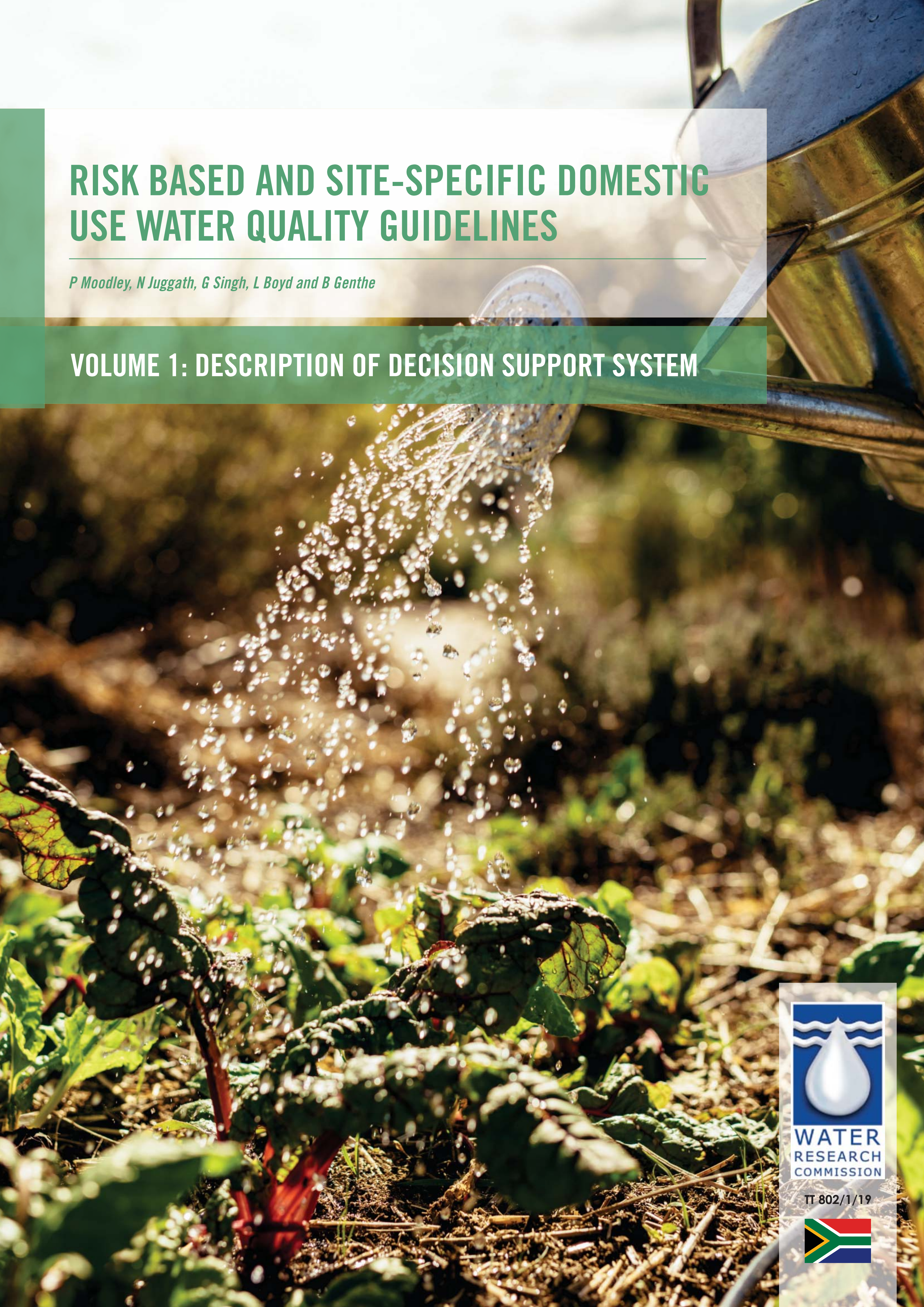

RISK BASED AND SITE-SPECIFIC DOMESTIC USE WATER QUALITY GUIDELINES

P Moodley, N Juggath, G Singh, L Boyd and B Genthe

VOLUME 1: DESCRIPTION OF DECISION SUPPORT SYSTEM

WATER RESEARCH COMMISSION

TT 802/1/19

RISK BASED AND SITE-SPECIFIC DOMESTIC USE WATER QUALITY GUIDELINES

VOLUME 1: DESCRIPTION OF DECISION SUPPORT SYSTEM

A Report
to the Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

The 1996 South African Water Quality Guidelines (Volume 1) (SAWQGs) has been used by water quality managers and water resource managers as a primary source for decision-making to judge the fitness for use of water for domestic use. The guidelines are essentially a user needs specification of the quality of water required for drinking, food and beverage preparation, bathing and person hygiene, laundry, household washing (dishes), hot water systems and for gardening in the domestic environment. It reflected the scientific thinking at the time. Subsequently, the decision support function of water quality guidance has grown and become more complex. Increased scientific understanding of the complexity of water ecosystems and adaptive catchment management processes has led to new ways of managing water quality. Traditional scientific and management approaches may not deal well with contemporary water quality issues. Since the evolvement of water resource management within South Africa, the SAWQGs have become decision support tools rather than just a list with limits. Both application and scope issues related to risk, site specificity and guidance on an expanded set of constituents have become more apparent. In 2007 a number of specific issues came to the fore that made it necessary to re-examine the philosophical basis used for determining and applying water quality guidelines. These included *inter alia* the implementation of resource directed measures (the classification of water resources, Reserve determination and determination of resource quality objectives) and the application of source directed controls under the National Water Act (Act No. 36 of 1998), the concept of risk as potential common basis for decision making in various contexts, site specificity and advancements in guideline determination internationally. Additional factors that have influenced the optimal use of the SAWQGs include the misapplication of the guidelines (e.g. guideline values are used interchangeably) or confusion in interpretation of terminology (e.g. guidelines versus standards).

These aspects highlighted the need for a quantifiable assessment system to judge fitness for use of water quality that moves beyond simple numeric values, to providing an assessment in terms of a water use scenario that considers spatial and temporal variability. In 2008, a national review by the Department of Water and Sanitation concluded that the water quality guidelines should support site specificity, be risked based, provide for fitness for use assessment and consider a software-based decision support tool. In light of these recommendations the Water Research Commission (WRC) initiated an overarching project that has seen the commissioning of a series of projects to develop risk-based decision support tools per water user group. This project addresses the 'Development of a Risk based Methodology and Decision Support System for Domestic Water Use" as part of the series.

AIMS AND OBJECTIVES OF THE PROJECT

The aim of this project was to develop a methodology for determining risk-based water quality guidelines for domestic use enabled through a user-friendly and practical decision support system (DSS). The specific objectives that have been addressed in terms of meeting this aim include firstly, the development of the approach and methodology for the risk calculations based on supporting science to be included in the technology demonstrator; and secondly the development of the informatics for a demonstrator decision support system that addresses the main decision contexts for the use of the guidelines.

SCOPE OF THIS PROJECT

The adoption of the risk approach is that it can provide a common philosophical basis for decision-making in different contexts, as it incorporates the data to support conclusions about the nature and extent of the risk from exposure. The intention is that the guidelines will no longer represent a simple pass-fail number, which ignored spatial and temporal variability. The risk science and the approach adopted for the domestic user water quality guidelines considers a combination of qualitative and quantitative risk assessment. At the core of the guidelines is a quantified risk estimate (probability of the risk), which is assessed in terms of threshold criteria that relates to fitness for use categories or water quality requirements. It is important to note that guidelines reflect the scientific environment whereas standards reflect the regulatory environment. These risk-based water quality guidelines for domestic use reflect an expression of the science that would support a decision on the designated use of a particular water. In South Africa, drinking water quality (potable water) is governed by Section 9 of the Water Services Act (Act No. 108 of 1997), and regulated through the South African National Standards for Drinking Water (SANS 241, 2015, Parts 1 and 2). SANS 241 is a mandatory potable water standard and has the overall objective to protect public health and is based on end-point analysis of treated drinking water supplies and is in line with international standards. For bottled water SANS 1675 is applicable. Most often standards are static while guidelines can be more flexible. The reason for this is that regardless of whether there are standards in place, a water user may want to know the risk of using a particular water source for a particular use because that may be the only water source available; which is where the guidelines come into play for water users. While there is a space for both standards and guidelines, they must not contradict each other and it must be clear that where a standard is legislated it obviously takes precedence over the guidelines. It must be emphasised that the existence of this guideline does not release the water services providers from their legal obligation to meet the SANS 241 standard. Thus, the need for the domestic use water quality guidelines does not stem from a legal obligation, but rather from the water resource management framework that demands decision support that accounts for all contexts of water use, in this case in the domestic environment.

DEVELOPMENT OF THE TECHNOLOGY DEMONSTRATOR DECISION SUPPORT SYSTEM (DSS)

The DSS is designed as a user-friendly tool to assess the impact of site-specific water quality on the domestic uses of the water and to provide generic risk-based water quality requirements on suitability for use. A simplified schematic representation of the DSS structure is shown in Figure 1. Generic and site-specific risk-based water quality guidelines are output of the decision support system. The generic risk-based water quality guidelines are reported as water quality requirements, as no site-specific components are inputted, the system reports on what would be the required water quality for an intended type of domestic use. The DSS allows for a three-tiered system for water quality risk assessments. Each tier provides an output that has to comply with the concept of classification or categorization. The difference between the tiers lies primarily in the degree of site-specificity required to produce an output, where:

- **Tier 1**: The lowest level is envisaged as being somewhat equivalent to the 1996 water quality guidelines. It requires no site-specific detail and it is intended to reflect the most conservative set of conditions, even if these do not occur together.
- **Tier 2:** The second tier is also provided for in the software decision support system and it caters for site-specific assessments, requiring some skills, but largely uses pre-defined water use scenarios and limited site characterisation choices with common field observation and or measurement input required from the user for scenarios manipulation.
- **Tier 3**: The third tier allows assessments and objective setting to be carried out in site-specific contexts not covered by tier 2.

The tool was developed in the Microsoft (MS) Excel Visual Basic for Applications (VBA) integrated development environment (IDE). The graphical user interface is developed using a series of 'UserForms' and results are displayed on worksheets and graph sheets. Custom dialog boxes, list boxes and message boxes are used to insert the input parameters of the tool. The tool also has the ability to export results to a 'PDF' format for a more formal reporting method.

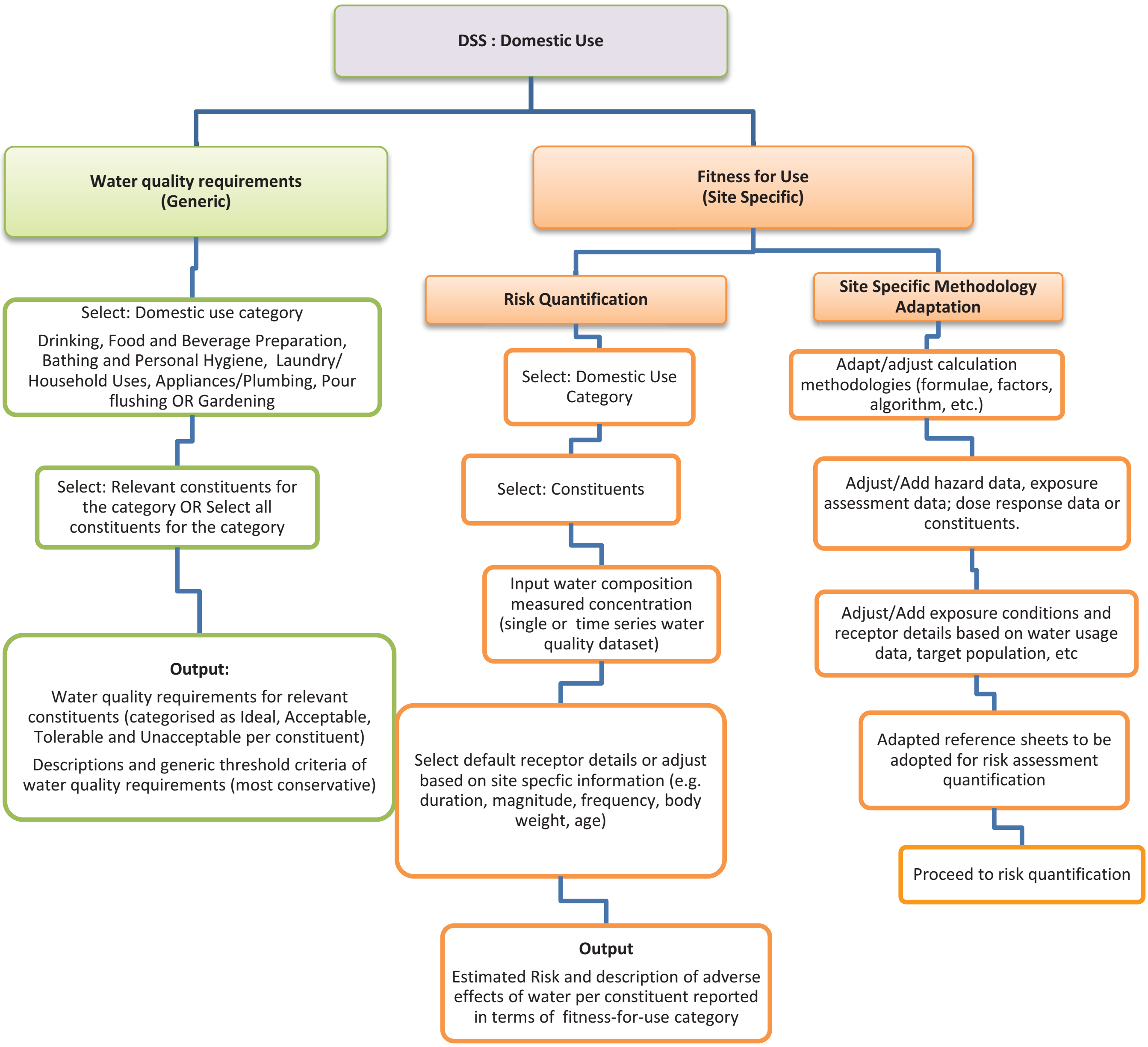
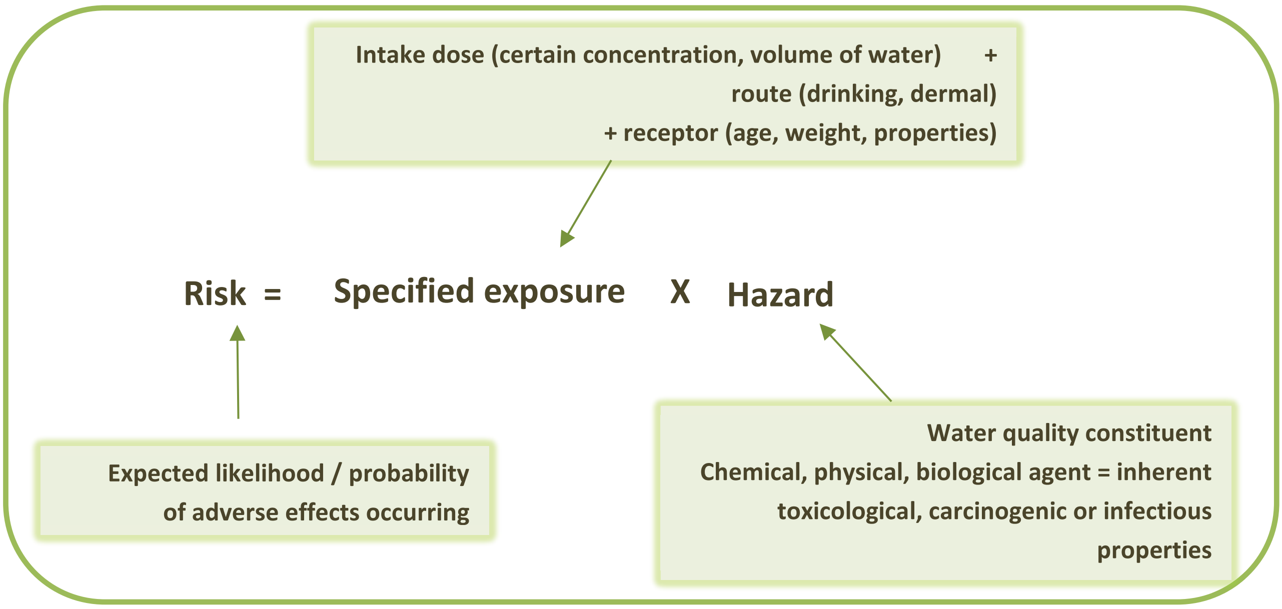


Figure 1: Functional structure of the DSS

GENERAL RISK APPROACH AND CALCULATING PROCEDURES

A water quality guideline is a recommended numerical concentration level (e.g. of a contaminant) or a descriptive statement (e.g. visual appearance of a water body) that will support and maintain the designated use of a particular water. The ultimate objective of drinking water quality guidelines (human consumption) is the protection of public health. Water quality guidelines for the domestic environment are also necessary to ensure that water is suitable for non-consumptive uses such as bathing and household use. The most effective means of ensuring safe drinking (and domestic) water supply should encompass a risk management approach at all steps in the water supply chain, from catchment to consumer. South Africa is one of the countries that has formally adopted the Water Safety Plan (WSP) approach, as a component of the Blue Drop Certification process, for the delivery of safe water supply to domestic users has been adopted. This is included. Thus, this framework has been used as a risk management tool to assess the risks associated with domestic water supply. Risk is generally taken to be the probability of injury, disease, or death under specific circumstances (WHO 2001). Acceptable risk is used in risk management to reflect the highest risk that can be tolerated for the specified adverse effect and target population. It depends on scientific data, social, economic, and political factors, and the perceived benefits arising from exposure to a contaminant (the hazard). The subject of what constitutes an acceptable risk is an extremely complex issue and must be handled from a policy perspective. Acceptable risk is very location-specific, and in some cases culturally specific. For this reason, it plays an important role in adapting guidelines to suit local circumstances, where local stakeholder involvement and available data is vital.

Risk quantification is applied as a basis to the assessment of fitness for use, while the site specificity relates to the nature of the water resource and the nature of the water user, based on the selected domestic use type. Risk, has been defined as the probability of the adverse/undesired effects to the domestic user of using water containing a potential hazard. The hazard in this context refers to a range of water quality constituents that may be present in the water that renders it less fit for use, and its consequences based on the how the water is to be used within the domestic environment. Thus, risk is a function of hazard and exposure. Where *hazard* = biological, chemical or radiological agent that has the potential to cause harm, *hazard effect* = adverse impact on human health/appliances/household items that can result from exposure to a substance and *exposure* = contact between a substance and an individual or a population. The threat caused by a hazard depends not only on the severity of its effect but also on whether or not the effect is reversible. Thus, the basic risk calculation method (generic or site-specific) applied in the DSS is based on the routes of exposure and type of hazard as shown in the graphic below.



The approach undertaken for the guideline development has incorporated the concepts of risk and site-specific concepts into the methodology to provide the risk-based water quality guidance to the user. The risk-based water quality guidance provided by the decision support system is a combination of the intrinsic risk (inherent properties) of the water quality constituent (its toxicity and known adverse effects) and the exposure scenario (how the water is used, by whom, for how long, etc) that is derived through a mathematical calculation which comprises the risk assessment. In the current guidelines, six calculations were considered, specifically addressing human health, aesthetic or physical risks. The six risk calculation methods are as follows:

1) Calculation 1 - Calculations associated with ingestion of water:
    - Chemical - Toxicant
    - Chemical - Carcinogen
    - Microbiological - Infectious agent
2) Calculation 2 – Calculations associated with inhalation
3) Calculation 3 - Calculations associated with dermal exposure
4) Calculation 4 – Calculations associated with physical effects
5) Calculation 5 – Calculations associated with aesthetic acceptability
6) Calculation 6 – Calculations associated with gardening.

RISK REPORTING

The risk-based water quality guidelines are reported at two levels based on whether the user selects generic or site specific (input based) guidance, as follows:

- ***For Water Quality Requirements (generic)***: a report of *all* risk threshold criteria and associated fitness for use levels (*i.e*. ideal, acceptable, tolerable or unacceptable) for the specific constituent(s) selected.
- ***For Fitness for Use (site specific)***: only the fitness for use category within which the quantified risk estimates falls (ideal OR acceptable OR tolerable OR unacceptable OR >DALY OR <DALY) together with the risk estimate value, the exposure concentration of the specific constituent and the description of the associated adverse effects is reported.

The risk output is categorised visually in a colour-coded manner (risk level as fitness for use description) that the user is able to immediately assess the level of threat posed. The two-type reporting system, includes either a four category or two category system which is dependent on the selected water quality constituent(s). The two-category system is applied to carcinogens and microbial infectious agents and the four-category system to toxicants and physical and aesthetic constituents. The two-category system reports a fitness for use either as (1) above or (2) below an acceptable risk target. The categorisation is based on threshold risk criteria as obtained from scientific literature and risk databases that include exposure assessment data for each constituent or on acceptable risk levels. The threshold limit criteria that apply to the reported fitness for use categorisation differs for each domestic user scenario. The four-category system is in harmony with a risk-based assessment of water quality in that the 'Ideal' category represents a no risk scenario (safe level), while the 'Unacceptable' category represents a high-risk scenario (likely presence of the adverse effects).

A generic description of the of the fitness for use categories used for tolerable burden of disease or cancer risk reporting

Reported Category	Description
Below acceptable risk target	< the upper limit target DALY tolerable burden of disease < the acceptable risk for cancer
Above acceptable risk target	> the upper limit target DALY tolerable burden of disease > acceptable risk for cancer

A generic description of the fitness for use categories used for risk reporting

Reported Category	Description
Ideal	A water quality fit for a lifetime of use.
Acceptable	A water quality that would exhibit minimal impairment to the fitness of the water for its intended use. No observed adverse effects.
Tolerable	A water quality that would exhibit some impairment to the fitness of the water for its intended use. Minor risk of adverse effects presenting themselves.
Unacceptable	A water quality that would exhibit unacceptable impairment to the fitness of the water for its intended use. Significant risk of adverse effects, presenting themselves.

RISK ESTIMATION IN THE DSS

The estimation of risk (probability of the risk occurring) in the decision support system constitutes the risk assessment process, which would then have to be taken by the user into the risk management phase to assess if the estimated risk is an acceptable one in the context of the situation. The risk assessment supports the risk management process, but the decision making will further also need to be based on target population, social concerns, public perceptions, economic issues or other related considerations. The decision support has been designed to assess:

- A quantitative risk - as a percentage probability of occurrence of the adverse effect (site specific guidelines), or as
- A qualitative risk - reported as a water quality requirement based on the risk threshold criteria levels at which the adverse effect is expected to manifest (generic guidelines)

The DSS home pages (see Figure below) allows the user to connect to the relevant assessment level that they wish to access. Each level requires additional information (user input) to assess the risk outcome involved in the use of water.

Example: Water quality requirement assessment

For example, manganese has a negative impact on both human health and laundry. If the user selected the 'Drinking' water use tab, the human health related equations to calculate the risk due to ingestion is used. The risk of ingestion is reported back to the user in the output report. If the user selects the 'Laundry' water use, the program will apply the inputted concentration to the risks of dermal contact and the colour thresholds on clothing (staining/discolouration) calculations. As these risks are derived through different formulae, the output report sheet will deliver the potential risk of the dermal contact effect (human health) separately to the potential risk of the laundry effect (physical effect). If the user submitted a sample set of water quality readings, the risk probability is calculated following statistical formulae.

Example: Fitness for Use Assessment

If the user selects the 'Fitness for Use Assessment' from the home page, the application will direct the user to the Fitness for Use Input page. Here, the user selects the domestic water use type, the constituents of concern and inputs their respective readings and the details of the receptor which is either based on default range which is incorporated into the risk probability calculations for human health calculations. If the user has a range of receptor details, the sensitive receptor details should be selected. If the user does not enter receptor details, the default values assigned for each parameter will be used in the calculation. Based on the inputs provided, the tool will process the respective calculations and generate a user-specific report. Three different reports are generated based on the user input. A single sample analysis generates a report based on a single water quality reading per constituent. A data series report is generated if the user provides a sample set of water quality readings.

CONCLUSION AND RECOMMENDATIONS

The project aim was successfully achieved, with the DSS as a product fulfilling the requirements of the technology demonstrator for risk based domestic use water quality guidelines. However, the following is required and recommended to develop the product further to a fully functional system to be utilised within the water resource management sector in South Africa:

- The further development of the domestic user DSS methodology in the next phases would need to address:
  - The functionality of the water quality objective setting at the fitness for use assessment level;
  - Expansion of the water quality constituent database to include all constituents relevant to domestic use, specifically in the South African context;
  - The consideration of synergistic and antagonistic effects of constituents and expansion of the calculation methodology to address this;
  - The update of the methodology to include the assessment of multiple constituents simultaneously;
  - Endpoint (Adverse effect levels) verification of all hazards;
  - The incorporation of local domestic water uses pattern information where applicable to improve site specificity, calculation methodology and receptor information;
  - Processes and procedures for the updating of the methodologies and exposure assessment data, based on the best available science information as it becomes available;
  - Functionality that allows export of water quality monitoring data from national and local monitoring programmes directly into the DSS;
  - A structured procedure applicable to the expert level users should be developed to control and maintain the original product while providing the user with a clear method of the detailed analysis and adjustment; and
  - Currently the DSS tool has been demonstrated using MS Excel, however in going forward to full scale application, it is recommended that available on-line databases be tested to select a software suitable for the DSS for the guideline series.
- Wider stakeholder buy-in and guidance is required to gain acceptance of the risk-based approach to the assessment of water quality. Users may be hesitant to want to take decisions on the basis of a risk

quantification that the DSS provides, without requisite understanding of the support it is meant to provide. More engagement is required to get users to accept the philosophy and approach;

- Further testing with the wider stakeholder user groups is required to refine the product and to update the DSS to improve user-friendliness and utility, based on feedback from users.
- A DSS tool that is available through an on-line platform is recommended.
- Next phases of the project require the integration with the user guidelines that needs to consider the selection of coding platform, intellectual property issues, controlled access to software system, version controls as well as processes and procedures on the updating of the methodologies and functionality of the DSS for the water user groups.
- Such a system places stringent demands on the custodianship of the product. An owner and champion within the DWS are required to spearhead the next phases of the DSS, its integration, its promotion and maintenance.

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Ms LS Mudau	Tshwane University of Technology, Dept of Environmental Health
Mrs S Freese	Water Science
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Ms M Swart	Rand Water
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Mr M du Plessis	University of Pretoria
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Mrs LA Boyd	Golder Associates Africa (Project Team)
Mr TJ Coleman	Golder Associates Africa (Project Team)
Mrs N Juggath	Golder Associates Africa (Project Team)
Mr G Singh	Golder Associates Africa (Project Team)
Mrs B Genthe	CSIR (Project Team)

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CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

The 1996 South African Water Quality Guidelines (SAWQGs) (DWAF, 1996) has been an extremely important contribution to water resource management in South Africa. It reflected the scientific thinking at the time it was produced and has been used by water quality managers and water resource managers as a primary source for decision-making to judge the fitness for use. Subsequently, the decision support function of water quality guidance has grown and become stronger, requiring contextual and integrated approaches. Since the evolvement of water resource management within South Africa, the SAWQGs have become decision support tools rather than just a list with limits. Both application and scope issues related to risk, site specificity and guidance on an expanded set of constituents have become more apparent. In 2007 a number of specific issues came to the fore that made it necessary to re-examine the philosophical basis used for determining and applying water quality guidelines. These included *inter alia* the implementation of resource directed measures (the classification of water resources, Reserve determination and determination of resource quality objectives) and the application of source directed controls under the National Water Act (Act No. 36 of 1998), the concept of risk as potential common basis for decision making in various contexts, site specificity and advancements in guideline determination internationally. Furthermore, additional factors have influenced the optimal use of the SAWQGs. These include the misapplication of the guidelines (e.g. guideline values are used interchangeably or confusion in interpretation of terminology; guidelines verse standards). These aspects highlighted the need of the regulator, water resource managers and water users for a quantifiable assessment system to judge fitness for use of water quality that moves beyond simple numeric values, to providing an assessment in terms of a scenario presented.

A review subsequently conducted in 2008 by the then Department of Water Affairs and Forestry (DWAF) concluded that the water quality guidelines need to be applied in manner that supported site specificity and be based on a risked philosophy. The revised guidelines should also allow for a tiered assessment approach that caters for the level of use and degree of complexity of the output and specifically be presented as a software-based decision support tool. In light of these recommendations the Water Research Commission (WRC) initiated an overarching project that has seen the commissioning of a series of projects to develop risk-based decision support tools per water user group. This project addresses the 'Development of a Risk based Methodology and Decision Support System for Domestic Water Use" as part of the series. Parallel projects addressing risk-based water quality guidelines for the irrigation and recreational water user groups have recently been completed, that are aligned in terms of the philosophy and concept fundamentals, to this, the domestic water user group guidelines.

1.2 PROJECT AIMS

The aim of this project was to develop a risk-based and site-specific methodology for assessing water quality requirements and fitness for domestic use, enabled through a user-friendly decision support System (DSS). The specific aspects that have been addressed in terms of meeting this objective include firstly, the development of the approach and methodology for the risk calculations based on supporting science to be included in the technology demonstrator; and secondly the development of the informatics for a demonstrator decision support system that addresses the main decision contexts for the use of the guidelines. The specific outputs of the project have included:

1. Definition of the risk-based approach and methodology for the domestic use risk-based water use guidelines (informatics of the decision support system);
2. Development of an intermediate technology demonstrator;
3. Decision support tool testing with user groups and individuals to assess functionality, design and user-friendliness, and the
4. Pilot technology demonstrator Domestic Water Use Decision Support System.

1.3 GENERAL APPROACH

The proposed extension to current guidelines lies in that the fitness for use assessment now relates to risk, which combines hazard and exposure, rather than the hazard predominantly, as applied in the 1996 guidelines. "Risk based" guidelines simply allow the suitability of the water to be interpreted in terms of risk of specific adverse effects. The development process of the project included a number of tasks and these are detailed in the sections that follow.

1.3.1 Inception phase

An inception phase that allowed for the conceptualization and contextualization of the envisaged DSS product. The basis for the development process was formulated which included defining the key concepts, project approach, the framework for the DSS, product definition and other relevant considerations for the project undertaking. It included a baseline literature review to determine the departure point for the risk-based approach and supporting science. The feedback received and discussion held with the reference group and the teams on the parallel projects was valuable in clarifying concepts and understanding, as well aligning the thinking of the concept fundamentals. The output of the phase was precursor document on the risk-based concept proposed for domestic water use.

1.3.2 Expansion of the list of water quality constituents

An aspect identified during the 2008 DWAF review requiring attention was the expansion of the current list of water quality constituents addressed for domestic water use. A focus group meeting was held with a committee of technical specialists and scientists (experts in the disciplines of human health, risk approaches and methodologies, drinking water domain, water use sector and related fields) to discuss the suite of water quality constituents that are included in the 1996 SAWQGs and its expansion to consider additional constituents. In addition, the current suite was also interrogated to determine which constituents should be removed and are no longer applicable in the current environment. Fruitful and robust discussion was held presenting varying viewpoints on the complement of constituents that must form part of the domestic use suite.

1.3.3 Review of supporting science and data on risk assessment

An in-depth review of literature to assess and characterise the hazards and to identify and collate the relevant information to support the risk assessment calculations to be applied was then conducted. The review assessed approaches, international databases, best practice and reference data to be adopted for the risk assessment in the DSS. The next step of the process focused on the definitions of the calculation methodology to be applied to quantify the risk. This involved the risk assessment component, providing a qualitative or quantitative estimate of the likelihood and severity of the adverse effects which could occur for an exposure scenario.

The methodology defined the mathematical calculations (formulae) and modelling that would be required to determine a risk estimate based on the scenario (receptor and site-specific exposure conditions). The adopted methodologies were guided by the reference group and the other project teams.

1.3.4 Development and testing of the decision support system

Concurrently with the risk calculation methodology development the specifications, minimum requirements and the design of the DSS were confirmed. This included the level of assessments required and the functionality of the system to provide the fitness for use assessment. The risk calculation methodologies were used as the basis to define the informatics for the software application. The team engaged with the irrigation and recreation water quality guidelines teams to ensure some degree of alignment among the respective DSSs. The demonstrator tool programming was then undertaken to develop the functionality and presentation as required. The definition of the levels of assessment, the application of the calculation methodologies to quantify the risk, the collation of all the reference data and the development of graphic user interface was undertaken. Further to this an important aspect was the fitness for use assessment and reporting of the outputs that was required. Testing and review were undertaken with identified individuals within DWS and the health sector. Further guidance was received from the reference group. Necessary refinements and adjustments were then made to the DSS based on this input. While wider stakeholder consultation was proposed at the outset of the project it was agreed by the project manager that this should be held off at this stage until further buy-in of the risk-based philosophy is obtained from the DWS and key stakeholders. This aspect would be taken forward through the WRC. Based on the outcomes of testing process and assessment, the risk calculations, the assessment definition, DSS design elements and user interfaces for the domestic use risk water quality guidelines were then finalized. This final report has been drawn up to include the risk methodologies and calculation procedures adopted and the presentation of prototype technology demonstrator DSS.

1.4 SCOPE AND LIMITATIONS

While a wide range of constituents were discussed and recommended for inclusion e.g. endocrine disrupting chemicals, pesticides, pharmaceuticals and contaminants of concern, the focus of this undertaking was to deliver on a technology demonstrator that included a suite of representative water quality constituents per domestic use category that addresses the different hazards types. For this technology demonstrator the recommendation of approximately additional 300 constituents-based water quality constituent lists of other countries were not taken up for inclusion in the DSS. However, the methodology adopted in the prototype DSS facilitates the incorporation of the selected additional constituents once confirmed, which is further dependent on the availability toxicological and exposure assessment data. The next phases of the project should focus on the extension of the water quality constituent list. This future undertaking will require the participation of toxicologists, risk assessment and medical practitioners to adequately assess the hazard effects and interrogate exposure assessment information.

CHAPTER 2: OVERVIEW OF THE DECISION SUPPORT SYSTEM

2.1 INTRODUCTION

The technology demonstrator decision support system (DSS) is an engineered computational software system presented as a pilot that provides a structured approach necessary for assessing water quality requirements and fitness for use for different domestic uses. The tool was developed in the Microsoft (MS) Excel Visual Basic for Applications (VBA) integrated development environment (IDE). The use of Microsoft Excel is motivated by its global acceptance as a powerful calculation and graphing program. It is easily accessible to most users, simple to understand and can be updated on a regular basis. The graphical user interface is developed using a series of 'UserForms' and results are displayed on worksheets and graph sheets. Custom dialog boxes, list boxes and message boxes are used to insert the input parameters of the tool. The tool also has the ability to export results to a 'PDF' format for a more formal reporting method. The tool is designed to guide users through a series of 'UserForms' at each assessment level to produce a relevant result based on the option selected. At this stage there is no separate database that is being utilised since the MS Excel platform performs a pseudo database function for the demonstrator tool. As the number of water quality constituents and their respective details grow, the demand for a separate database will probably grow. Microsoft Excel is limited as a database program and the vast amount of information that will be developed (water quality data) will require a stronger database management program such as MS SQL, or MYSQL or similar.

2.2 FUNCTIONALITY OF THE DSS

2.2.1 The three-tier approach system

The revised approach, allows for a three-tiered system for water quality risk assessments. Each tier provides an output that has to comply with the concept of classification or categorization. The difference between the tiers lies primarily in the degree of site-specificity required to produce an output. The three tiers are as follows:

- **Tier 1**: The lowest level is envisaged as being somewhat equivalent to the 1996 water quality guidelines. It requires no site-specific detail and it is intended to reflect the most conservative set of conditions, even if these do not occur together.
- **Tier 2:** The second tier is also provided for in the software decision support system and it caters for site-specific assessments, requiring some skills, but largely uses pre-defined water use scenarios and limited site characterisation choices with common field observation and or measurement input required from the user for scenarios manipulation. Possibly rule-based output interpretation. This tier is aimed at a guideline user with reasonable insight into the water uses and who is able to select site specific options presented in a pre-selected set of scenarios.
- **Tier 3**: The third tier allows assessments and objective setting to be carried out in site-specific contexts not covered by tier 2. The third tier of the guidelines is intended for use in highly site-specific contexts. This comprises a description of what is expected of risk assessment or risk-based objective setting. It would provide the most site-specific guidance – probably a risk assessment protocol, requiring highly skilled input- and output interpretation. The tier would likely require considerable expertise and would be used occasionally in practice and in specific situations.

2.2.2 Generic and site-specific water quality assessments

A simplified schematic representation of the DSS structure is shown in Figure 2-1. Based on the tiered approach, the risk-based water quality guidelines for domestic use is presented as a software decision support tool which operates at two levels of functionality. The difference between the levels lies primarily in the degree of site-specificity required to produce an output. The two-level assessment system accommodates for the needs of the novice, intermediate and expert user. Table 2-1 provides the definition of the assessment levels that inform the basis of design for the DSS informatics. Generic and site-specific risk-based water quality guidelines are output of the decision support system. The generic risk-based water quality guidelines are reported as water quality requirements, as no site-specific components are inputted, the system reports on what would be the required water quality for an intended type of domestic use.

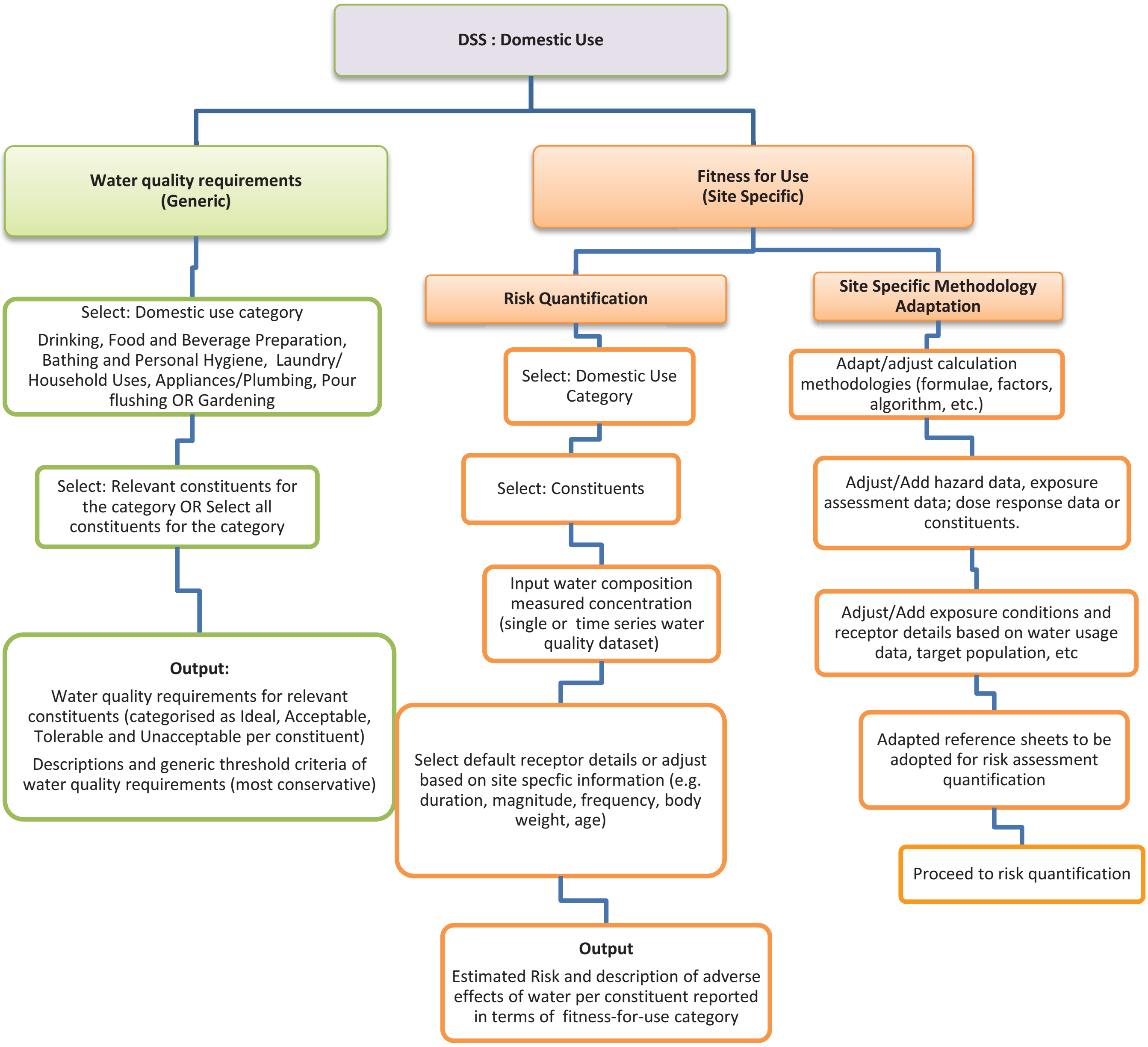


Figure 2-1: Functional structure of the DSS

Table 2-1: Water Quality Risk Assessment in the DSS

Fitness for Use		Water Quality requirement
Site specific		**Generic**
Expert	**Intermediate**	**Novice**
The most site-specific guidance. A risk assessment protocol, requiring highly skilled input and output interpretation. Allows for the adjustment of the algorithm and reference data. Default site specific component options that can be changed to suit site specific circumstances (more specific models and parameters). Functionality/permissions to adjust the calculation methodologies, reference databases and algorithms to provide the detailed site-specific risk quantification for the scenario.	Moderately site-specific, requiring some skills, but largely uses pre-defined water use scenarios and limited site characterisation choices with common field observation and or measurement input required from the user for scenarios manipulation. Rule-based output interpretation. Calculations are specific to the domestic water use categories and are based on the detail of the site-specific information entered	Most generic (and by implication the most conservative) approach to risk guidance. Minimum user input required and simple output provided. Simplified generic conservative assumptions used and totally reliant on the default datasets (worst case exposure). Does not involve rigorous calculation methodology.

2.3 RISK REPORTING IN THE DSS

The DSS incorporates the exposure scenarios (how the water is contacted and used), the risk assessment (the consideration of the water quality constituent and the user) and the two-level functionality (generic or specific) that is run through a calculation methodology (mathematical calculations) to provide risk-based guidance on water quality used for domestic purposes, using MS Excel as the user platform. The risk-based water quality guidelines are reported at two levels based on whether the user selects generic or site specific (input based) guidance, as follows:

- ***For Water Quality Requirements (generic)***: The DSS report screen reports *all* risk threshold criteria and associated fitness for use levels (*i.e*. ideal, acceptable, tolerable or unacceptable) for the specific constituent(s) selected.
- ***For Fitness for Use (site specific)***: The DSS report screen reports only the fitness for use category within which the quantified risk estimates falls (ideal OR acceptable OR tolerable OR unacceptable OR >DALY OR <DALY) together with the risk estimate value, the exposure concentration of the specific constituent and the description of the associated adverse effects.

A key feature of the DSS is that the risk output (risk-based guideline), is categorised visually in a colour-coded manner (risk level as fitness for use description) that the user is able to immediately assess the level of threat posed. The DSS uses a two-type reporting system, either a four category or two category system which is dependent on the selected water quality constituent(s). This fitness for use two- and four categorisation system is represented in Table 2-2 and 2-3, respectively. This is aligned with the standard practice within the Department of Water and Sanitation (DWS).

Table 2-2: A generic description of the of the fitness for use categories used for tolerable burden of disease or cancer risk reporting

Reported Category	Description
Below acceptable risk target	< the upper limit target DALY tolerable burden of disease < the acceptable risk for cancer
Above acceptable risk target	> the upper limit target DALY tolerable burden of disease > acceptable risk for cancer

Table 2-3: A generic description of the fitness for use categories used for risk reporting

Reported Category	Description
Ideal	A water quality fit for a lifetime of use.
Acceptable	A water quality that would exhibit minimal impairment to the fitness of the water for its intended use. No observed adverse effects.
Tolerable	A water quality that would exhibit some impairment to the fitness of the water for its intended use. Minor risk of adverse effects presenting themselves.
Unacceptable	A water quality that would exhibit unacceptable impairment to the fitness of the water for its intended use. Significant risk of adverse effects, presenting themselves.

The two-category system is applied to carcinogens and microbial infectious agents and the four-category system to toxicants and physical and aesthetic constituents. The two-category system reports a fitness for use either as (1) above or (2) below an acceptable risk target. The categorisation is based on threshold risk criteria as obtained from scientific literature and risk databases that include exposure assessment data for each constituent or on acceptable risk levels. The threshold limit criteria that apply to the reported fitness for use categorisation differs for each domestic user scenario. The four-category system is in harmony with a risk-based assessment of water quality in that the 'Ideal' category represents a no risk scenario (safe level), while the 'Unacceptable' category represents a high-risk scenario (likely presence of the adverse effects). The two-category system is aligned to the WHO (2017a) health-based target guidelines that is based on the health outcome type. The first outcome considers the burden of disease associated with different water-related hazards, taking into account varying probabilities, severities and duration of effects, and uses the disability-adjusted life years (DALY) tolerable burden of disease target as the metric. The second outcome considers the incidence of cancer and includes an acceptable risk target level (no adverse effect or negligible risk).

CHAPTER 3: GENERAL APPROACH AND RISK CALCULATION IN THE DECISION SUPPORT SYSTEM

3.1 RISK ASSESSMENT APPROACH

3.1.1 Definition of risk

Risk is generally taken to be the probability of injury, disease, or death under specific circumstances (WHO 2001). In general terms, risk depends on the following three factors:

- How much of a contaminant is present in the water?
- How much contact (exposure) a person or other receptor has with the contaminated water, and
- The inherent toxicity of the contaminant.

3.1.2 Acceptable risk

Acceptable risk is used in risk management to reflect the highest risk that can be tolerated for the specified adverse effect and target population. It depends on scientific data, social, economic, and political factors, and the perceived benefits arising from exposure to a contaminant (the hazard). Acceptable risk decisions are rarely easy. The subject of what constitutes an acceptable risk is an extremely complex issue and must be handled from a policy perspective. In determining acceptability, it is however largely the perceived risk that determines the basis of what can be tolerated. Acceptable risk is very location-specific, and in some cases culturally specific. For this reason, it plays an important role in adapting guidelines to suit local circumstances, where local stakeholder involvement and available data is vital. For purposes of the risk-based guidelines acceptable risk applied includes internationally applied risk levels derived from the probability approach, the tolerated approach and disease burden approach.

3.1.3 Risk assessment approach

Risk assessment is a process by which the extent of exposure is compared against the hazard of the contaminant to determine whether it is likely to result in harm to the exposed individual(s)/situations. Exposure to a contaminant can be by oral, inhalational or dermal routes (WHO, 2006). Figure 3-1 presents the building blocks to the risk-based guideline development which that comprise key elements required to quantify the risk. The supporting science and the way in which it has been applied, the quantification relationships and the calculation methodology protocols applied to the domestic use scenarios for the risk assessment calculation are detailed in the supporting report to this report.

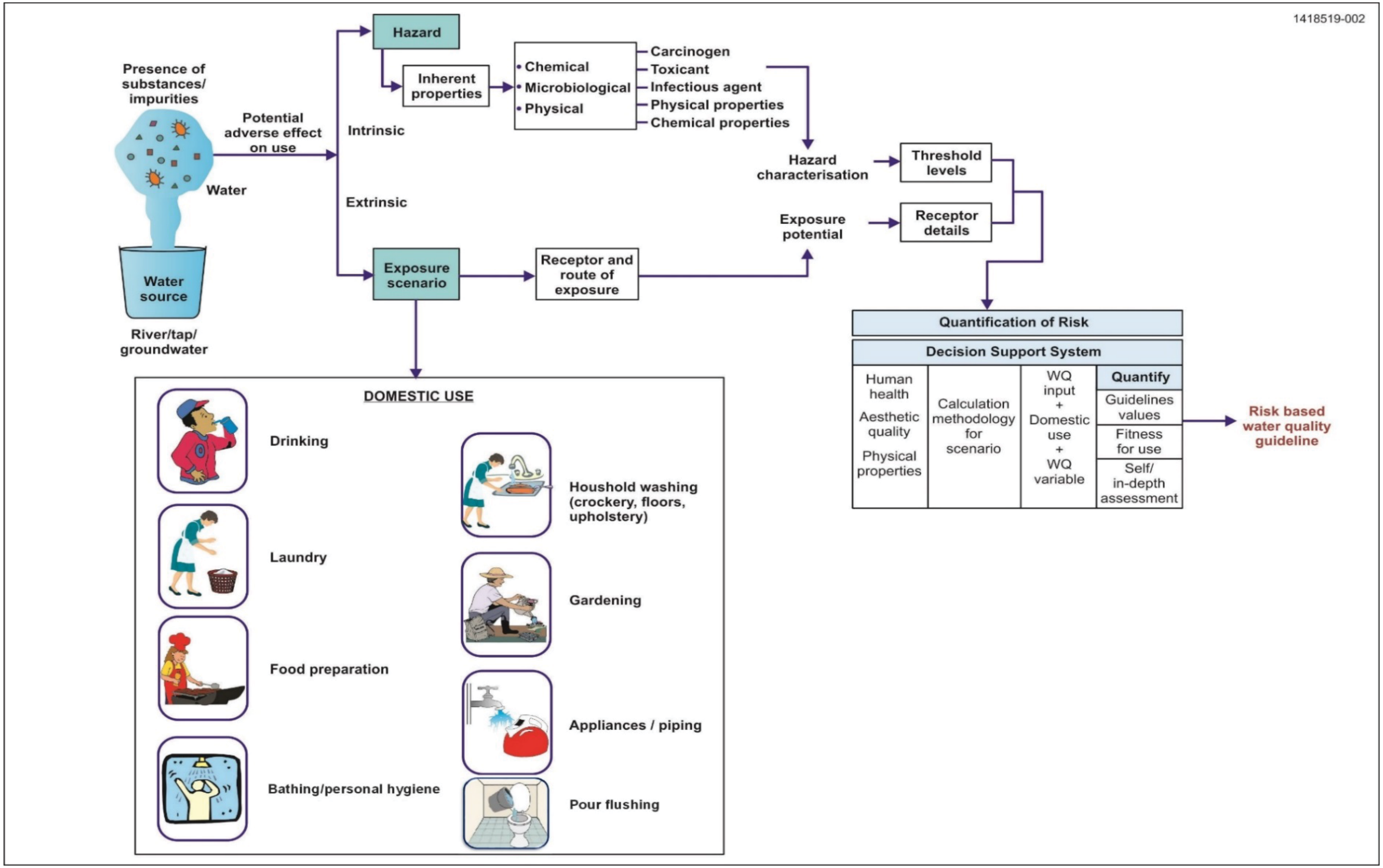


Figure 3-1: Building blocks to the risk-based water quality guideline development

The building blocks comprising the risk approach applied in the development of the domestic user water quality guidelines therefore involves:

- Definition of Extrinsic Risk component - description of the exposure scenarios
- Characterisation of the Intrinsic Risk component
- Hazard identification; and characterisation - defining effect concentrations of no effect and the full adverse effect i.e. the hazard function.
- Categories of hazard (as related to the calculation methodology to be applied)
- Quantification of risk
- Calculation Methodology formulation; and
- Output

3.2 PERFORMING WATER QUALITY ASSESSMENTS IN THE DSS

3.2.1 Overview

The DSS allows the user to perform two types of water quality assessments (Figure 3-2), either:

- as a water quality requirement *i.e.* generic conservative threshold risk criteria per constituent for a selected domestic use category, or
- as a quantified risk estimate of fitness for use, expressed for a selected domestic use category based on an input and selected exposure conditions.

Figure 3-2: DSS homepage showing functionality for preforming water quality requirement and fitness for use assessments

3.2.2 Assessing water quality requirements

Figure 3-3 shows the steps for performing water quality requirements for different domestic uses in the DSS. In terms of the domestic user and for the purposes of the risk-based guidelines output generated from each domestic use category is defined as follows:

- **Water quality required for drinking** is defined by the effect water quality constituents have in the event of ingestion of water or inhalation of volatiles released from the water during ingestion; and on the aesthetic quality of the water as it relates to taste, odour and colour.
- **Water quality required for food and beverage preparation** is defined by the effect water quality constituents have upon ingestion and on aesthetics, after food has undergone preparation using the water (cooking and boiling in water, washing of food and use in constitution of beverages).
- **Water quality required for bathing and personal hygiene** is defined by the effect water quality constituents have in the event of skin contact of water due to bathing and other personal hygiene applications. Small volumes ingestion of water or inhalation of volatiles released from the water and the effect of the aesthetic quality is also considered.
- **Water quality required for household washing** is defined based on the effects the water quality constituents will have on the washing application (dishes, floors). The consideration of water contact on skin is covered the human health aspect as related to the water use categories of drinking and bathing;
- **Water quality required for laundry** is defined by the effect water quality constituents have on clothing. The consideration of water contact on skin is covered by the human health aspect as related to the water use categories of drinking and bathing;
- **Water quality required for appliances and distribution systems** is defined by the effect water quality constituents will have on appliances and on general plumbing equipment.
- **Water quality required for gardening** is defined by the effect water quality constituents have as it relates to domestic gardening. This definition relates specifically to plants grown for subsistence purposes. The effects as related to crop reduction and microbial contamination are considered as part of domestic use. The water quality requirements (generic application) from the irrigation user water quality guidelines are relied upon and are adopted for domestic use. For more advanced assessments the user is directed to the risk-based irrigation water quality guidelines.
- **Pour flushing:** is defined by the use of greywater[1] for pour flushing (manual flushing) of toilets. The effect water quality constituents have in the event of skin contact of aerosols that arise from the water and small volumes of inhalation of volatiles released from the water during the pour flushing process is considered.

[1] Greywater: wastewater resulting from the use of water for domestic purposes but does not include human excreta. National Sanitation Policy, Department of Water and Sanitation, 2016.

Figure 3-3: Steps for performing water quality requirements for different domestic uses

3.2.3 Fitness for use and site-specific assessments

The site-specific components of the risk-based guidelines relates primarily to the nature of the water resource (source water) and the nature of the water user. The nature of the water resource will relate to the composition of the water quality to be assessed (constituents and concentrations), while the nature of the water user will need to consider how the water is exposed to the domestic user. This considers the selected the conditions of the exposure (duration, volume, route, frequency) and the characteristics of the receptor (e.g. human – age, body weight). It is important to note that guidelines reflect the scientific environment whereas standards reflect the regulatory environment (Figure 3-4).

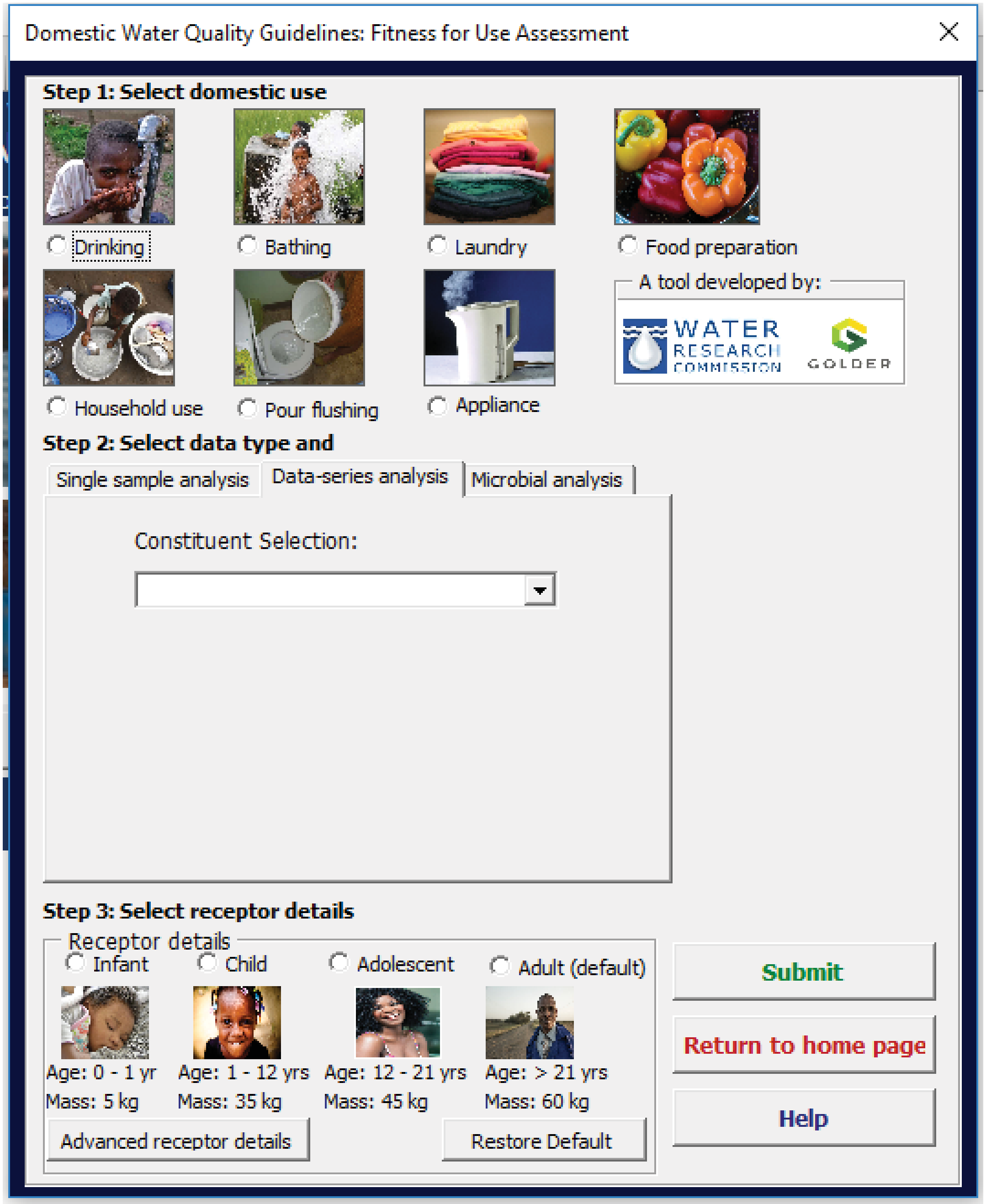


Figure 3-4: Steps for performing fitness for use assessments for different domestic uses

3.3 INPUT REQUIREMENTS

3.3.1 Overview

Risk is assessed in the DSS based on the following components:

- *Domestic use Categories*: The domestic use categories incorporate what the water is to be used for and as previously indicated, the categories of water use in terms of the domestic user include:
  - Drinking;
  - Food and beverage preparation;
  - Bathing and personal hygiene use;
  - Laundry;
  - Household washing;
  - Appliances/Piping;
  - Gardening; and
  - Pour flushing.

- *For hazard identification:* The contaminant (water quality constituent) (the dose response hazard assessment - literature data).

- *For hazard characterisation*:
  - For the contaminant (water quality constituent) – determination how the potential adverse effect is experienced
  - The exposure route (how)
  - The receptors (humans/circumstances/appliances)
  - The exposure conditions

- *For risk characterisation (quantification)*: Domestic use category and the incorporation of all of the above.

The tool processes the user inputs based on the above to provide a generic guideline or site-specific risk estimate as an output. The input elements that each component incorporates are described below.

3.3.2 Hazard identification

3.3.2.1 Selecting the water quality constituent(s)

Based on the hazard identification and characterisation (determining the inherent properties of water quality constituents) five categories of hazards are identified for domestic use. These hazard categories dictate the calculation methodology applied in the DSS for the risk quantification, and include the following:

- Carcinogens (non-threshold - those that do not appear to have a threshold)
- Toxicants (effects are observed only above a certain threshold dose, with no effects observed at doses below this threshold even with lifetime exposure)
- Infectious agents (microbiological – disease burden quantification)
- Physical properties (aesthetic acceptability and physical damage); and
- Chemical properties (damage to subsistence garden crops)

3.3.2.2 *Determining inherent toxicity*

This process has relied on existing international literature and research for which the hazards have been characterised *e.g.* human health related hazards (chemical toxicants, carcinogens). To determine the hazard or inherent toxicity of a chemical/contaminant, a comprehensive array of toxicity tests is performed, from which the critical effect and a "**no-observed-adverse-effect level**" (NOAEL) are derived. An uncertainty factor (sometimes called a safety factor), which is chosen in recognition of intra- and interspecies variability (maximum 10-fold for each) and the adequacy of the toxicological database, is applied to the NOAEL, to give a guidance value. Alternatively, a margin of safety of exposure can be calculated for a specific scenario by comparing the NOAEL with the actual exposure conditions (WHO, 2006). The objective of toxicity assessment is to identify potentially toxic effects of the hazard and determination of the amount of constituent that a receptor can be exposed to without experiencing unacceptable effects. This value is called the **toxicity reference value** (TRV) or toxicity benchmark.

For humans the TRV is expressed as mg of a chemical per kg of body weight per day (mg/kg-d) for non-carcinogens, and as a slope factor (mg/kg-d)$^{-1}$ for carcinogenic chemicals (for human health only). The toxicity assessment provides the basis for evaluating what is an acceptable exposure and what level of exposure may adversely affect human health. The toxicity assessment is based on chronic exposure and not acute exposure. A dose response relationship describes how the likelihood and severity of adverse health effects (the responses) are related to the amount and condition of exposure to a contaminant (dose provided). The same principles apply for studies where the dose is the exposure to a concentration of an airborne contaminant (inhalation studies), referred to as a concentration-response relationship.

A NOAEL is the highest exposure level of a chemical in a study, found by experiment or observation, where statistically or biologically no significant increases are seen in the frequency or severity of the adverse effect between the exposed population and its appropriate control population. Wherever possible, the NOAEL, is based on long term studies, preferably of ingestion of drinking water. However, NOAELs obtained from short terms studies using other sources of exposure e.g. (food, air) may also be used. If a NOAEL is not available a **Lowest-Observed-Adverse-Effect** (LOAEL) may be used. The LOAEL refers to the lowest dose or concentration of a contaminant (hazard) tested at which a detectable adverse effect is noted. Should the LOAEL be used, an additional uncertainty factor is usually applied. (https://www.epa.gov/risk/guidelines-developmental-toxicity-risk-assessment; WHO 2017).

The **reference dose** (RfD) is an oral or dermal dose derived from the LOAEL or NOAEL by application of order of magnitude uncertainty factors. The RfD is defined as an estimate of a daily oral exposure to the human population (including sensitive populations) that is likely to be without an appreciable risk of harmful effects during a lifetime (the acceptable risk level). The **RfD is generally expressed** in **units of milligrams per kilogram of bodyweight per day: mg/kg/day.** A similar term, known as **reference concentration** (RfC) is used to assess inhalation risks, where concentration refers to levels in the air (generally expressed in the units of milligrams agent per cubic meter of air: mg/m^3). For carcinogens these chemicals are capable of producing an adverse effect at any level of exposure. The extrapolation phase of this type of assessment does not use uncertainty factors; rather, a straight line is drawn from the point of departure for the observed data to the origin (where there is zero dose and zero response). The slope of this straight line, called the slope factor or cancer slope factor, is used to estimate risk at exposure levels that fall along the line (an excess lifetime cancer risk is calculated *i.e.*, probability that an individual will contract cancer over a lifetime) resulting from exposure to a contaminant by considering the degree to which individuals were exposed, as compared to the slope factor.

The hazard characterisation data (the reference dose (RfD), reference concentration (RfC), oral slope factor, or inhalation unit risk), NOAEL and LOAEL collated for the water quality constituents are the key components of the risk assessment and are incorporated into the technology demonstrator as the reference data and are applied as threshold risk criteria. This hazard assessment data may be adjusted by the expert user who has sufficient knowledge and new scientific data to update the values. For the purposes of the development of a technology demonstrator the number of water quality constituents (hazards) addressed were limited to 50 constituents, comprising the different types – toxicants, carcinogens, infectious agents, physical and aesthetic aspects. The suite of constituents comprises selected constituents of the 1996 Domestic Use Water Quality Guidelines (Volume 1), relevant constituents from SANS 241 (that are currently not included in the 1996, Volume 1 suite), and selected constituents of WHO Drinking Water quality guidelines.

3.3.3 The Adverse Effect 'Experience'

These are the common risks based on the use category of how the potential adverse effect is experienced by a domestic user (Figure 3-5). They include:

- human health impact,
- aesthetic quality impairment and
- physical effects.

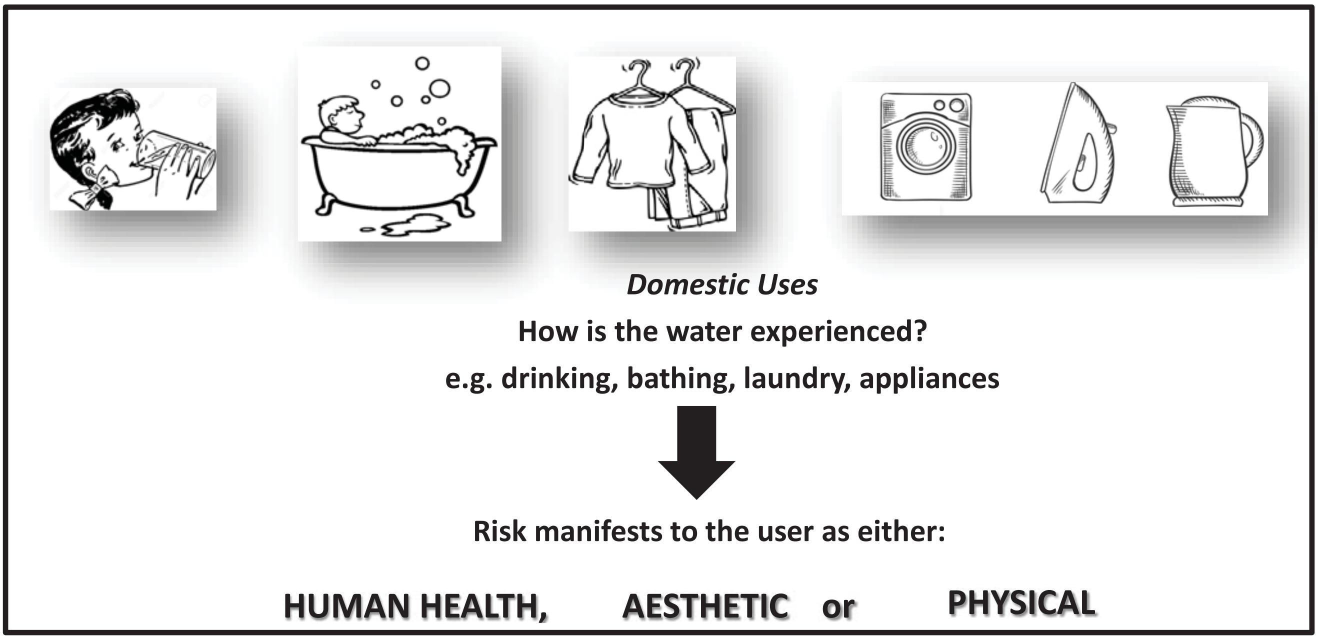


Figure 3-5: Water quality effects

3.3.4 The Exposure Route (The How)

This component considers how the water is being contacted by the domestic user. The exposure route means of entry of the contaminant (water quality constituent). The exposure route is generally further described as intake (as eating, drinking, or inhaling) or uptake (absorption through skin or eye) on contact. Five pathways are assessed operable for each receptor identified.

- ingestion
- inhalation
- dermal
- aesthetic acceptability (contact)

- physical/chemical contact household items/objects, gardening crops

3.3.5 The Receptor

In assessing risk, exposure assessment is the process of estimating the exposure of a human receptor/situation to a contaminant under a given scenario. The most susceptible receptor varies depending on the expected water use. Three receptors are considered in the DSS with respect to domestic use:

- humans (health and aesthetics)
- household items/equipment/appliances, laundry
- subsistence crops

An exposure assessment is conducted for each potential hazard identified. For humans (health) exposure is determined as a dose (intake amount) and is called the estimated daily intake (EDI). The EDI is typically expressed as milligram (mg) on a body mass basis. The EDI is calculated from site-specific concentrations of the contaminants (water quality constituent) in water, the amount of time a human experience the water uses and human-specific parameters, including body weight and ingestion rates. For example;

- For the human health risk assessment, the very young and the elderly are considered the most susceptible.
- For human palatability (aesthetics), exposure is determined as the desirability of the water based on the threshold tolerance levels to colour and odour/taste.
- For the household items, laundry, appliances and equipment exposure is determined based on the threshold tolerance levels of each receptor to the chemical constituents of relevance relative to the increasing intensity of physical effects as experienced.
- For subsistence crops exposure is determined as relative crop yield, degree of leaf scorching and number of infections associated with microbial contamination.

3.3.6 The Exposure Conditions

3.3.6.1 Performing water quality requirement assessments

The exposure conditions consider aspects such frequency, duration, magnitude and levels of contact of the receptor with the hazard (water quality constituent. Table 3-1 lists the default exposure conditions included in the DSS. With selection of this option the assessment does not involve rigorous calculation methodology. The Use simplified conservative assumptions requiring no input for the assessment.

Output: The water quality requirements per constituent are categorised as ideal, acceptable, tolerable or unacceptable based on the risk level and the associated adverse effect is reported for the domestic use type and routes of exposure (most conservative and generic). This information is reported for each constituent as selected by the user.

Table 3-1: Default exposure conditions for assessing generic water quality requirements

ROUTE AND RECEPTOR	MAGNITUDE	BODY WEIGHT	FREQUENCY		DURATION
	Quantity	Mass (kg)	Per day	Per year	Age (years)
INGESTION					
Drinking (For Chemical)	Consumption volume				
Adult	2L	60	1	365	65
Drinking (For Microbial)	Consumption volume				
Adult	1L		1	365	
Bathing and Personal hygiene	Ingestion volume				
Adult	15ml	60	1	365	65
Food preparation	Ingestion volume				
Adult	500ml	60	1	365	65
Via sprays	Ingestion volume				
Pour flushing					
Adult	0.01ml		1	365	
Laundry	Ingestion volume				
Adult	15 ml	60	1	365	65
INHALATION					
	Volume				
Adult	0.306 m^3	60	1	365	65
DERMAL					
	Surface area				
Bathing	6 600 cm^2		0.5 hour	365	65
Laundry	2 800 cm^2		0.5 hour	365	65
Household use	2 800 cm^2		0.5 hour	365	65

Example: a user wants to know what the water quality requirements are for domestic use for drinking purposes. The user selects 'Water Quality Requirements' tab on the homepage, the 'Drinking' use category; then water quality constituent of interest or 'All' constituents applicable to drinking. The risk-based threshold limit criteria for the water quality constituents relevant to drinking use are reported at the ideal, acceptable, tolerable or unacceptable levels as the DSS output, with a description of the adverse endpoint effects.

3.3.6.2 Performing fitness for use assessments

Table 3-2 shows the range exposure conditions available to be applied to the site-specific fitness for use assessments. The user has the option to select the conditions suited to the site-specific context. Specific to the selected domestic water use categories and are based on the detail of the site-specific information entered or selected. It provides options and allows the user to define point concentrations and exposure details. The assessment can be utilised to obtain a conservative fitness for use output based on a specific domestic water composition (water quality) entered by the user. *Output:* A simplified risk estimate of the water quality specified by the user as compared to threshold risk criteria. The calculation of risk is based on a predefined (default) set of conditions with receptor and hazard characterisation remaining constant, allowing a single exposure input or input of a range of exposure concentrations (a record of historical water quality data); or the option to adjust receptor details to account for variabilities in the target population (magnitude, duration, frequency) as the components of site specificity.

Example: a domestic user who has a borehole and would like to know whether it is safe to drink takes a sample to a laboratory and gets a laboratory certificate of analysis. The user selects the 'Fitness for Use' tab on the homepage. The 'Drinking' use category is then selected. The user selects water quality constituents of interest and inputs the values (single or time series) per water quality constituent into the DSS for the drinking use category. The user may change the details of who is primarily drinking this water *i.e.* whether it is an adult, child or infant. The DSS provides a colour coded risk percentage output for each constituent for drinking that is linked to a probability of the adverse effects (endpoints) occurring that may be associated with that risk quantified.

3.3.6.3 Performing fitness for Use: site-specific assessments

The user is able to make changes and tailor the fitness for use assessment in the DSS to suit more detailed site-specific scenarios/conditions. This functionality is targeted at the expert/experienced user. The user may change the risk calculation methodology and/or adjust the exposure assessment parameters (site specific exposure conditions), hazard reference data (dose-response assessments) or acceptable risk targets as required, based on new empirical scientific data or advancements, or more up to date literature, or based on site specific circumstances. New constituents of interest or of local relevance may also be included. Accessibility to this functionality in the DSS may be password permitted.

Example: The user uses new toxicological study data to adjust the uncertainty factors and reference doses of the hazard (water quality constituent) in the reference data sheets or adjust the body weights of the receptors in the reference data sheets based on local knowledge and site-specific circumstances of target population. The user then accesses the 'Fitness for Use' functionality as described above to run the risk assessment on the selected scenario.

Table 3-2: Exposure Conditions for determining fitness for use - site specific

ROUTE AND RECEPTOR	MAGNITUDE	BODY WEIGHT	FREQUENCY		DURATION
	Quantity	Mass (kg)	Per day	Per year	Age (years)
INGESTION					
Drinking (For Chemical)	Consumption volume				
Adult	2L	60	1	365	65
Adolescent	2L	45	1	365	21
Children	1L	35	1	365	12
Infants	750ml	5	1	365	1
Drinking (For Microbial)	Consumption volume				
Adult	1L		1	365	
Adolescent	1L		1	365	
Children	1L		1	365	
Infants	1L		1	365	
Bathing and Personal hygiene	Ingestion volume				
Adult	15ml	60	1	365	65
Adolescent	15ml	45	1	365	21
Children	15ml	35	1	365	12
Infants	15ml	5	1	365	1
Food preparation	Ingestion volume				
Adult	500ml	60	1	365	65
Adolescent	500ml	45	1	365	21
Children	500ml	35	1	365	12
Infants	500ml	5	1	365	1
Via sprays	Ingestion volume				
Pour flushing					
Adult	0.01ml		1	365	
Adolescent	0.01ml		1	365	
Children	0.01ml		1	365	
Infants	0.01ml		1	365	
Laundry	Ingestion volume				
Adult	15 ml	60	1	365	65
Adolescent	15 ml	45	1	365	21
Children	15 ml	35	1	365	12
Infants	15 ml	5	1	365	1
INHALATION					
	Volume				
Adult	0.306 m^3	60	1	365	65
Adolescent	0.329 m^3	45	1	365	21
Children	0.226 m^3	35	1	365	12
Infants	0.273 m^3	5	1	365	1
DERMAL					
	Surface area				
Bathing	6 600 cm^2		0.5 hour	365	65
Laundry	2 800 cm^2		0.5 hour	365	65
Household use	2 800 cm^2		0.5 hour	365	65

3.4 RISK CALCULATION IN THE DSS

3.4.1 Overview

Quantification of the risk depends on whether the risks are human health, aesthetic or physical associated adverse effects. For example;

- The health-related acceptable risk values (for chemicals) are conservative, incorporate a range of safety factors and are based on reference toxicological data. Characterization of the hazard as either a threshold (toxicant) or non-threshold (carcinogen) chemical is important as different approaches are used for the quantification of the risk estimate. The use of threshold criteria has been applied to quantifying risk of the aesthetic and physical effects of the chemical constituents based on exposure and threshold tolerance levels for each.
- The health risk associated pathogenic bacteria, viruses and parasites present in water for domestic use is determined by a quantitative microbial risk assessment (QMRA), an approach adopted by the World Health Organisation in the Drinking Water Quality Guidelines (WHO, 2017). The QMRA provides an estimate of the probability of infection based on the number of pathogens ingested (dose). The QMRA is the adopted calculation methodology.
- For the purposes of the domestic use risk-based water quality guidelines, the risk to the domestic user who relies on subsistence crops is included at a reference level as generic risk-based water quality requirement. The domestic use guidelines have adopted the generic fitness for use criteria of the Irrigation Risk Based Water Quality Guidelines (conservative limits). For further risk-based site-specific guidance the user is directed to the Irrigation Risk Based Water Quality Guidelines (Meiring, *et al*. 2017).

3.4.2 Risk calculation method

The basic risk calculation method (generic or site-specific) applied in the DSS is based on the routes of exposure and type of hazard as shown in Figure 3-3 below.

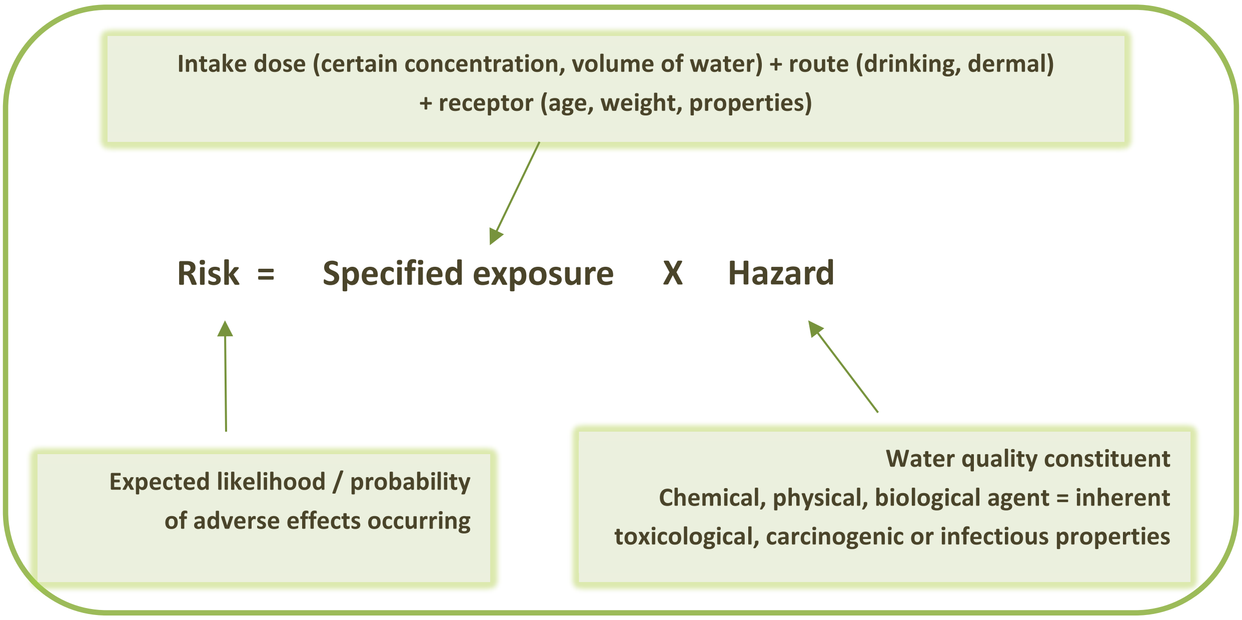


Figure 3-6: Risk as a function of hazard and exposure

The following calculation procedures are included in the DSS:

- Calculation 1 - Calculations associated with ingestion of water:
  - Chemical - Toxicant
  - Chemical - Carcinogen
  - Microbiological - Infectious agent

- Calculation 2 – Calculations associated with inhalation

- Calculation 3 - Calculations associated with dermal exposure

- Calculation 4 – Calculations associated with physical effects

- Calculation 5 – Calculations associated with aesthetic acceptability

- Calculation 6 – Calculations associated with gardening

The procedures for performing these calculations are elaborated separately in the Chapters that follow.

CHAPTER 4: PROCEDURES TO CALCULATE AND CRITERIA USED TO ASSESS HUMAN HEALTH RISKS

4.1 INPUT REQUIREMENTS

- Select type of assessment
- Determine the water quality constituents (hazards) that require evaluation.
- For fitness for use and site-specific assessments - determine the receptor (infant, child, adolescent, adult)
- For fitness for use and site-specific assessments - identify the exposure pathway (e.g. ingestion)

4.2 CALCULATION OF RISKS ASSOCIATED WITH CHEMICALS

4.2.1 Ingestion of chemicals in water

If a chemical has a threshold affect it is considered to have a 'safe' dose where no adverse effects will occur. For these chemicals, a reference dose is derived or calculated based on tolerable daily intakes from which a guideline value will be derived. Developing guidelines for chemicals without a threshold effect (carcinogens) it is assumed that the carcinogenic effect may be induced at any level of exposure and therefore no threshold exists below which it is considered 'safe'. The Exposure Ratio (ER) is required to be calculated. The DSS adopts the calculation methodology as described below:

Calculating EDI: The expected daily intake (EDI) is calculated as follows in mg/kg.d:

$$EDI_{water} = [(C_W \times IR_W \times EF \times ED)/ (BW \times AT \times LE)] \times AF_{GIT}$$

Where: EDI_{water} = exposure due to ingestion of water
C_W = chemical concentration in water (mg/l)
IR_W = receptor water ingestion rate (l/d)
EF = Exposure frequency (d/yr)
AF_{GIT} = Absorption Factor Gastrointestinal tract
ED = Exposure Duration (years) (= 1 for non-carcinogens)
BW = receptor body weight (kg)
AT = 365 days (d)
LE = life expectancy (years) (for assessment of carcinogens only)
AF_{GIT} = 1

For carcinogens in water EDI is calculated as follows in mg/kg.d:

$$EDI_{water} = [(C_W \times IR_W \times AF_{GIT} \times D_2 \times D_3 \times ED)/ (BW \times AT \times LE)]$$

Where D_2 = days/7 days and D_3 = weeks/52 weeks

Calculating the exposure ratio: The exposure ratio is then calculated as follows:

- **ER (non-carcinogens) = EDI/TRV**; where TRV is either the RfD, NOAEL or LOAEL. If ER < 1 then the risk is negligible and the water is safe for use. If ER>1 then Step 4 needs to be conducted

- **ILCR (carcinogens)** = (EDI*TRV) X ADAF where TRV = slope factor
  Where: ER = Exposure Ratio
  TRV = Toxicity reference value
  RfD = Reference dose
  ADAF = Age dependent adjustment factor

If ILCR <10E-05, risk is negligible and the water is safe for use. If ILCR> 10E-05, the risk level for carcinogens is exceeded.

Comparing threshold values for fitness for use
The TRVs can be presented as oral reference doses (RfD's) for non-carcinogenic chemicals. These reference doses are defined as the amount of constituent per unit body weight that can be taken into the body each day, with negligible risk of adverse health effects.

4.2.2 Inhalation of chemicals in water

Volatile substances in water may be released into the atmosphere during showering and through household washing and flushing of toilets with grey water. For the inhalation chemical risk as a result of bathing, personal hygiene and flushing, Exposure Ratio (ER) is calculated using RfC and not RfD, and the same methodology as for the ingestion risk is followed.

Calculating EDI: the ingestion rate of water of 2L/day is replaced with the following inhalation volume for the calculation (based average inhalation volumes for the age groups below):

- Infant (birth to 1 year) – 0.092 m^3/day
- Child (1 to 16 years) – 0.226 m^3/day
- Adult (16 to 61 years) – 0.332 m^3/day
- Elderly person (above 61 years) – 0.273 m^3/day

Calculating the exposure ration: The exposure ratio is then calculated as follows:

- **ER (non-carcinogens) = EDI/TRV**; where TRV is the RfC or NOAEL or LOAEL

If ER < 1 then the risk is negligible and the water is safe for use.

- ILCR (carcinogens) = (∑EDI*TRV) x ADAF where TRV = slope factor

If ILCR <10E-05, risk is negligible and the water is safe for use. If ILCR> 10E-05, the risk level for carcinogens is exceeded.

Comparing threshold values for fitness for use
The TRV's can be presented as inhalation reference concentrations (RfC's) for non-carcinogenic chemicals. These reference doses are defined as the amount of constituent per unit body weight that can be taken into the body each day, with negligible risk of adverse health effects.

4.2.3 Calculations associated with dermal exposure to chemicals in water

Dermal exposure is described as the amount of an agent that contacts the outer boundary of the body (dose) and is capable of being distributed to one or more organs to exert a toxic effect (target dose). The amount of exposure will depend on the concentration of the chemical contacting a given area of skin, the ability of the chemical to penetrate and pass through the skin and the duration and frequency of contact in terms of the intervals of contact and the number of intervals per day, weeks, months or even a lifetime. For the case of the domestic use guidelines, the duration and frequency of contact can be summarised as:

- Intervals of contact – 0.5 hour
- Number of intervals per day – 1

In dermal exposure assessment, the contaminant concentration is the amount of chemical contaminant in the water that is available for contact that can be deposited on the skin during a given activity. For dermal water pathways, the dermal absorbed dose that results from the contact of chemicals in contaminated water is calculated as:

$$DAD = (DA_{event} \times ED \times EV \times EF \times SA) / (BW \times AT)$$

Where DAD = dermal absorbed dose (mg/kg-d)
DA_{event} = absorbed dose per event (mg/cm^2 – event)
SA = skin surface area available for contact (cm^2)
EV – event frequency (events/d)
EF – exposure frequency (d/yr)
ED = exposure duration (yr)
BW = body weight (kg)
AT = averaging time (d)

Where $DA_{event} = K_p \times C_w \times t_{event}$
K_p = dermal permeability coefficient (cm/h)
C_w = concentration in water (mg/l)
t_{event} = event duration (h/event)

For carcinogens in contaminated water dermal risk is calculated as follows:

$$DALY = DAD \times \text{slope factor}$$

Where DAD = dermal absorbed dose (mg/kg-d)
DALY = Daily adjusted life years

The value of K_p for inorganics ranges from 0.0006 to 0.002 cm/h for metals, except mercury vapour which is 0.24cm/h. For all other inorganics, K_p is given as 0.001 cm/h. For organics it was assumed that K_p is 0.001 cm/h.

4.3 CALCULATION OF RISKS ASSOCIATED WITH MICROORGANISMS

4.3.1 Risk calculation method in the DSS - QMRA

The Quantitative Microbial Risk Assessment (QMRA) is adopted as the basis of the calculation methodology adopted in the DSS. The QMRA approach provides an estimate of the probability of infection based on the number of pathogens ingested (dose) and pathogen specific dose-response models based on data from human volunteer or outbreak studies to provide an estimate of the probability of infection associated with that exposure (based on assumptions using daily risk of infection models). Depending on the type of pathogen of interest, different surrogate organisms can be used in assessing probabilities of infection. The risk of virus infection is usually higher than for bacteria and parasites. Viruses can persist for long periods in water and have low infective doses. Rotaviruses, enteroviruses and noroviruses have been identified as potential reference pathogens in QMRA. Rotaviruses and Noroviruses are the most important cause of gastrointestinal infection in children. The microbial risk assessment methodology for domestic use, makes use of *E. coli* levels in the DSS to calculate protection from Norovirus infection as this protects against bacterial and parasite infections. Norovirus is recognised as one of the most common agents of viral diarrhoea. The *E. coli* dose is used to estimate a norovirus concentration to predict the probability of illness established using Norovirus dose-response parameters (Teunis *et al*, 2008). Table 4-1 shows probability of infection models used in QMRA.

Table 4-1: Probability of Infection Models

Daily risk (probability) of infection	
Beta-Poisson Model (WHO, 2001) $$\boldsymbol{Pi = 1 - [1 + \frac{dose}{\beta}]^{-\alpha}}$$ and $$\boldsymbol{N_{50} = \beta * [2^{1/\alpha} - 1]}$$ therefore $$\boldsymbol{P_i = 1 - [1 + \frac{d}{N_{50}}](2^{1/\alpha} - 1)^{-\alpha}}$$	Exponential model (Haas, 1996) $$P_i = 1 - e^{-rN}$$
P_i = probability (risk) of infection ***d*** = dose or exposure (number of organisms ingested based on consumption of water (l) per day β = parameter characterised by dose-response relationship α = parameter characterised by dose-response relationship *N_{50}* = median infectious dose **r** = parameter characterised by dose-response relationship	

4.3.2 Disability-adjusted life years (DALYs)

The disability-adjusted life year (DALY) measure is more recently used for water quality guidelines to develop health-based guidelines. A tolerable burden of disease (or acceptable risk) must be defined to calculate allowable levels of microbial contamination. The WHO Drinking Water Guidelines define safe drinking water as not representing any risk to health over a lifetime of consumption, setting the tolerable disease burden at an upper limit of 10^{-6} DALYs per person per year (WHO 2004, 2011 and 2017). This measure takes into account illness, premature death and life lived with a disability. The DALY allows for quantification and comparison of the burden of diseases between areas, population groups and different diseases. The burden of a single case of disease is calculated to determine the tolerable number of disease cases per year. 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*. A norovirus dose of 1.14 $X10^{-5}$ noroviruses per L (or 0.00001142/L) is the target concentration to satisfy the 10^{-6} DALY. If the ratio of norovirus to *E. coli* is 1 to 100 000, less than 1 *E coli* /100ml of water is the target value. Table he following table (Table 4-2) illustrates *E. coli* levels and associated probability of infections and DALYs. If water used for drinking water contains 1 *E. coli* /100 ml the DALY is 1.25 $X10^{-5}$ which is more than 10 times higher than the "target" 10^{-6} DALY.

This calculation methodology based on the tolerable burden of disease has been adopted in the DSS. The WHO health-based guideline defined as a tolerable burden of disease of 10^{-6} DALY per person per year is used as the target guideline in the DSS to determine microbiological risk. The concentration of *E. coli* in the sample is used to calculate protection from Norovirus infection as this protects against bacterial and parasite infections. Here the risk of norovirus infection per person per year is determined using *E. coli* counts per 100 ml. The *E. coli* count is converted to a dosage per litre of predicted Norovirus dose based on a dose response function, and the individual risk and annual risk of infection is then determined per person per year, represented as the DALY.

Table 4-2: *E. coli* levels and associated probability of infections and DALYs

E coli /100 ml	Volume (ml) ingested based on water use	Calculated *E. coli* dose	Predicted Norovirus Dose (number of organisms)	Probability infection	Number of events per annum	Annual probability of infection	DALY
0.1	1000	1	0.00001	6.88E-06	365	2.51E-03	1.25E-06
1	1000	10	0.0001	6.88E-05	365	2.48E-02	1.25E-05
5	1000	50	0.0005	3.44E-04	365	1.18E-01	6.27E-05
10	1000	100	0.001	6.88E-04	365	2.22E-01	1.25E-04

4.4 RISK REPORTING RELATED TO HUMAN HEALTH

For human health related adverse effects experienced through ingestion, inhalation and dermal contact exposure routes; human health toxicological exposure assessment threshold limits apply. For the human health risk-based guidelines pertaining the toxicants a four-level categorisation of the threshold limit criteria apply. The threshold criteria adopted in the DSS are defined in Table 4-3 with each marking a distinction in the fitness for use category and the estimate risk as a percentage. The threshold limit criteria represent how the adverse effects and likelihood of occurrence of the risk would be linked to the fitness for use category. A risk percentage as discussed above has been allocated to these threshold limits and represents the potential risk (occurrence and severity) associated with the adverse effect (e.g., if the risk is between 1 and 5% (acceptable), this implies that there is a rare chance of the risk occurring and that the adverse effect would be negligible to the individual). Risks are reported relative to these effects and levels.

Table 4-3: Threshold limit criteria defining the fitness for use categories for the toxicant human health risk reporting

Fitness for use Category	Threshold limit criteria	Percentage risk
Ideal	< RfD/RfC	<1
Acceptable	> RfD/RfC; <NOAEL	1 – 5
Tolerable	>NOAEL; < LOAEL	>5 – 15
Unacceptable	> LOAEL	>15 - 100

RfD: Oral Reference Dose

RfC: Inhalation Reference Concentrations

NOAEL: No observable adverse effect

LOAEL: Lowest observable adverse effect

The reference dose (RfD) is an oral or dermal dose, and the RfC, an inhalation reference concentration, are defined as an estimate of a daily oral/inhalation exposure to the humans that is likely to be without an appreciable risk of harmful effects during a lifetime. A No-Observed-Adverse-Effect Level (NOAEL) is the highest exposure level at which there are no biologically significant increases in the frequency or severity of adverse effect. The Lowest-Observed-Adverse-Effect (LOAEL) refers to the lowest exposure level at which there are biologically significant increases in frequency or severity of adverse effects. For the human health risk-based guidelines pertaining the carcinogens and microbial infectious agents a two-level fitness for use categorisation of the threshold limit criteria applies. The acceptable risk targets adopted in the DSS are defined in Table 4-4.

Table 4-4: Acceptable risk and DALY risk targets defining the fitness for use categories for the carcinogens and microbial agents risk reporting

Fitness for use	Threshold limit criteria (acceptable risk)
Below acceptable risk target	< 10^{-6} DALY target per person per year (microbial) < 10^{-5} lifetime risk of cancer
Above acceptable risk target	> 10^{-6} DALY target per person per year (microbial) > 10^{-5} excess lifetime risk of cancer

The DALY (disability-adjusted life years) is a common metric that is used to quantify the burden of disease associated with water related hazards, which takes account of probabilities, severities and duration of effects. The DALY accounts for the impact on the quality and quantity of life and focuses on the health outcome. DALYs can be used to define tolerable burden of disease and related reference level of risk (WHO, 2017a). The 'Tolerable burden of disease' (or reference level of risk) represents the upper limit of the burden of the health effects associated with the disease. The WHO tolerable burden of disease target applicable to the risk of cancer is 10^{-5} lifetime risk and microbial risk is 10^{-6} DALY per person per year (WHO, 2017a). These targets have been adopted in the DSS as the threshold criteria to quantify the risk and related fitness for use.

CHAPTER 5: PROCEDURES TO CALCULATE AND CRITERIA USED TO ASSESS RISKS ASSOCIATED WITH PHYSICAL AND AESTHETIC EFFECTS

5.1 INTRODUCTION

For water quality constituents resulting in a “physical effect risk” guideline values or thresholds are not absolute and are considered to be value judgments determined from a wide range of values that may be broadly classed as acceptable. Quantification of the risk has considered the concentration of the relevant hazards (water quality constituents) that would:

- Influence soap lathering for laundry, household washing (e.g. hardness, alkalinity)
- produce noticeable stains on laundry or household objects/items (dishes; floors) (e.g. iron, manganese, copper, sulphur, suspended solids);
- cause scaling, corrosion and encrustation of appliances pipes or fittings (Hardness, alkalinity, pH)

Review of local and international drinking water guidelines and international data sources physical characteristics and thresholds was undertaken to characterise the physical effects of hazards.

5.2 CALCULATION PROCEDURES FOR PHYSICAL IMPACT

5.2.1 Household washing/laundry with impacted water

The quantification of risk of the physical effects of the chemical constituents is based on exposure and threshold tolerance levels for each. A range of 5 data points with increasing concentrations has been selected to define the exposure curve. This is categorised in terms of the increasing intensity of the adverse effect *i.e.* the severity of the consequence increases linearly with increasing concentration of the constituent of concern. For the different water uses the data points will differ per constituent based on the exposure route and tolerance level related to the water use. The risk estimate in the DSS is determined by assuming that for one range, the values increase linearly, relative to the risk probability which is also linear. The risk probability is then calculated from where the sample concentration sits on the range. For example, Table 5-1 shows categorisation of manganese for staining of laundry, in terms of the exposure effect.

Table 5-1: Staining effect by different Manganese concentrations

Range	Manganese concentration	Effect of the exposure
0	0.0-0.05mg/L	No staining
1	0.05-.1mg/L	Slight staining of white clothes
2	0.1-0.4mg/L)	Moderate staining of clothes and fixtures
3	0.4-5mg/L)	Severe staining of clothes and fixtures
4	5-10mg/L)	Extreme staining of clothes and fixtures

Increasing intensity of the effect

5.2.2 Calculation procedures for physical impact for appliances and equipment

The Langelier saturation index (a formula) is an approximate indicator of the degree of saturation of calcium carbonate in water, and is widely used to predict corrosion and scaling effects. It is calculated using the pH, alkalinity, calcium concentration, total dissolved solids and water temperature and is based on a study of carbonate equilibrium in water. The Langlier Saturation Index is used to determine how well water is balanced between corrosive and scale-forming.

- Langelier Index is negative, then the water is under saturated with calcium carbonate and will tend to be corrosive.
- Langelier Index is positive, then the water is over saturated with calcium carbonate and will tend to deposit calcium carbonate forming scales in appliances and equipment.
- If Langelier Index is close to zero, then the water is just saturated with calcium carbonate and will neither be strongly corrosive or scale forming.

The formula for the calculation of the Langelier saturation index (LSI) is:

$$LSI = pH + \frac{\log\left(K_a\, \gamma_{Ca^{2+}}[Ca^{2+}]\gamma_{HCO_3^-}[HCO_3^-]\right)}{\gamma_{H^+}\, K_{sp}}$$

The Langlier Index is defined as the difference between the actual pH (measured) and modelled pHs. (from the chemical analysis of water quality constituents). The pHs represents the theoretical equilibrium.

The Saturation Index (SI) = pH – pHs

The magnitude and sign of the Langlier Index value shows water's tendency to dissolve scale, and thus to inhibit or encourage corrosion. If the pHs is lower than the actual pH (negative SI), the water is corrosive. Vice versa, a positive SI is indicative of a scale forming water. A Langelier Index in the range of -1 to +1 has a relatively low corrosion impact on metallic components of the appliances and equipment. Langelier Index values outside this range may result in laundry stains or leaks.

The calculation methodology adopted in the DSS to quantify the risk of corrosion and scaling on appliance equipment makes use of the Langlier Index calculation. The calculation requires the water composition of TDS, water temperature, pH and Calcium Carbonate and alkalinity to be inputted by the user. The calculation adopted is as follows:

$$LI = pH_a - pH_s$$

Where: pH_a is the measured pH of the water sample, and pHs the calculated pH of a water of the given analysis when in chemical equilibrium with solid $CaCO_3$. pHs is calculated as follows:

$$pH_s = (9.3 + A + B) - (C + D)$$

Where: A = (Log_{10} (TDS) – 1) / 10

B = -13.12 x Log_{10} (^oC + 273) + 34.55

C = Log_{10} (Ca as $CaCO_3$) – 0.4

D = Log_{10} (Alkalinity as $CaCO_3$)

(Concentrations are measured as mg/L).

The following threshold ranges of the LI, are used to define the acceptability of corrosion and scaling (Table 5-2). The calculated LI is assessed against the threshold criteria to determine risk-level of corrosion and scaling.

Table 5-2: Langelier index thresholds for corrosion and scaling

	Langelier Index	
Range	**Corrosion**	**Scaling**
Ideal	> -0.5	<+0.5
Acceptable	-0.5 to -1.0	+0.5 to +1.0
Tolerable	-1.0 to -2.0	+1.0 to +2.0
Unacceptable	< -2.0	>+2.0

5.3 CALCULATIONS ASSOCIATED WITH AESTHETIC EFFECTS

Water for domestic use should not only be safe but acceptable in colour, appearance and taste. The acceptability of drinking-water to users is subjective and can be influenced by many different constituents. The concentration at which constituents are objectionable to users is variable and dependent on individual and local factors (WHO 2017). Taste and odour are two of the primary criteria domestic users use to judge the quality and acceptability of drinking water. People's sense of taste and smell tends to vary, and so the acceptability of the same water can vary from person to person and from day to day for the same person. Whilst taste and odour present in water does not generally have a health impact, the presence of tastes and odours may raise consumer concern with regard to water quality.

Taste and odour can originate from natural inorganic and organic chemical contaminants and biological sources or processes (e.g. aquatic microorganisms), from contamination by synthetic chemicals, from corrosion or as a result of problems with water treatment (e.g. chlorination). Taste and odour may also develop during storage and distribution as a result of microbial activity (WHO, 2017a). Colour, cloudiness, particulate matter and visible organisms may also be noticed by consumers and may create concerns about the quality and acceptability of a domestic water. Drinking-water should ideally have no visible colour. Colour in drinking-water is usually due to the presence of coloured organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products or by waste discharges, for example from dyeing operations in the textile industry, and paper manufacture.

The calculation methodology in the DSS includes the use of ranges to quantify acceptable aesthetic aspects of odour and colour derived from literature-based exposure and threshold criteria levels determined for each. The risk in the DSS is determined by assuming that for one range, the values increase linearly, relative to the risk probability which is also linear. The risk probability is then calculated from where the sample concentration sits on the range.

For Colour:

Most users can detect colour above 15 true colour units (TCU) in a glass of water. A threshold level of 15 TCU is often acceptable to users, and is generally accepted as a guideline value. No health-based guideline value is currently proposed for colour in drinking-water internationally.

For Odour:

Table 5-3: Threshold criteria adopted in the DSS are as follows (adapted from SAWQGs, 1996):

Range	Threshold odour number	Effect of the exposure
Ideal	1	Odourless
Acceptable	1-2	Noticeable odour
Tolerable	2-5	Strong odour which is likely to be objectionable to a large percentage of users
Unacceptable	5 -10	Stronger odour, increasingly objectionable

5.4 RISK REPORTING RELATED TO AESTHETIC QUALITY AND PHYSICAL EFFECTS

For the reporting of the physical effect and aesthetic risk probabilities, threshold limits are used as the risk criteria for the four-level categorisation, as outlined in Tables 5-4 to 5-7. The threshold limits are defined by the consequences (scaling, corrosion, odour) that apply for each level of the physical or aesthetic effect (which is categorised in terms of the increasing intensity of the adverse effect *i.e*. the severity of the consequence increases linearly with increasing concentration of the constituent of concern. A risk percentage as discussed above has been allocated to these threshold limits and represents the potential risk (occurrence and severity) associated with the adverse effect (e.g., if the risk is between 1 and 5% (acceptable), this implies that there is a rare chance of the risk (e.g. scaling) occurring and that the adverse effect would be negligible on the appliance. Risks are reported relative to these effects and levels. A risk estimate (as a percentage) has been has been defined based on these threshold limit criteria and represents the risk probability of occurrence and the severity associated with the end point effect (e.g., scaling or staining) as shown in Table 5-4 below.

Table 5-4: Risk estimate (as a percentage), probability of occurrence and the severity associated with the end point effect (e.g., scaling or staining)

Risk estimate (Percentage)	Probability of Occurrence	Severity of the effect
<1	None	None
1 – 5	Rare	Negligible
>5 – 15	Possible	Minor
>15 - 100	Certain	Significant

For the physical effect risks associated with corrosion and scaling, the Langlier Index threshold limits are used as the criteria to define the four-level fitness for use risk categorisation. In terms of aesthetic water quality risk (colour and odour) the literature-based threshold limits have been applied. The threshold criteria adopted for the risk descriptors for physical effects and aesthetic quality are described in Table 13, Table 14 and Table 15.

Table 5-5: Threshold limit criteria defining the fitness for use categories for physical effect risk reporting

Physical Effect				
Fitness-for-Use Category	Threshold limit criteria			
	Hardness (mg/l)	Total Dissolved Salts (mg/l)	Turbidity (NTU)	Percentage risk
Ideal	0-100	0-450	0-0.1	<1
Acceptable	100-150	450-1000	0.1-1.0	1 – 5
Tolerable	150-200	1000-2000	1-5	>5 – 15
Unacceptable	>200	>2000	>5	>15 - 100

Table 5-6: Threshold limit criteria defining the fitness for use categories for the Physical Effects: Scaling and Corrosion risk reporting

Corrosion or Scaling			
Fitness-for-Use Category	Threshold limit criteria		
	Corrosion (Langelier Index)	Scaling (Langelier Index)	Percentage risk
Ideal	> -0.5	< 0.5	<1
Acceptable	-0.5 to -1.0	+0.5 to +1.0	1 – 5
Tolerable	-1.0 to -2.0	+1.0 to 2.0	>5 – 15
Unacceptable	< -2.0	> +2.0	>15 - 100

Table 5-7: Threshold limit criteria defining the fitness for use categories for Aesthetic Quality (Odour and Colour) risk reporting

Colour and Odour			
Fitness-for-Use Category	Threshold limit criteria		
	Colour (Total Colour units)	Odour (Threshold Odour numbers) (linked to taste)	Percentage risk
Ideal	< 5	1	<1
Acceptable	5 to -10	1 - 2	1 – 5
Tolerable	10 to 15	2-5	>5 – 15
Unacceptable	> 15	5-10	>15 - 100

CHAPTER 6: PROCEDURES TO CALCULATE AND CRITERIA USED TO ASSESS RISKS ASSOCIATED WITH THE USE OF IMPACTED WATER FOR GARDENING

6.1 INTRODUCTION

Gardening as a use is a component in both the domestic use and the irrigation use risk-based water quality guidelines. For the purposes of the domestic use risk-based water quality guidelines, the risk associated with the impact on the domestic user who relies on the crops for subsistence is included at a reference level as generic risk-based water quality requirement. The DSS for domestic use has adopted the generic fitness for use criteria of the Irrigation Risk Based Water Quality Guidelines (conservative limits). For further risk-based guidance the user is directed to the Irrigation Risk Based Water Quality Guidelines DSS (Meiring, *et al*. 2017).

6.2 IMPACTS OF IRRIGATION WATER QUALITY ON CROPS

Irrigation water quality impacts associated with crop yield and quality is of specific relevance to domestic use. The water quality indicators for domestic gardening use include root zone effects, leaf scorching and microbial contamination. The criteria per water quality suitability indicator as specified in the irrigation risk-based water quality guidelines are used. The following have been used in the risk-based irrigation water use guidelines (Meiring, *et al*. 2017) in terms of assessing the impacts of the hazards of the gardening related effects:

(1) **Root zone effects -** the tolerance of the crops to electrical conductivity (EC), boron (B), chloride (Cl) and sodium (Na) in the root zone assessed in terms of the yield response i.e. sensitivity based on either a maximum threshold concentration or on a range dependant concentration, is defined. The approach to deduce the yield response of the crops uses the concentration of salts (EC), B, Cl and Na concentration in the root zone which is then linked to the crop yield response data of the concentration of the individual constituents in the root zone, in order to estimate how the crop yield is affected. The criteria used in the DSS to specify water quality requirements based on the relative yield are indicated in Table 8 (Meiring, *et al*. 2017).

(2) **Leaf scorching** - crops susceptible to foliar damage caused by salts absorbed directly through their leaves exhibit great yield reductions than when only exposed to root zone effects. Limited quantitative data is however available to assess the susceptible of crops to foliar damage. In the DSS, the degree of leaf scorching is thus evaluated only in qualitative terms of leaves sprinkled with saline water (sodium and chloride concentration ranges associated with the indicated qualitative degree of leaf scorching). The criteria used in the DSS are indicated in Table 9 (Meiring, *et al*. 2017).

(3) **Microbial contamination** - the main concern is the health risk posed by crops destined for human consumption that have been contaminated during irrigation (*i.e*. crops consumed raw or with minimal processing). Microbial risk for irrigation it is determined by a quantitative microbial risk assessment, using *E. coli* as an indicator of microbial pathogens, and is based on an annual intake which is calculated from the volume of irrigation water retained by the crop and how much is consumed on an annual basis. The risk of norovirus infection is then determined based on the *E.coli* count based on a dose response function, and the individual risk and annual risk of infection is then determined per

person per year. The risk is expressed as the number of excess infections per 1000 persons per annum.

The criteria used in the DSS to specify the water quality requirements for E. coli based on the calculated number of excess infections per thousand persons per annum are indicated in Table 6-1. For this calculation the excess infections are reported assuming lettuce to be the most sensitive crop (retaining the largest volume of irrigated water consumed for crops assessed, *viz.* 11ml (Meiring, *et al*. 2017).

Table 6-1: Fitness for use criteria as related to the number of excess infections per one thousand persons

	Excess infections per 1000 persons p.a	Irrigation water concentration predicted to give rise to the indicated excess infections per 1000 persons p.a (*E. coli* counts per 100ml)
Microbial contamination	<1	<351
	1 - 3	351 - 1052
	3 - 10	1052 - 3506
	>10	>3506

6.3 RISK REPORTING RELATED TO GARDENING

The DSS for domestic use has adopted the generic fitness for use criteria of the irrigation risk-based water quality guidelines, as its water quality requirement (conservative) guidelines. The water quality indicators for domestic gardening use include root zone effects, leaf scorching and microbial contamination. The criteria per water quality suitability indicator as specified in the irrigation risk-based water quality guidelines are used as the four-level categorisation. The threshold limits applicable to the fitness for use risk categorisation for root zone effects, leaf scorching and microbial contamination are indicated in Table 6-2 to 6-4, respectively.

Table 6-2: Risk level categories for crop yield and associated fitness for use categorisation

	Fitness-for-Use	Relative crop yield (%)	Irrigation water concentration that will give rise to the corresponding relative crop yield			
			Salinity (EC) mS/m	Boron (B) mg/L	Chloride (Cl) mg/l	Sodium (Na) (SAR)
Root Zone effects	Ideal	90-100	<57	<0.40	<208	<2.99
	Acceptable	80-90	57-75	0.40 - 0.67	208 - 269	2.99 - 3.27
	Tolerable	70-80	75-92	0.67 - 0.93	269 - 331	3.27 - 3.54
	Unacceptable	<70	>92	>0.93	>331	>3.54

Table 6-3: Risk level categories for leaf scorching and associated fitness for use categorisation

	Fitness-for-Use	Degree of leaf scorching	Irrigation water concentration that may cause the corresponding degree of leaf scorching under sprinkler irrigation	
			Chloride (Cl) mg/l	Sodium (Na) (mg/l)
Leaf Scorching when wetted	Ideal	None	<70	<50
	Acceptable	Slight	70 - 135	50 - 83
	Tolerable	Moderate	135- 180	83 - 115
	Unacceptable	Severe	> 180	>115

Table 6-4: Risk level categories for microbial contamination and associated fitness for use categorisation

	Fitness-for-Use	Excess infections per 1000 persons p.a	Irrigation water concentration that may cause the corresponding degree of leaf scorching under sprinkler irrigation
Microbial contamination	Ideal	<1	<351
	Acceptable	1 - 3	351 - 1052
	Tolerable	3 - 10	1052 - 3506
	Unacceptable	>10	>3506

CHAPTER 7: EXAMPLES OF USING THE DSS TO PERFORM WATER QUALITY ASSESSMENTS

7.1 INTRODUCTION

The DSS is designed as a user-friendly tool to assess the impact of site-specific water quality on the domestic uses of the water and to provide generic risk-based water quality requirements on suitability for use. The risk associated with a water's domestic use is quantified through calculation and comparison between its specific water quality composition and threshold criteria. The level of the assessment is based on a 'no input' or input of a water quality composition and exposure conditions or methodology adjustment functionality. The tool incorporates the colour-coded categorization to provide risk-based guidance as discussed before.

7.2 DEMONSTRATOR TOOL USER INTERFACES

7.2.1 The Home Page

When a user opens the application, the home page will appear (Figure 7-1). From this page, the user has the option to choose between the different levels of assessment to analyse the water quality risk for domestic use. The home page also provides the user with help via the 'Help' button. If the user wishes to exit the program, the 'Exit' button is provided. This allows the user to save their version of the tool as a macro-enabled excel worksheet and will close the application thereafter.

Figure 7-1: Decision Support Tool home page

Upon the selection of this level analysis from the Home Page, the user is brought to the Water Quality Requirements assessment. Once this is selected, the home page will automatically close and another user interface will open allowing the user to set the domestic water use of interest (Figure 10). Note that only one domestic use can be assessed at one time. If the user wishes to return to the home page, the 'Return to Home page' button is clicked. This will close the Water Quality Requirements assessment level and return the user to the Home Page. As with the Home Page, a 'Help' button is provided to assist the user. Following the required inputs for the assessment the tool will generate a user-specific report.

7.2.2 Data Storage: Reference sheets

The DSS draws on multiple data sheets in order to perform any calculation. These reference sheets include the dose response data, exposure assessment data, quantitative definitions, the hazard characterisation and adverse effect endpoint descriptions derived for each constituent from the literature-based data and risk databases. Reference sheets are set up for each category of domestic use. These reference sheets are hidden and locked for editing purposes by the novice or intermediate user, but password protected for the expert/experienced user who wishes to adjust the methodologies. The reference sheet is the primary sheet of the hazard (water quality constituent) data per domestic use. It stores the threshold criteria set for each constituent (e.g. for human health – safe level dose, no effect level dose, lowest effect level dose) and the exposure assessment parameters (receptor, volume, exposure route, frequency, magnitude, duration). When the user selects a constituent of interest, the programme identifies the constituent and the domestic type and uses the input parameters to process the site-specific water quality to determine the risk estimate, which is then compared to the fitness for use threshold risk criteria/acceptable target of the respective constituent under the reference sheet. Due to the differences in risk assessments between human, physical and aesthetic water quality impacts, each domestic use are separated to different tabs within the workbook application. For example, the Ingestion Reference Sheet (see Figure 7-1 and 7-2) considers the safe level dose (RfD, RfC), no effect level dose (NOAEL) and lowest effect level dose (LOAEL) as threshold criteria for ingestion to assess potential risk whereas the Bathing Reference Sheet considers the threshold criteria for dermal contact. At this point in the demonstrator tool development, the human health reference sheets are completed for a selected number of water quality constituents.

Domestic Water Quality Guidelines' DECISION SUPPORT TOOL

INGESTION REFERENCE SHEET

	DATA							
Constituent	**RfD**	**Potential adverse effect (Ideal)**	**NOEL/ NOAEL**	**Potential adverse effect (Acceptable)**	**Arb value**	**Potential adverse effect (Tolerable)**	**LOAEL**	**Potential adverse effect (Unacceptable)**
Unit	**mg/kg-day**		**mg/kg-day**		**mg/kg-day**		**mg/kg-day**	
Acrylamide	1.00E-09	No negative health impacts.	NA	NA	NA	NA	0.00001	Carcinogenic. Skin irritation, fatigue, foot weakness and sensory changes.
Aluminium	0.225	No negative health impacts.	0.45	No negative health impacts.	0.675	Corrodes skin, irritates mucous membranes in the eyes, perspiration, shortness of breath and coughing.	0.9	Functional lung disorder,Parkinsonism dementia (PD) and amyotrophic lateral sclerosis (ALS).
Ammonia	0.5	No negative health impacts.	4.9	No negative health impacts.	9.3	Influences metabolism.	13.7	Cells mutagenicity.
Antimony	0.0004	No negative health impacts.	0.004	No negative health impacts.	0.020	Distributed mainly to the liver, spleen and heart, and to the thyroid and adrenal glands, and is excreted in	0.35	Respiratory and eye problems, staining of tooth surface.
Arsenic	1.00E-09	No negative health impacts.	NA	NA	NA	NA	0.00001	Confirmed carcinogenic, numbness and tingling of the extremities, muscle cramping, death.
Asbestos	0.225	No negative health impacts.	0.45	No negative health impacts.	0.675	Bronchial diseases/illnesses.	0.9	Asbestosis, cancer of the bronchial tubes, malignant mesothelioma, and possibly cancers of the gastrointestinal tract and larynx.
Atrazine	1.75	No negative health impacts.	3.5	No negative health impacts.	14.25	Lowering of the immune system.	25	Affect neuroendocrine function, leading to disruption of the oestrous cycle or developmental effects.
Barium	0.2	No negative health impacts.	0.21	No negative health impacts.	0.22	Vomiting, abdominal cramps, and watery diarrhea are typically reported shortly after ingestion.	0.23	Cardiovascular (hypertension) effects, toxic.
Benzene	1.00E-09	No negative health impacts.	NA	NA	NA	NA	0.00001	Carcinogenic. Pancytopenia, aplastic anaemia, thrombocytopenia, granulocytopenia and lymphocytopenia, death.

Figure 7-2: Ingestion Reference Sheet

Figure 7-3: A screenshot of the reference worksheet tabs

7.2.3 Calculation Sheets

Calculation sheets are developed as separate worksheets in the program. The main function of the calculation sheets is to extract data from the reference sheets, incorporate the user's input data and determine the risk estimate from the information. This is done are as per the calculation methodologies described in the previous Chapters. Formulas are used in the development of the calculation sheets so that each equation can be viewed and easier adjustments can be made. "Index-match" searches are used to find the appropriate information in each sheet. Once the user selects the level of assessment to analyse the risk associated with a water quality, the consistuents of interest are selected and the site-specific consistuent concentration is inputted. The program will then use these inputted concentrations to quantify a potential risk (see Figure 7-4).

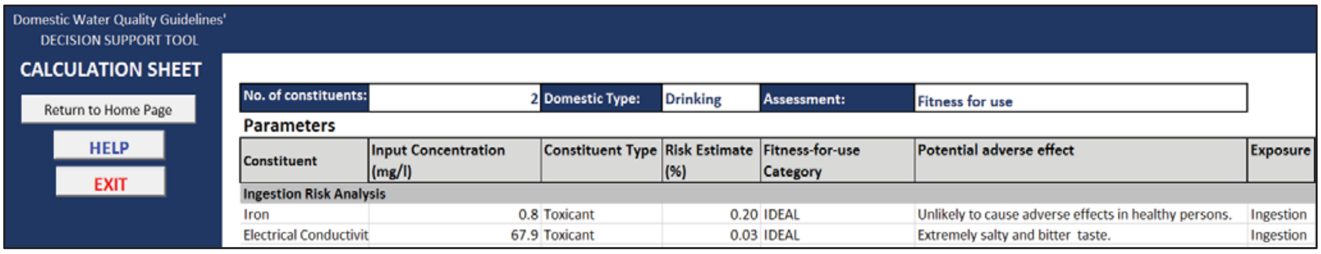


Figure 7-4: Screenshot of calculation sheet

7.3 WATER QUALITY ASSESSMENTS IN THE DSS

7.3.1 Water quality requirement assessment

Due to the low level of complexity at this level, the user is able to perform generic and site-specific assessments. If the user clicks on the water quality requirement tab on the home page, the next page requires the user to either specify the domestic use category and constituent, or select for all domestic uses and all constituents (Figure 7-5). If the user selects all domestic uses, the 'AllReportSheet' tab is displayed, which shows the risk rating for all the constituents for the different uses. If a specific domestic use category is selected, the information is collated under the respective reporting worksheets with the risk probability and the fitness for use (defined as ideal, acceptable, tolerable and unacceptable). The report is generated in an excel spreadsheet, with an option to save to a pdf. For example, manganese has a negative impact on both human health and laundry. If the user selected the 'Drinking' domestic use type tab, the human health related equations to calculate the risk due to ingestion are used. The risk of ingestion is reported back to the user in the output report (Figure 7-6). If the user selects the 'Laundry' water use, the program will apply the inputted concentration to the risks of dermal contact and the colour thresholds on clothing (staining/discolouration) calculations. As these risks are derived through different formulae, the output report sheet will deliver the potential risk of the dermal contact effect (human health) separately to the potential risk of the laundry effect (physical effect). The Water Quality Requirement's calculation sheet matches the constituent data selected by the user to the constituent database in the reference sheets. The data is extracted and displayed in Water Quality Requirement's reporting worksheet which presents the risk-based threshold limit criteria defined for each level of fitness for use expressed as a concentration

(Figure 7-6). The user also has the option to save the report as a pdf document by selecting the arrow to the right of the output page. The 'Return to Home page' button will direct the user to the Home page of the application. The 'Exit' button will give the user the option to save their progress and exit the application. A fact sheet per constituent is also available should the user wish to access background information.

Figure 7-5: Water Quality Requirements Input Page

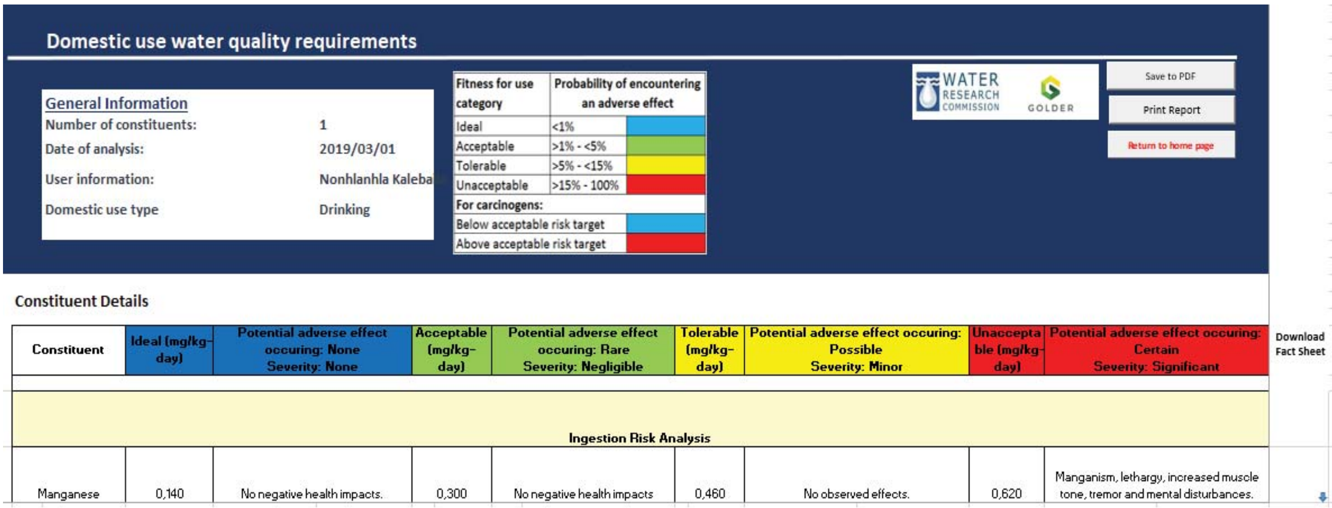


Figure 7-6: Water Quality Requirements for Manganese in drinking water

7.3.2 Fitness for Use Assessment

If the user selects the ‘Fitness for Use Assessment’ from the home page, the application will direct the user to the Fitness for Use Input page (Figure 7-7). Here, the user selects the domestic water use type, the constituents of concern and inputs their respective readings and the details of the receptor which is either based on default range which is incorporated into the risk probability calculations for human health calculations. If the user has a range of receptor details, the sensitive receptor details should be selected (Figure 7-8).

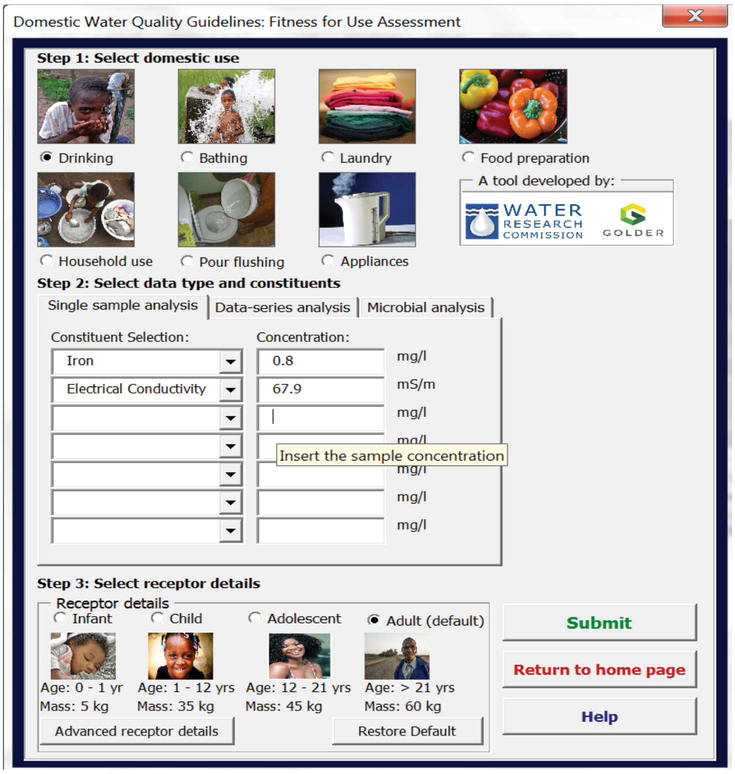


Figure 7-7: Fitness for Use Assessment input page

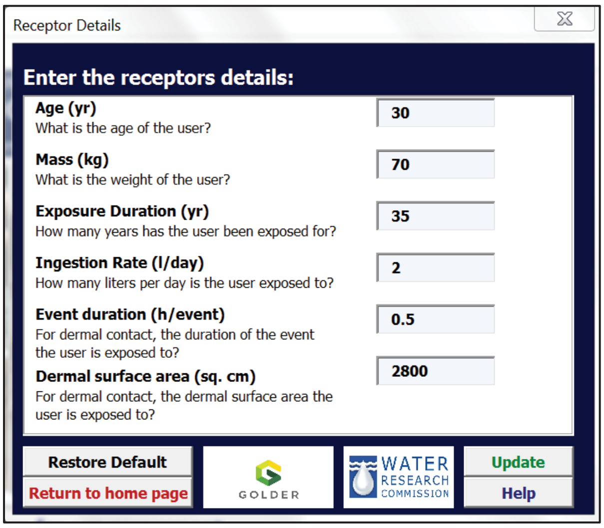


Figure 7-8: Advanced Receptor details input page

If the user does not enter receptor details, the default values assigned for each parameter will be used in the calculation. Based on the inputs provided, the tool will process the respective calculations and generate a user-specific report. Three different reports are generated based on the user input. A single sample analysis generates a report based on a single water quality reading per constituent (Figure 7-9). A microbial risk report is generated provided the user inputs the *E. coli* reading of his/her specific water sample (Figure 7-10). A data series report is generated if the user provides a sample set of water quality readings (Figure 7-11). The user will be directed to an additional input page to enter the range of water quality data series.

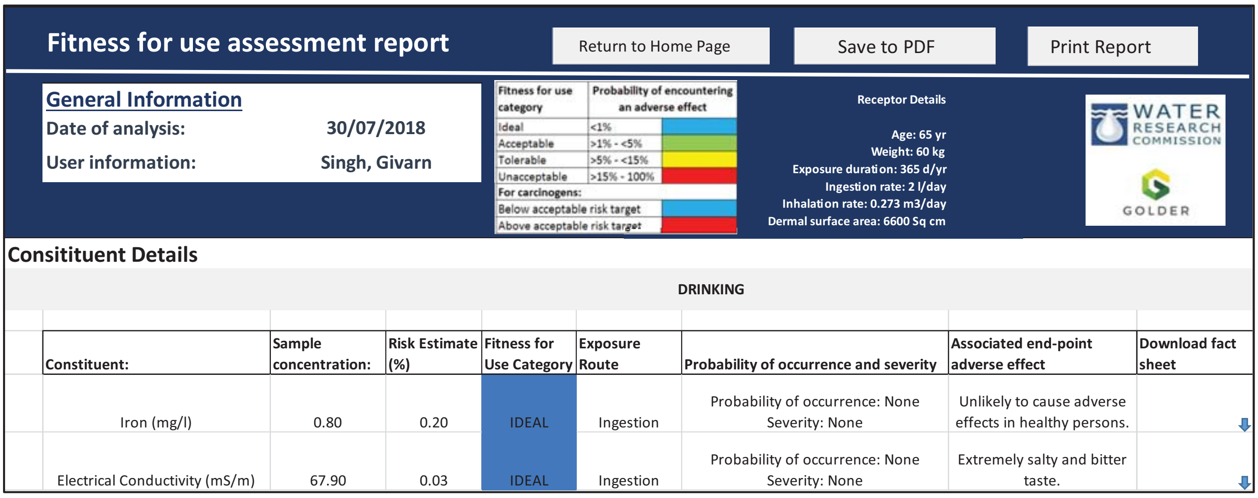


Figure 7-9: Single sample fitness for use report

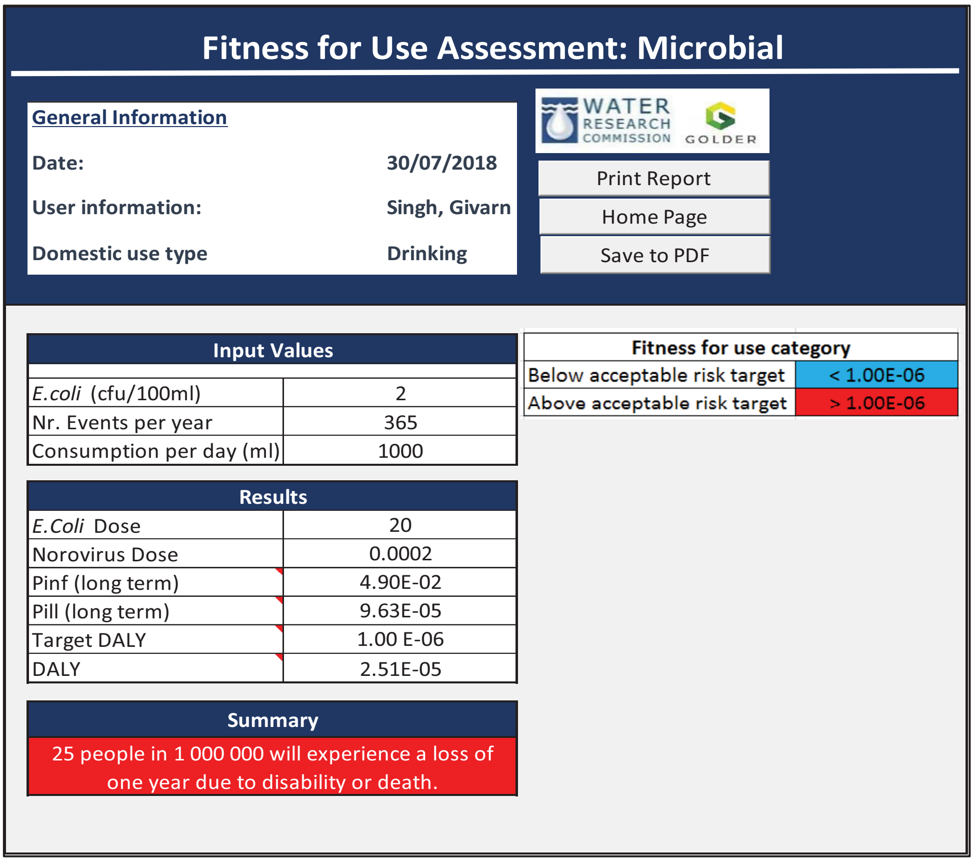
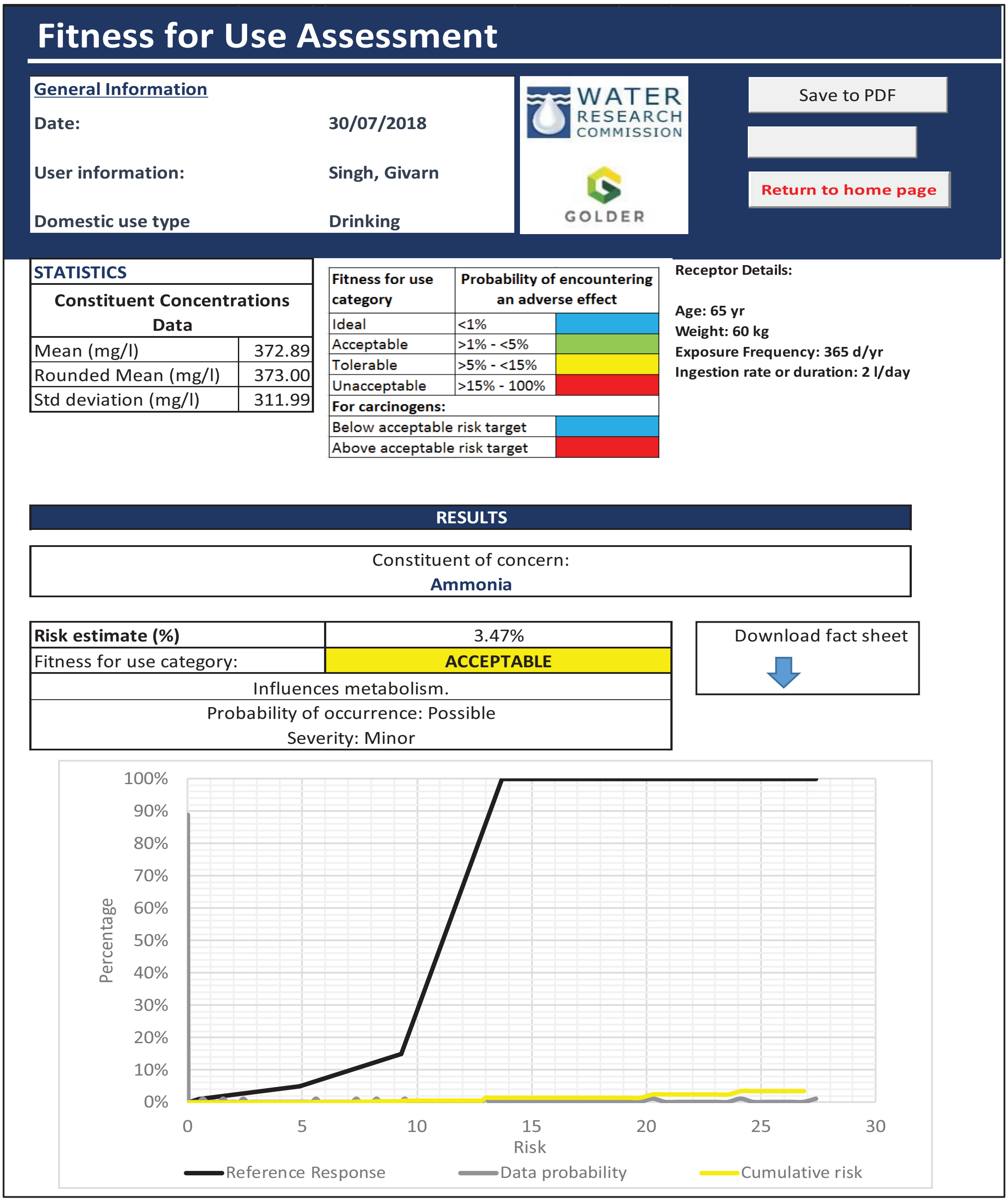


Figure 7-10: Microbial risk report



Fitness for Use Assessment

General Information

Date:	**30/07/2018**
User information:	**Singh, Givarn**
Domestic use type	**Drinking**

Save to PDF

Return to home page

STATISTICS	
Constituent Concentrations Data	
Mean (mg/l)	372.89
Rounded Mean (mg/l)	373.00
Std deviation (mg/l)	311.99

Fitness for use category	Probability of encountering an adverse effect
Ideal	<1%
Acceptable	>1% - <5%
Tolerable	>5% - <15%
Unacceptable	>15% - 100%
For carcinogens:	
Below acceptable risk target	
Above acceptable risk target	

Receptor Details:

Age: 65 yr
Weight: 60 kg
Exposure Frequency: 365 d/yr
Ingestion rate or duration: 2 l/day

RESULTS

Constituent of concern:
Ammonia

Risk estimate (%)	3.47%
Fitness for use category:	**ACCEPTABLE**

Influences metabolism.
Probability of occurrence: Possible
Severity: Minor

Download fact sheet

Figure 7-11: Data series fitness for use report

The fitness for use assessment level incorporates the user's input data, such as the water sample's constituents of concern, the concentration of constituents, the exposure conditions (volume, duration, etc.) and the receptor details (age, weight). Based on the adverse effect level threshold criteria limits, the risk probability is calculated using the respective methodologies that apply to the routes of exposure and exposure scenarios (human health, physical or aesthetic). Here, the program differentiates between the different domestic water uses and uses the appropriate equation to quantify the risk estimate of the water use. If the user submitted a sample set of water quality readings, the risk probability is calculated following statistical formulae.

7.5 EXAMPLES OF APPLICATION

A water analysis indicates a 0.8 mg/l iron concentration and 67.90 mS/m conductivity. You wish to assess the risk presented for drinking and its fitness for use.

- Select Fitness for Use Tab
- Select Drinking Use category
    - Select constituents of concern, in this case iron and electrical conductivity
    - Input the readings (analyis data) – 0.8 mg/l and 67.9 mS/m respectively
    - Submit using default receptor range , OR
    - Select new receptor details from pre-defined range e.g. infant, 1 years, 10kg, 750 ml, 365 days (as opposed to adult)
    - Click submit
    - Output:

DRINKING

Constituent:	Sample concentration:	Risk Estimate (%)	Fitness for Use Category	Exposure Route	Probability of occurrence and severity	Associated end-point adverse effect	Download fact sheet
Iron (mg/l)	0.80	0.20	IDEAL	Ingestion	Probability of occurrence: None Severity: None	Unlikely to cause adverse effects in healthy persons.	
Electrical Conductivity (mS/m)	67.90	0.03	IDEAL	Ingestion	Probability of occurrence: None Severity: None	Extremely salty and bitter taste.	

You have a water source and need to determine if the water is suitable for drinking and laundry?

- Select Water Quality Requirement Tab
- Select Drinking Use category
    - Click submit
    - *Output:* Risk based water quality requirements for drinking are reported for ingestion-based water quality constituents at an ideal, acceptable, tolerable and unacceptable level of use. Report may be saved as a pdf and/or printed.
- *For Drinking*: Default parameters apply: volume of 2L, once day for a duration of 365 days for an adult (65 years) of 60kg is applied to the calculation
- Select Laundry use category
    - Click submit
    - *Output:* Risk based water quality requirements for laundry are reported for physical water quality constituents at an ideal, acceptable, tolerable and unacceptable level of use. Report may be saved as a pdf and/or printed.
- *For Laundry*: The threshold limits that apply in terms of increasing intensity of the adverse effect (increasing concentration) is applied (e.g. for manganese, iron)

CHAPTER 8: CONCLUSIONS & RECOMMENDATIONS

The project objective was to develop a methodology for providing risk-based Water Quality Guidelines for Domestic Use enabled through a user-friendly and practical Decision Support System (DSS). The key components of the undertaking comprised firstly, the development of the approach and methodology for the risk calculations based on supporting science to be included in the technology demonstrator; and secondly the development of the informatics for a demonstrator decision support system that addresses the main decision contexts for the use of the guidelines. The DSS is an engineered computational software system presented as a demonstrator. It incorporates the key features of risk and site specificity to provide risk-based guidance on water quality used for domestic purposes, using MS Excel as the user platform.

The following core elements which comprise the fundamentals to the risk based domestic water quality guidance provided, define the DSS product:

- **The Exposure Scenario** – This comprises what is known about the exposure situation – *i.e.* the types of domestic water use typically encountered in the domestic environment catered for in the DSS. It also includes characterisation of how the potential adverse effect is experienced by a domestic user. These include human health, aesthetic quality and physical effects. These exposure scenarios direct the criteria and considerations into the selection of the type of methodologies that apply to determining the risk.

- **Characterisation of the Hazards** – This comprises what is known about the hazard; (1) Hazard/stressor identification (suite of water quality constituents); (2) hazard categorisation - toxicants, carcinogens, infectious agents, physical and/or aesthetic effects and (3) hazard characterisation as related to exposure scenario and route and determination of the individual adverse effects and levels.

- **Quantification of the risk** – This comprises how this risk is quantified to reflect a probability of occurrence of an adverse effect. Quantification of relationships was undertaken to determine applicable methodologies to quantify the risk within the decision context framework, which required a formulation of a hazard expression for each constituent. Risk assessment best practices were adapted and applied to the risk assessment quantification based on the exposure scenarios to best represent the expression of risk.

- **Report Risk Guidance** – This comprises a system and criteria of how the risk is reported as the water quality guidelines output. It is the quantitative (site specific) and/or qualitative (generic) risk output that the user is presented with, which represents the 'risk-based water quality guideline'. The reporting categorisation system is colour coded for ease of reference to the risk level quantified and associated fitness for use, with a description of adverse effect if applicable.

The domestic risk-based water quality guidelines represent a paradigm shift in the decision-making context to water quality management and in how water quality guidelines are used and applied. The development methodology of the decision support tool presents a fundamental change from the use of simple numeric values to providing both regulators and water users with a quantifiable assessment of the risk. In doing so the user would need to make a judgement call based on the available information, context and influencing factors.

The project aim was successfully achieved, with the DSS as a product fulfilling the requirements of the technology demonstrator for risk based domestic use water quality guidelines. However, the following is required and recommended to develop the product further to a fully functional system to be utilised within the water resource management sector in South Africa:

- Further development of the domestic user DSS methodology in the next phases would need to address:
  - The functionality of the water quality objective setting at the fitness for use assessment level;
  - Expansion of the water quality constituent database to include all constituents relevant to domestic use, specifically in the South African context;
  - The consideration of synergistic and antagonistic effects of constituents and expansion of the calculation methodology to address this;
  - The update of the methodology to include the assessment of multiple constituents simultaneously;
  - Endpoint (adverse effect) verification of all hazards;
  - The incorporation of local domestic water uses pattern information where applicable to improve site specificity, calculation methodology and receptor information;
  - Processes and procedures for the updating of the methodologies and exposure assessment data, based on the best available science information as it becomes available;
  - Functionality that allows export of water quality monitoring data from national and local monitoring programmes directly into the DSS;
  - A structured procedure applicable to the expert level users should be developed to control and maintain the original product while providing the user with a clear method of the detailed analysis and adjustment; and
  - Currently the DSS tool has been demonstrated using MS Excel, however in going forward to full scale application, it is recommended that available on-line databases be tested to select a software suitable for the DSS for the guideline series.

- Wider stakeholder buy-in and guidance is required to gain acceptance of the risk-based approach to the assessment of water quality. Users may be hesitant to want to take decisions on the basis of a risk quantification that the DSS provides, without requisite understanding of the support it is meant to provide. More engagement is required to get users to accept the philosophy and approach;

- Further testing with the wider stakeholder user groups is required to refine the product and to update the DSS to improve user-friendliness and utility, based on feedback from users.

- A DSS tool that is available through an on-line platform is recommended.

- Next phases of the project require the integration with the user guidelines that needs to consider the selection of coding platform, intellectual property issues, controlled access to software system, version controls as well as processes and procedures on the updating of the methodologies and functionality of the DSS for the water user groups.

- Such a system places stringent demands on the custodianship of the product. An owner and champion within the DWS are required to spearhead the next phases of the DSS, its integration, its promotion and maintenance.

The following key challenges were experienced during life of project:

- The innovative and progressive nature of the project brief involved breaking new ground which resulted in much discussion and time in the definition of the envisaged product. Deliberation and discussion over much of the project was needed to adjust and confirm the scope of work and to manage the expectations of the reference group and users. This took longer than anticipated and resulted in adjustments over the course of the project from the original project scope, which proved to be challenging from a time and budget point of view.

- The lack of understanding and total buy-in of the reference group on a quantifiable risk-based approach concept to provide water quality guidance proved to be challenging. The idea that the user of the DSS is required to make a judgement call on the fitness for use of the water has proven to be a challenge, that has highlighted the fact that more engagement is required with the water resources sector and then on to the general public. The understanding that the DSS is not providing a ‘line in the sand’ in terms of a static guideline value needs to be sufficiently and adequately communicated. For the DSS to be fully utilised to its potential and achieve the purpose for which it has been developed, a fundamental mind set change is required among users. It is no longer a situation of a simple ‘pass-fail’ number, the DSS provides common philosophical basis for decision-making in different contexts.

- The technical assessments and deliberations proved to be complex and very time-consuming, which presented a challenge from the project delivery point of view. The two-year period time was not adequate do to justice to all the aspects that continually emerged on the approach and product development.

- The process required intensive literature review and assessments which proved to be data intensive. While international scientific databases and algorithms were adopted and adapted for the DSS development as these were easily accessible and tested, limited time and budget prevented investigations to make adjustment for local circumstances.

- The availability of toxicological data and exposure assessment studies and time constraints, limited the range of the constituents included at this phase of the project.

- Lack of risk-based assessment data of physical and aesthetic constituents, limited the extent of the risk quantification as compared to the human health related constituents. Internationally most countries focus on drinking water and not in the domestic use context as South Africa does.

- The lack of documented available domestic water uses pattern data for the South African context prevented the adjustment of the risk calculation methodologies to reflect local circumstances. While the risk calculations are scientifically sound, they are based much on the USEPA and WHO water use data.

- The inclusion of the functionality to determine a water quality objective (for the water resource) based on an accepted risk level and risk management scenario, (reverse functionality of the fitness for use) was not feasible during this process, however is recommended for the next phase.

In conclusion it can be said that the development of risk-based approach and a technology demonstrator DSS for domestic water quality guidelines was a challenging undertaking requiring a shift in thinking and approach and innovation in conceptualisation and development. It however proved to be exciting and forward thinking, with the resultant DSS product presenting a novel and revolutionary manner of how domestic water quality may be expressed in supporting the multifaceted dimensions and complexities to water quality management in South Africa.

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