risk assessments (WHO, 2004). This level of health burden is equivalent to a mild illness such as watery diarrhoea with a low fatality at an approximately 1 in 1000 annual risk of disease to an individual (WHO, 1996; Havelaar & Melse, 2003[2]). A "tolerable" risk of 10^{-6} DALY per person per year allows for the loss of 365 healthy days in a population of one million over the course of one year. Concentrations of pathogens equivalent to a health outcome target of 10^{-6} DALY per person per year are typically less than 1 organism per 10 000-100 000 litres making it more feasible and cost-effective to monitor for indicator organisms such as *E. coli*. QMRA is a sensitive tool that can estimate the probability of infection that could not be measured through epidemiological studies and is a complement to epidemiological studies. QMRA predicts infection or illness rates based on the measured or predicted densities of a specific pathogen ingestion rates of water associated with different activities.

The agricultural water quality guidelines for irrigation made use of *E. coli* levels to calculate protection from Norovirus infection as this will also protect against bacterial and parasite infections. Norovirus is recognized as one of the most common agents of viral diarrhoea. Although the risk of infection by norovirus would usually be modelled based on measured or modelled norovirus particles, here the risk of norovirus infection per person per year is determined using *E. coli* counts per 100 ml. This is used to estimate a norovirus concentration to predict the probability of illness established using Norovirus dose-response parameters (Teunis et al., 2008).

[2] Havelaar AH, Melse JM (2003). Quantifying public health risks in the WHO guidelines for drinking water quality: a burden of disease approach. Bilthoven, The Netherlands, Rijksinstituut voor Volksgezondheid en Milieu [National Institute for Public Health and the Environment], (RIVM Report 734301022/2003).

3.4.2 Low-dose approximation formulae

The WHO (2016, 2017b) suggests using low-dose approximations of the QMRA formulae. The traditional dose dependent beta Poisson model adopted by WHO (2017) was used in these Recreational Water Quality Guidelines (Table 2) with the focus on Norovirus as the reference pathogen.

Table 3-2: Reference pathogen formulae and data to calculate DALYs (Source: FAO/WHO, 2003; WHO, 2017b)

Reference pathogen	Campylobacter	Norovirus	Cryptosporidium
Dose-response parameters	α = 0.145 β = 7.58 Approx beta Poisson	α = 0.0044 β = 0.002 Hypergeometric	r = 0.2 exponential
Low-dose extrapolation formula	$Pinf = \frac{\alpha}{\beta} \times dose$	$Pinf = \frac{\alpha}{(\alpha + \beta)} \times dose$	$Pinf = r \times dose$
Probability of infection from a single organism	0.019	0.69	0.7
Likelihood of becoming ill if infected	0.3	0.7	0.7

3.4.3 Uncertainty and variability

When we have incomplete knowledge about values (such as exposure or response), we specify this as uncertainty. When such values change over time and space (exposure) or between endpoints (effects), it results in variability. Although uncertainty and variability have different origins, both phenomena give rise to distributions of data, thus expressions of likelihood. For the calculation of risk-based guidelines, uncertainty and variability are accommodated through the same mathematical approach.

3.4.4 How we calculate risk

We have said that risk refers to the likelihood that an undesired affect could occur. The undesired effect in this case is a health-related effect due to exposure to water through a recreational activity. The risk is calculated as the function of the (likelihood of) exposure to a stressor and (the likelihood of) the recipient expressing a specific response to the exposure.

For example, if there is a 20% chance of a recipient being exposed to a stressor at a particular level, and there is a 50% chance of a particular effect being expressed at that level, then there will be a 10% change of the recipient expressing the effect (20% x 50% = 10%).

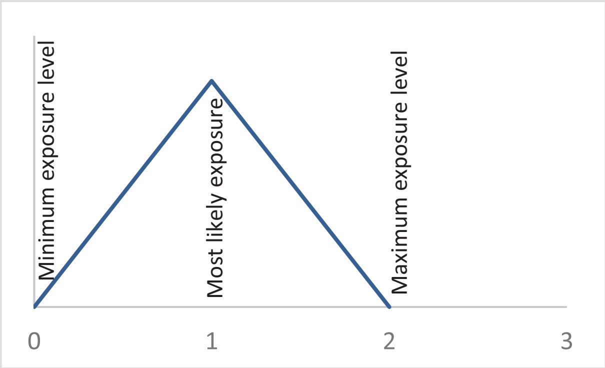
EXAMPLE

Risk of severe reaction due to a bee sting

If 5% of people are stung by bees at a particular location and if 3% of people are allergic to a bee sting, the risk of a severe reaction due to a bee sting at that

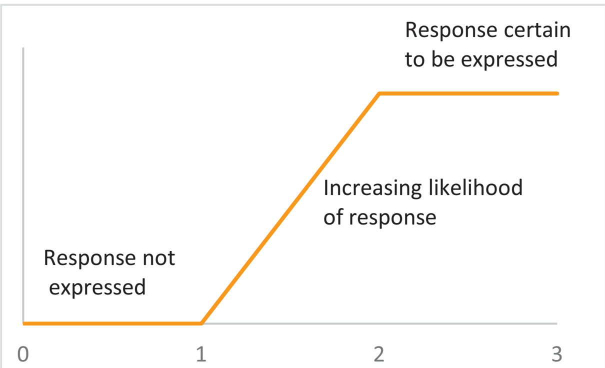
This calculation is explicitly risk-based, but does not represent the uncertainty (and variability) of the exposure or the effect. We can specify uncertainty in exposure by taking into account the level of the stressor in the water, as well as the exposure pathway(s) to the recipient, which results in a certain level of exposure. When the exposure level is uncertain, we can represent this uncertainty as a probability distribution. Similarly, if the exposure is variable (changes over time), we can represent the variability as a distribution. In simple terms, we can specify a most likely exposure and a distribution around the value.

For example, if the most likely level of exposure is 1 and the exposure is between 0 and 2, the exposure distribution can be represented by a triangular distribution, as indicated by the adjacent graph. However, the distribution can also be a standard distribution, binomial distribution, or any other distribution. (The surface area under the graph should always be 1, which defines the normalised y-axis value.)



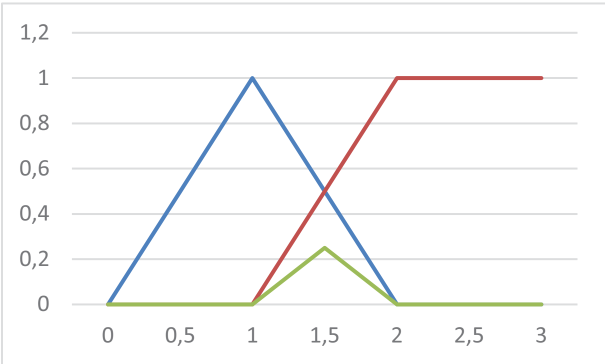
Similarly, the effect of the stressor on the recipient can also be uncertainty. This uncertainty can be a function of using toxicity data from other species, insufficient epidemiological studies, variability between different populations, etc. Whatever the source of the uncertainty, we can specify a level at which we are certain that the effect will not be expressed, a level at which we are certain that the effect will be expressed and a distribution of likelihood that the effect will be expressed between the two points. This distribution can also incorporate variability, whereas certain members of the target population may be more or less sensitive to the stressor.

For example, if a particular response is not expected to be expressed between exposure levels 0 and 1, and the response is certain to be expressed above an exposure level of 2 and the likelihood of the response increases in a linear fashion between 1 and 2, then the uncertainty (and/or variability) of the response can be represented by the adjacent graph.



The response distribution can be represented by any cummulative distribution function (with a maximum y-value of 1). The risk of the response being expressed, given the particular exposure and response distributions can thus be determined by calculating the product of the surface areas under the lines (after the surface area of the exposure distribution is normalised to 1), thus the overlap of the exposure distributions and response distributions represent the risk.

For example, if we use the above exposure and response distributions, the resultant risk is represented by the grey line in the adjacent graph. There is no risk of the response being expressed above a level of 2, which is due to the likelihood of exposure above a level of 2 being zero. There is also no risk of the response being expressed below a level of 1, which is due to the likelihood of the response below a level of 1 being zero. The surface area under the grey line is 0.25, which means there is a 25% probability that the effect will be expressed.



Bartram J, Fewtrell L, Stenström T-A (2001). Harmonised assessment of risk and risk management for water related infectious disease: an overview. In: Fewtrell L, Bartram J, eds. Water quality – guidelines, standards and health: assessment of risk and risk management for water-related infectious disease. London, IWA Publishing.

3.5 EXAMPLES OF DSS CALCULATIONS

Figure 3-2 shows an example of the worksheet for pH indicating the components listed above. Depending on data entered for the parameters, a risk result will be displayed on the activities and results page, in a colour-coded format based on the risk level calculated. These are considered as ideal, acceptable, tolerable or unacceptable (Fitness-for-use) and coloured according to Table 3-3.

Table 3-3: Suggested Risk Management Classes for consideration based on resulting risk levels

	Lower (>)	Upper (<=)
Ideal	0%	5%
Acceptable	5%	10%
Tolerable	10%	50%
Unacceptable	50%	100%

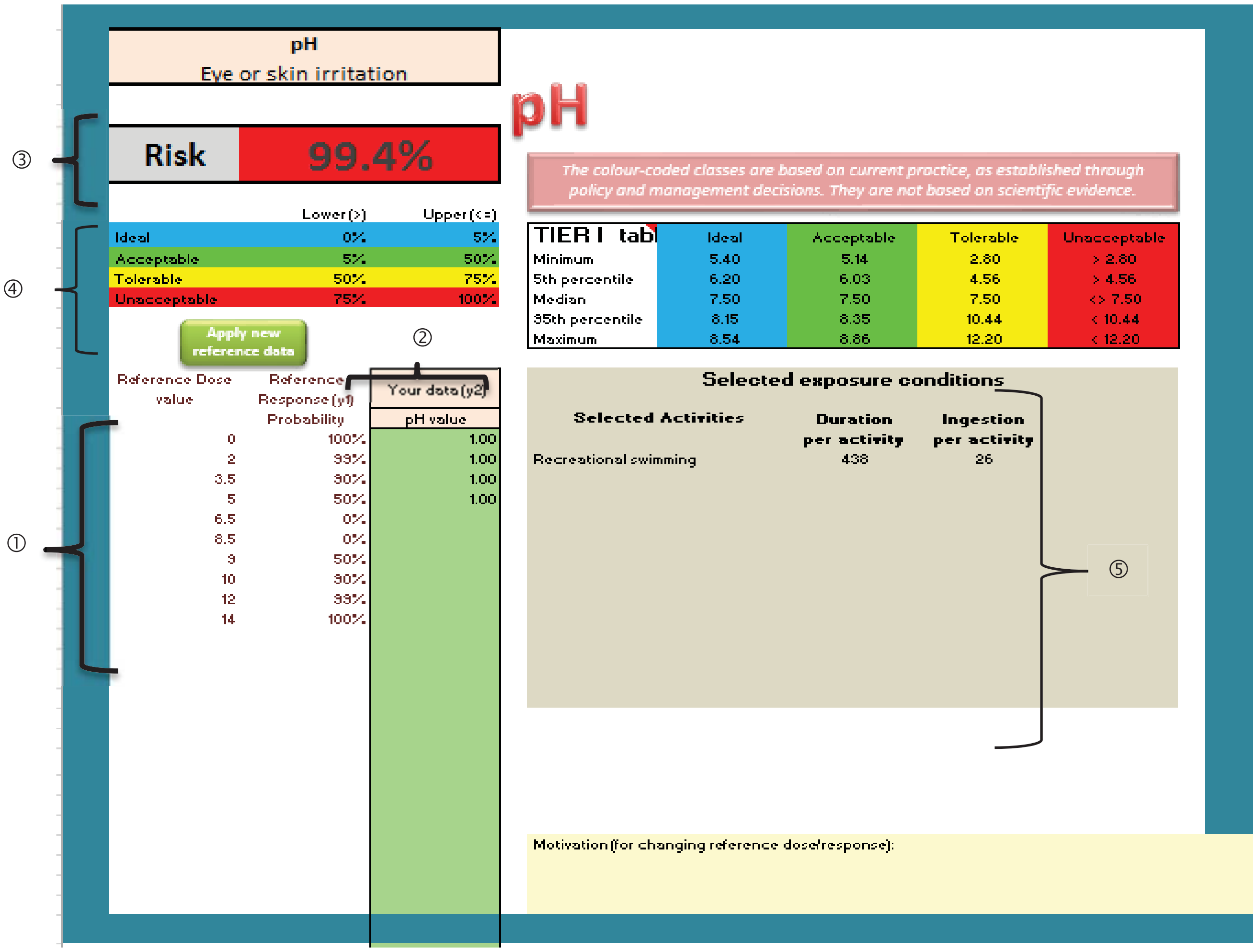


Figure 3-2: Example of worksheet for pH showing different components and layout

In the following example (Figure 3-3) for Clarity the "your data" exposure data readings varied between 1.5 m and 3.0 m and when entered into the DSS Tool, resulted in an **8.8%** risk of possible injury which is interpreted (by the tool) to be in the acceptable risk level (green). Similarly, if all Secchi disk readings were 2.0 m or less, (indicating turbid water) the resulting risk would be **36.4%** (Figure 3-4), which could be considered as a **"tolerable"** risk.

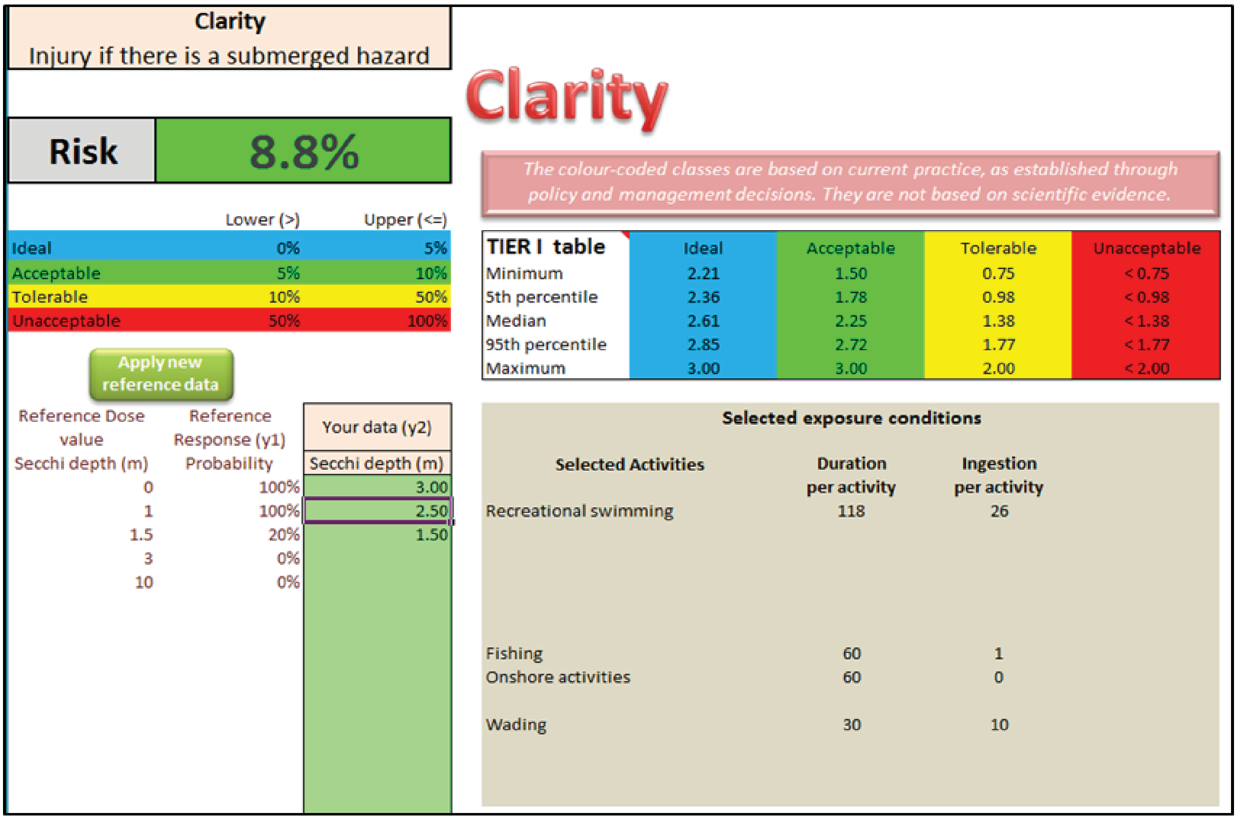


Figure 3-3: Example of clarity risk results where all readings occur between 1.5 m and 3.0 m

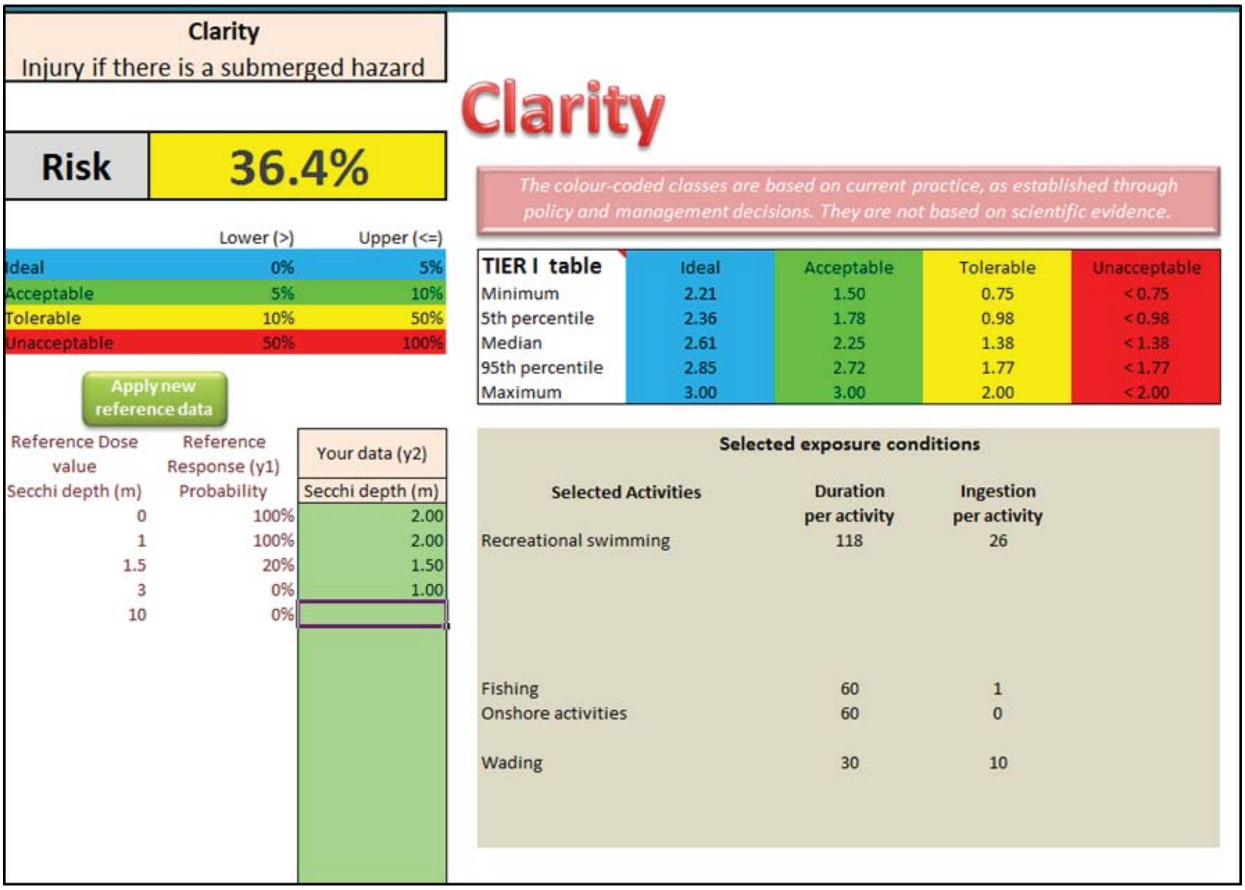


Figure 3-4: Example of clarity risk results where all readings occur between the 1.0 m and 2.0 m

Once data has been entered into the different worksheets for the different parameters, a summary page with all the data and risk summaries are displayed as can be seen in Figure 3-5. More detailed guidance for using the different tiers of the DSS Tool is provided in the next section. The first step is deciding which tier is desired. If Tier I is selected, no selection of activity is needed where the DSS makes use of default activities which assumes an overall ingestion rate of 50 ml water, as it is thought to protect the average user (Figure 3-6).

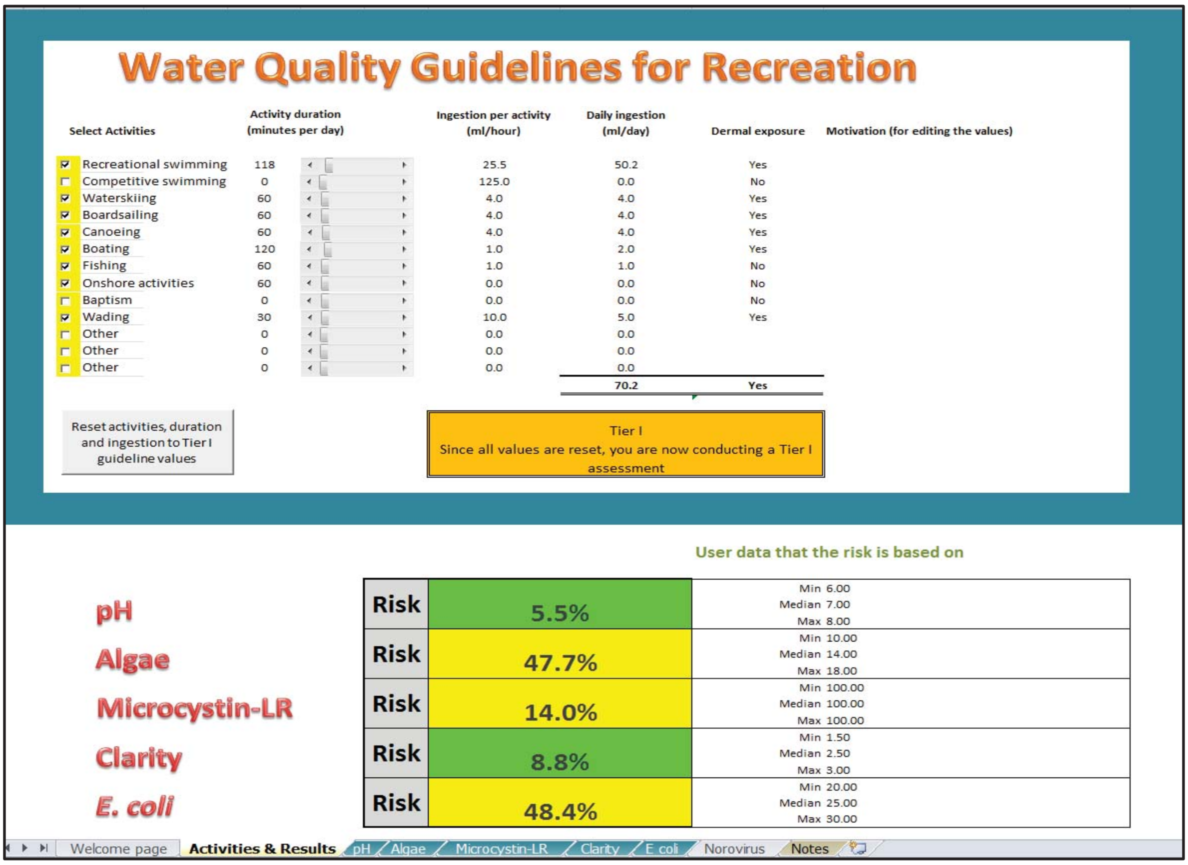


Figure 3-5: DSS screen provides a summary of the risks of each parameter where data was entered

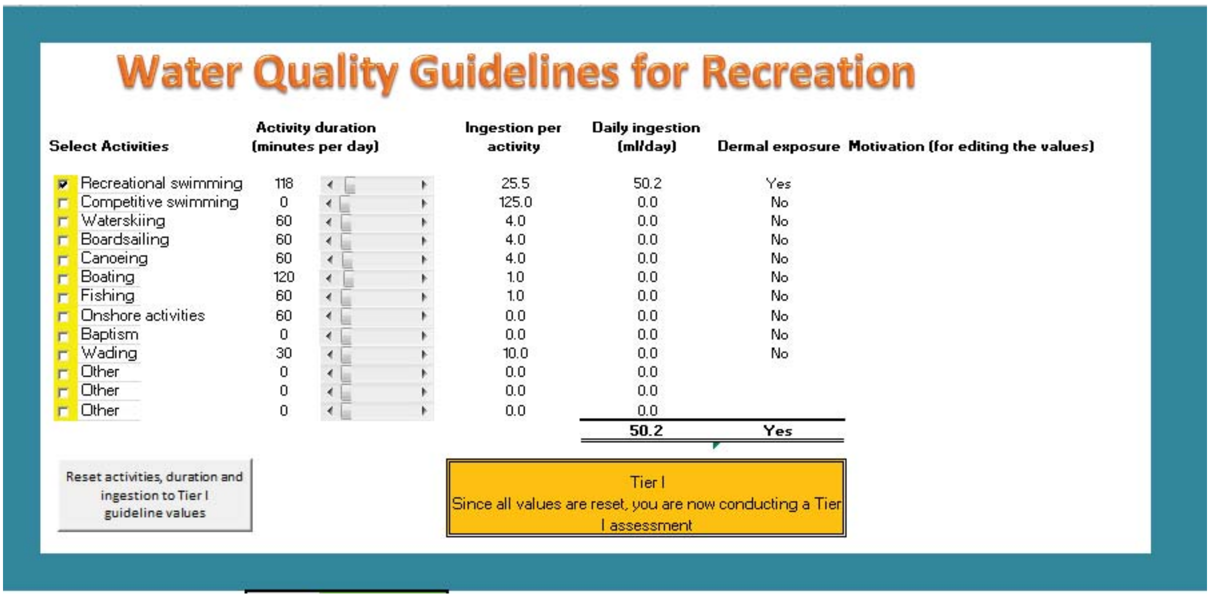


Figure 3-6: DSS screen that the users begin to assess the risks associated with recreational water use by selecting recreational activities with the default as Tier I

If Tier II is selected, a range of activities can be selected including type of activities expected and the duration of activity envisaged. This allows the calculation of the volume of water ingested for the period. If activity durations are changed, a Tier II is considered where the duration of recreational swimming was reduced to just less than 1 hour (Figure 3-7). Estimates of water ingestion are based on international studies that have attempted to measure this and are summarised in Table 3-4. Time spent exposed to water differs according to the type of recreational activity. Time spent swimming is typically reported as minutes/month. The amount of time was based on 2 key studies reported in the US EPA Exposure Factors Handbook (US EPA, 2011). For instance, if competitive swimming is chosen and is expected to occur for an hour, the ingestion calculated is approximately 5 times that expected through recreational activity with 125 ml ingestion expected (Figure 3-8).

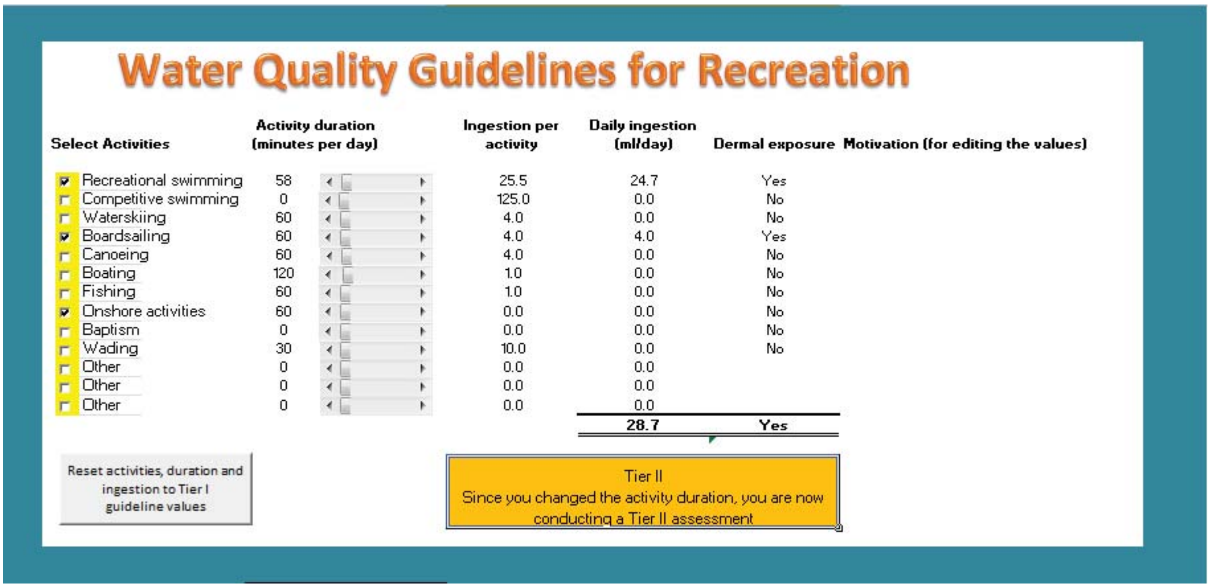


Figure 3-7: DSS screen where the user can change the activity duration in a Tier II assessment

Table 3-4: Volumes of water ingested in association with specific recreational activities according to exposure studies

Activity	Volume ingested	Reference
Canoeing	4 ml/h	Sunger and Haas, 2015
Boating	1 ml/h	
Fishing	1 ml/h	
Wading	10 ml/h	
Playing	12 ml/h	
Swimming	25 ml/h	
Swimming – men	27-34 ml/event	Schets et al., 2011
Swimming – women	18-23 ml/event	
Children	31-51 ml/event	
Swimming – children	47 ml/event	Evan's et al., 2006
Swimming males	30 ml/event	
Swimming females	19 ml/event	
Limited contact	3-4 ml	Dorevitch et al., 2011
Swimming	10-15 ml	
Children	37 ml	Dufour et al., 2006, 2017
Adults	16 ml	
Competitive swimmers	125 ml	
Wading	10 ml/h	US-EPA, 2000

Select Activities	Activity duration (minutes per day)	Ingestion per activity (ml/hour)	Daily ingestion (ml/day)
Recreational swimming	118	25.5	0.0
Competitive swimming	60	125.0	125.0
Waterskiing	60	4.0	0.0
Boardsailing	60	4.0	0.0
Canoeing	60	4.0	0.0
Boating	120	1.0	0.0
Fishing	60	1.0	0.0
Onshore activities	60	0.0	0.0
Baptism	0	0.0	0.0
Other	0	0.0	0.0
Other	0	0.0	0.0
Other	0	0.0	0.0
Other	0	0.0	0.0
			125.0

Figure 3-7: Competitive swimming selected for Tier II assessment

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