WATER QUALITY MANAGEMENT FOR SMALL COMMUNITIES: *WATTREAT* GUIDELINES MANUAL.

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DISCLAIMER

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This manual and the associated software contain guidelines, recommendations and comments only, and should not be seen as having regulatory authority.

NOTES ON THE USE OF THE SOFTWARE and the GUIDELINES MANUAL

Responsibility for decisions made using WATTREAT software and this guidelines manual rests with the user.

CURRENT STATUS AND FURTHER CHANGES

Please note that the current version of WATTREAT has components whose scope of application could potentially be expanded in future versions. For example, the water source protection advisor addresses in-house treatment of water only in general terms, and mostly only relating to in-house disinfection with chlorine. The latter could be expanded to include chlorination of turbid water, what to do about foul tasting water, etc. Another component that could be expanded is the microbial sampling and water supply disinfection advisor to address further aspects of disinfection in different places in the water treatment and water supply network. When a cost-free version of the water stabilization programme, STASOFT, becomes available, it could be incorporated so as to complement the water corrosion and hardness advisor.

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DEFINITIONS

Small Community: A community of less than 5000 people, with special reference to one dependent on a local water supply.

DNOM: Dissolved natural organic matter.
GAC: Granular Activated Carbon
PCBs: Poly-chlorinated biphenyls
THMs: Trihalomethanes
TDS: Total Dissolved Solids
EC: Electrical conductivity (Approximation: TDS = 6.5 * EC)

1 Introduction

1.1 Water treatment and water supply protection for small communities

Being a semi-arid country with an expanding population, South Africa is facing challenges regarding the deterioration of its water resources and the need to treat the water to acceptable standards for potable use. South Africa faces the following challenges regarding the provision of potable water supplies:

(i) Good quality water is a scarce resource. As the market demand for water increases, this requires that water sources of lower quality be utilized for domestic purposes. Specialised treatment, monitoring and control is likely to be required for these sources, involving sometimes significant and perhaps unnecessary cost.

(ii) Due to the increased production of waste and the lack of will or ability to dispose of it effectively, the resulting pollution has become an ever-increasing threat to the quality of our potable water supplies. This again requires the need for specialized treatment and regular monitoring and control in order to produce safe potable water.

Due to lack of resources and the poor quality/ reliability of source water, the provision of conventional water treatment systems alone is unlikely to ensure sustainable water supplies of sufficient quality for many small communities. There is a need to have access to readily available knowledge on suitable water treatment processes and systems that will enable the provision of appropriate and cost-effective potable water for small communities.

The need for decision-support guidelines for water treatment is becoming more acute, and due to the dubious quality/reliability of water resources these guidelines are necessarily complex. There is therefore a need for such guidelines to be incorporated in user-friendly software. Software which supplies tools to help in guideline interpretation and implementation, if this is integrated with some form of routine "intelligence", should be of value to potential users, as such users are not likely to have all the expertise needed in order to interpret and implement the guidelines. The development of expert systems-based decision-support tools is believed to be a way of obtaining the required decision support, even though the knowledge contained in the software is of a routine nature.

1.2 Expert systems based decision support

Expert systems development tools provide a framework for modelling both qualitative and quantitative data as well as expertise (Richey, 1985). Expert systems are computer programs which are designed to provide certain types of expertise as well as other forms of decision support, where the latter are driven by, or else incorporate routine intelligence. They may be used to provide decision-support tools for decision makers who address complex tasks involving multiple disciplines. The aims of using expert systems in this project are (Starfield and Bleloch, 1983):

- To model the required expertise, and
- to make expertise of a routine nature readily available on computers, and
- to make the expertise comprehensive yet concise.

Expert systems are potentially useful as decision modelling aids and as decision support tools for the following reasons:

- They help to make the reasoning behind decision-making explicit and make the resulting decisions replicable (Hayes-Roth, 1985);
- Besides modelling expertise, they may be used to model partial or conflicting information (Hayes Roth, 1985);
- They can be used for numerical modelling, provided the tasks are not too large, and are able to integrate qualitative aspects into such models (Starfield and Bleloch, 1983);
- They can address issues specifically relevant to a current context or goal, so helping to simplify complex tasks (Winston, 1984; Starfield and Bleloch, 1983);
- As modelling tools, expert systems help to formalise existing knowledge, thus capturing data for more efficient use (Starfield and Bleloch, 1983);
- They can reveal important gaps in current knowledge and also, loopholes in regulations (Murphy, 1989; Barr and Feigenbaum, 1982);
- Experience shows that they may be used as a basis for incremental development of larger systems.

Whereas most decision support tools provide information and knowledge in a descriptive form (graphs, maps, etc.), expert systems present knowledge in a combination of both logical and descriptive forms, where they can perform tasks involving interpretation of data, “recognition” of data patterns, problem diagnosis, risk assessment and more (see **Figure 1**). A test to identify the activity of an expert system is where questions asked are dependent on answers given to previous questions (Starfield and Bleloch, 1983).

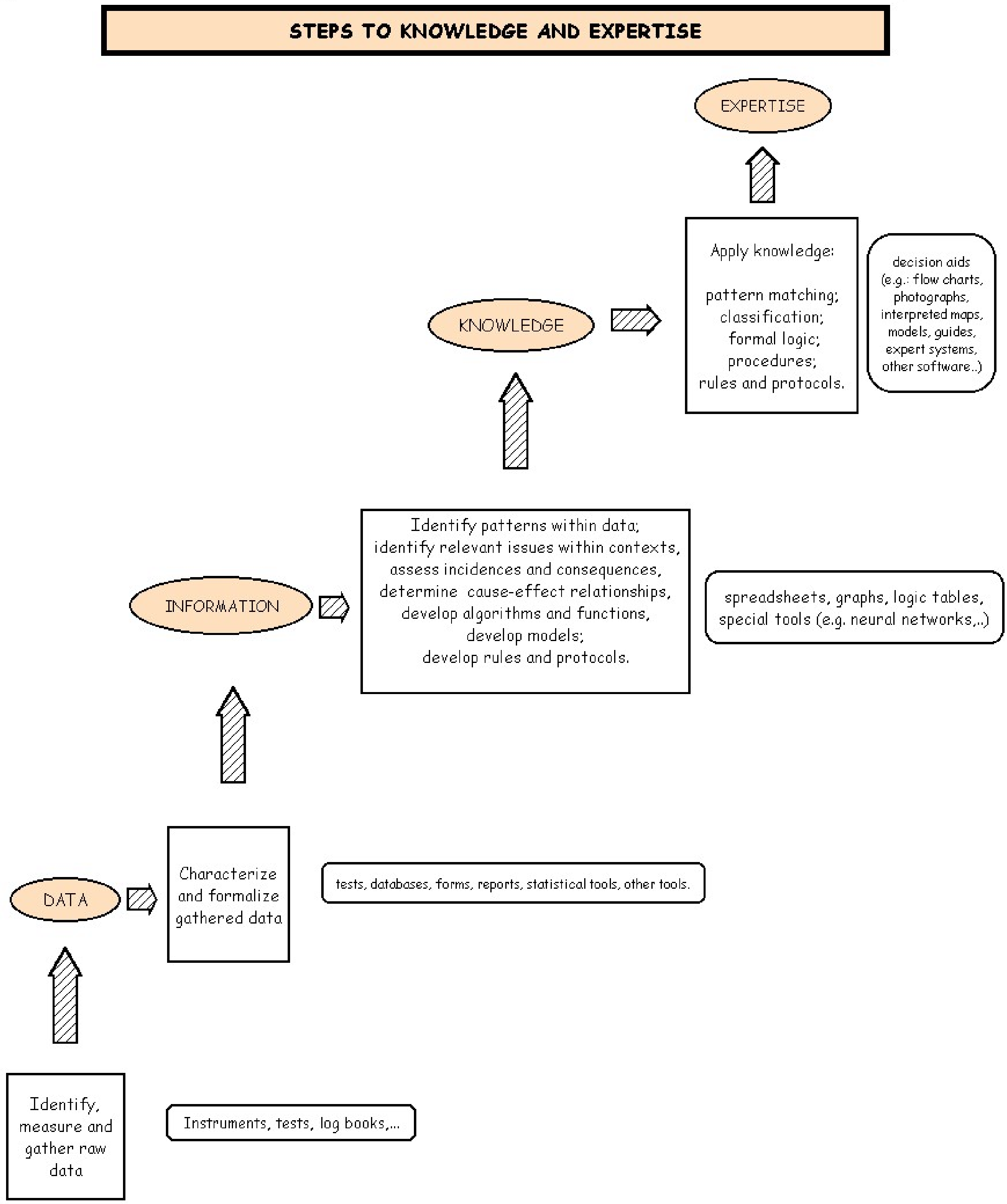

Figure1: Where expert systems development fits in to the knowledge hierarchy

The development of expert systems in this project involved two stages, namely, the knowledge engineering stage and the software development stage

(i) The knowledge engineering stage

Given the problem area to be addressed, the knowledge engineering stage involves knowledge acquisition and knowledge representation:

Knowledge acquisition:

This involves identifying relevant sources of knowledge and expertise , identifying objectives, goals and issues of tasks to be performed and eliciting required knowledge / expertise.

Knowledge representation:

- Identify all the objects or entities which are relevant to the problem area (e.g. reservoirs, chlorination strength, treatment options, etc.) and identify which ones represent issues and which ones represent goals.
- Identify object values (e.g. 1,2,3,4,5; "High, Medium, Low"; "Spring, Borehole, River"; etc.).
- Establish cause => consequence relationships between objects.
- Assign value ranges to objects and draw up IF – THEN rules (or, depending on the shell used, node-link relationships).
- Group rules into contexts (i.e. conditions in which specific sets of rules are valid).
- Develop procedures (or methods) to address specific tasks when these are needed, such as to generate a report, or to carry out a weighting and rating method and then rank the results.

(ii) The software development stage involves encoding, testing and validation.

The building block of an expert system is the production rule, represented as an IF – THEN statement, where

IF A THEN B

is interpreted as:

If object **A** is evaluated as **True**, **then** object **B** is **True**.

(Assuming that object **A** and object **B** can only take on the values **True** or **False**.)

How an expert system reasons using production rules:

Consider the following rule:

IF A OR (B AND C) THEN D

If **A** evaluates to **True**, then **D** is **True**. There is no need to evaluate **B** or **C**.

If **A** evaluates to **False**, or its value cannot be determined, the values of **B** and **C** then need to be determined.

If **B** is **False**, then **D** is **False** and a value for **C** is not needed.

However, if **B** is **True** then a value for **C** is needed in order to determine if **D** is **True**.

If **B** is **True** and a value for **C** cannot be found, then other rules are sought which assign a value to **C**. If no rules can be found, or **C** cannot be evaluated this way, then other avenues may be sought in order to obtain a value for **C** (e.g. run a procedure, access an external database, or ask the user). If there is still no success, then the value of **D** remains unknown for this rule. Other rules are then sought in order to obtain a value for **D**.

Rules and objects within rules are investigated according to different “reasoning” strategies. Normally, rules are investigated in the order they appear in the expert system, and objects are evaluated in the order they appear in rules. In the above rule, **B** is investigated before **C**. If **A** is the easiest to evaluate then it would normally be preferable to put it first. If **C** normally cannot be evaluated from existing rules, and requires the user to be asked for a value, it should come last. The reason for this is that the user should normally not be asked for the value of an object if that value can be determined from within the expert system. This is one way in which the user is prevented from having to answer unnecessary questions.

A rule-base in an expert system is a set of production rules grouped together to perform a specific task. These rules are often designed also to be applicable within specific contexts. For example, a rule-base may assign a value to **D,** where **D** represents the p**rotection status of a water source**. There may be several rule-bases with the same task, but which have contexts relating to different environments, say, urban, agricultural, rural, etc.

The expert-systems-based decision support programs developed for this project include:

The water supply microbial sampling and chlorination advisor

Laboratory determinand test selection aid

Laboratory determinand test interpreter and water treatment advisor.

Water limits assessment tool.

The water hardness and corrosion potential advisor.

Water treatment option suitability ranking tool

Drinking water contaminant limits exceedance tool

Water corrosivity/ scaling and aggressiveness tendency advisor

Microbial sampling/ monitoring and chlorine disinfection advisor

Water source protection advisor

Another component of WATTREAT, the menu-selection component, is not based on any rules, and so is not included in the above list.

The components of WATTREAT are described in some detail in the following chapters, for each we address the logic used and then describe how to use the component in a step-by step fashion.

2 Components of WATTREAT

The Menu-selection component

This is the introductory screen for WATTREAT. On it are displayed various buttons which you can click on to take you to the component whose functions are described on the labels. Next to each of these buttons is a small square button with a "?" label. These buttons link to a screen with background information on the component of concern.
Text boxes on the Menu-selection screen give a background description of the software and restrictions on use of the software. The components are described in the diagram which follows (**Figure 2**).
In **Figure 2**, the boxes on the left represent the buttons that appear on the menu-selection screen. The text in these boxes briefly describes the component and the boxes to the right of these boxes contain a summary of what each component does. The following chapters describe each component in detail.

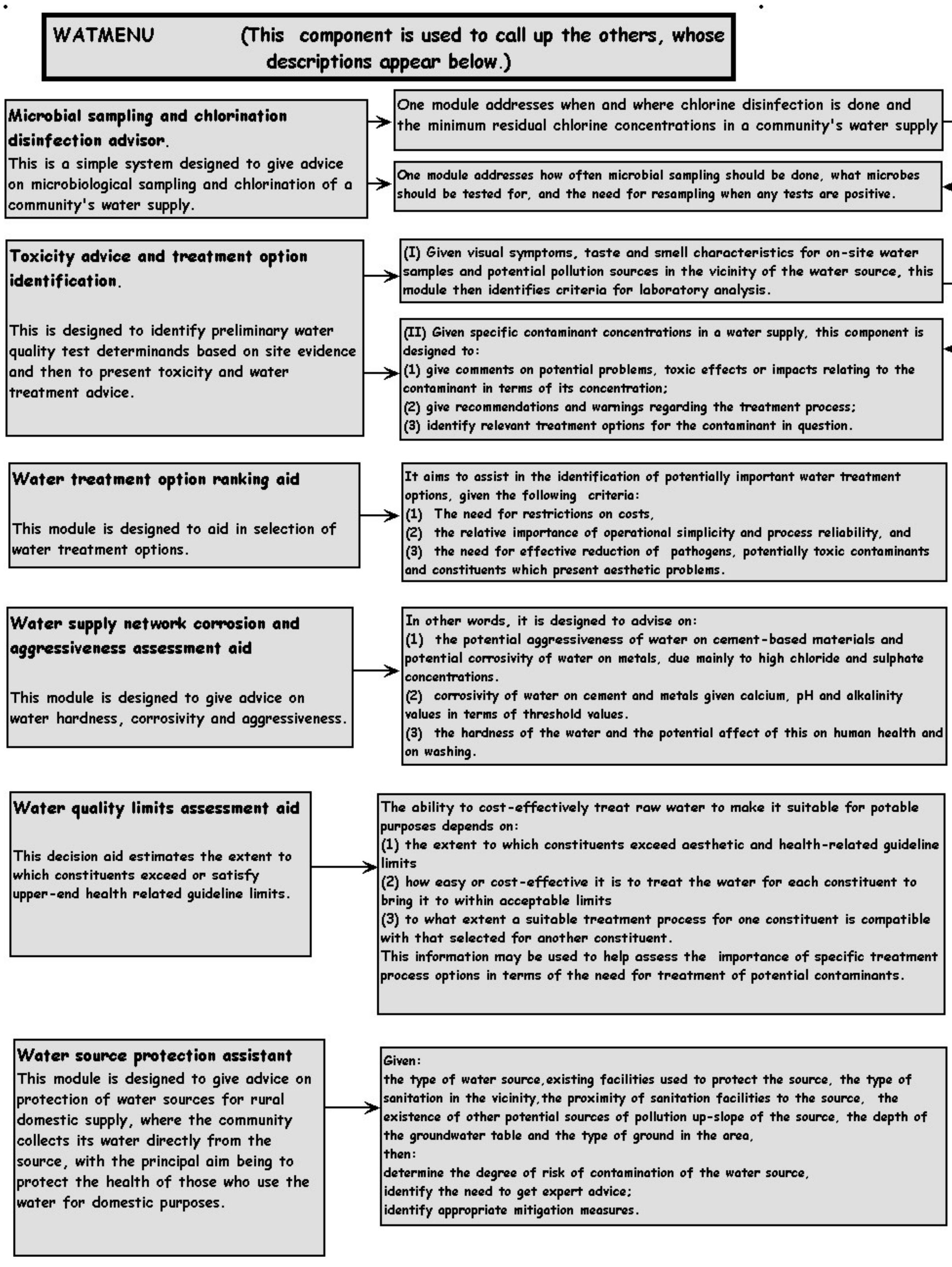

Figure 2: The Menu Selection Component.

3 Microbial Sampling/ Monitoring and Chlorine Disinfection Advisors.

This decision-support tool gives advice on taking microbiological tests and for disinfection of a community's water supply system. It consists of two components, the microbial monitoring advisor and the chlorine disinfection advisor.

The microbial monitoring advisor asks what microbial monitoring is being done at an actual or imaginary water supply system. In response to answers it gives advice on what should be done, and then it presents further questions. Questions asked are dependent on the answers to previous questions.

The chlorine disinfection advisor asks what disinfection is being carried out and then in response to positive answers on chlorination or chloramination it attempts to advise where chlorination is required, and also what residual concentrations of disinfectant are needed in the water distribution network. Most of the available advice relates to chlorination.

The expert system rules for these two components may be suitably presented in tables, where answers to questions and other preconditions in the IF part of the rules appear in the columns on the left-hand side (LHS) of each table and results in the THEN part of the rules appear in columns on the right-hand side of each table (See **Table 1** and **Table 2**).

Table 1: Rule Table for the Microbial Water Sampling Advisor

Step 1 T= True	Step 2 T= True	Monitoring for microbes done ?	Monitoring frequency ?	Test pos/ or neg ?	Sampling after treatment done ? T= True; F= False	Any of the following test positive?		Comments ? T= True	Step 1 T= True	Step 2 T= True	Report and finish T= True
		F						T			T
		T	Once per year or less					T	T		
		T	More than once per year					T	T		
T				Pos	F			T			T
T				Neg				T			T
T				Pos	T			T		T	
	T					Enteric viruses		T			T
	T					Cryptosporidium Giardia		T			T
	T					Coliforms		T			T
	T					No tests positive		T			T

TABLE 2: Rule Table for the Chlorine Disinfection Advisor

Step No:	Is any Disinfect-ion being carried out ?	What type of disinfect-ion is used ?	Where is chlorina-tion being done ?	What strength of chlorina-tion is done ?	What is the chlorine residual ? Units = mg/l	What is the chlorin-ation contact time (minutes) ?	Any monit-oring program ?		Comments applicable ? T=True	Go to Step 2 ? T= True	Report and finish ? T=True
1	F								T		T
1	T	NOT Chlor							T		T
1	T	Chlor				< 15			T	T	
1	T	Chlor				15 to 30			T	T	
1	T	Chlor				> 30			T	T	
1	T	Chlor					Yes		T	T	
1	T	Chlor					No		T	T	
2			After stabilizn	High					T		T
2			After stabilizn	NOT High							T
2			Before treatment						T		T
2			Reser-voirs.		> .5				T		T
2			Reser-voirs		< .5				T		T
2			Retic. system		> .2				T		T
2			Retic. system		< .2				T		T

The reasoning process used by the microbial water sampling advisor may be made clearer by using an example (See **Table 1**): If monitoring for microbes is being done, and the monitoring frequency is more than once a year then comments on microbial monitoring and on monitoring frequency are valid and **Step 1** is then complete (i.e **True**). Since **Step 1** is **True**, a second group of rules become available for consulting. The next question presented to the user relates to whether any test results turn out positive. If the answer is yes, then the following question asks whether sampling is done after treatment or not. If sampling is done, then comments relating to the positive test results and re-sampling are relevant, and **Step 2** is then **True**. Once **Step 2** is evaluated as **True**, a third group of rules becomes available for consulting. The last question presented relates to which pathogen group, if any, tests positive. If one or more pathogen group tests are positive, then comments relating to treatment problems relevant to each group testing positive are added to the list of comments to be sent to the report generator. If no tests are positive, then comments noting this answer become relevant. The report generator is then called up and a report is prepared. The report is then presented in a report viewer displayed on the concluding screen of the microbial sampling advisor.

The reasoning process used by the chlorine disinfection advisor (See **Table 2**) follows a similar pattern to that used by the microbial water sampling advisor.

In order to understand how the reasoning pathways represented as rows in each table are related to each other, each consultation process is probably better presented visually as a flow chart (See **Figure 3** and **Figure 4**).

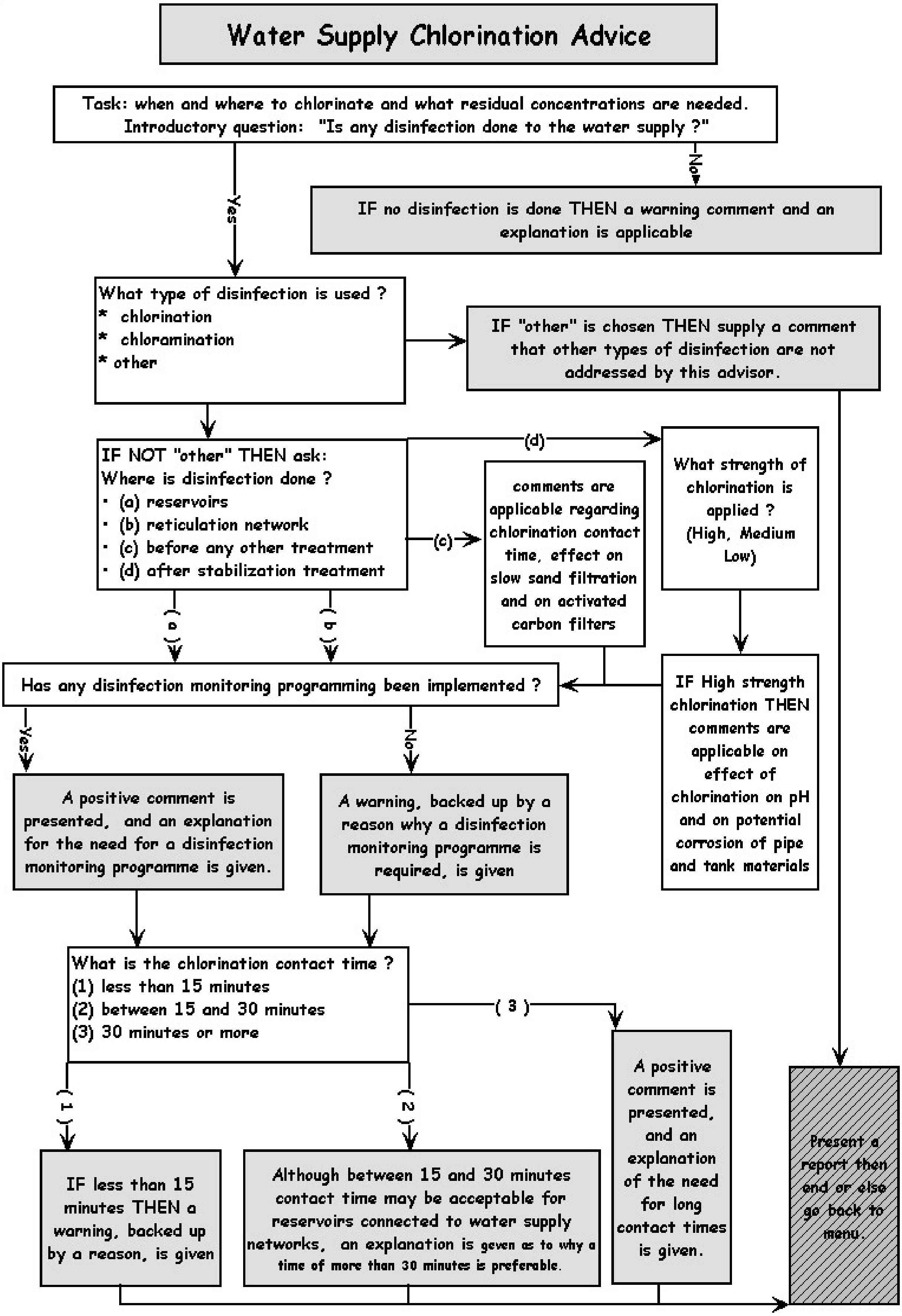

Figure 3: Water Supply Chlorination Advice Flow Chart.

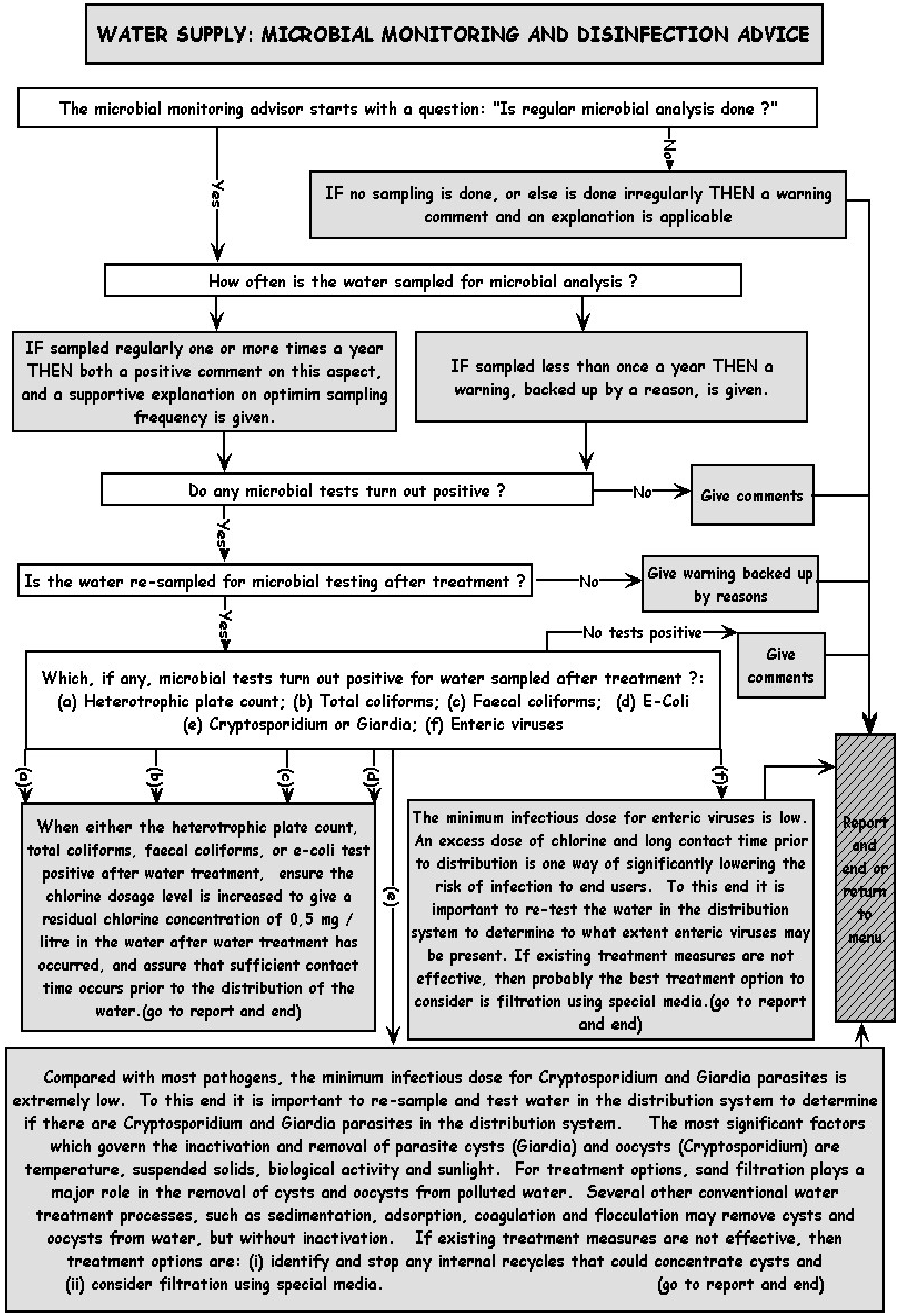

Figure 4: The Microbial Monitoring and Disinfection Advice Flow Chart.

4 Laboratory Determinand Test Selection Aid, Toxicity Interpreter and Water Treatment Advisor

Treatment of small water supplies often requires the use of local water sources which may have some unusual characteristics requiring special consideration when selecting a suitable treatment process. Selection of a conventional water treatment system for small water supplies is generally not the best choice because of the need for highly trained personnel to operate the plant, and the high capital and running costs associated with such a system. Small water supplies usually require a less costly form of treatment than that normally given to municipal supplies, thus requiring the selection of treatment processes which are taylor-made to suit the water supply characteristics, resource availability and which at the same time take into account community requirements/ characteristics. The *laboratory determinand test selection aid, test interpreter and water treatment advisor* is designed to help address the need for the selection of suitable treatment processes for source water with specific water quality characteristics.

The laboratory determinand test selection aid, test interpreter and water treatment advisor consists of two sequential components:

Laboratory determinand test-selection aid and
the water toxicity interpreter and water treatment advisor.

Laboratory determinand test-selection aid

The ability to cost-effectively analyse water to determine what constituents are likely to need treatment to make the water suitable for domestic use is believed to be partly dependent on the need to determine beforehand what laboratory tests are needed.

The laboratory determinand test selection aid is an expert system which is designed to help identify preliminary water quality test determinands based on the source of the water (surface water, spring or ground water) as well as on taste, colour, smell and cloudiness of a water sample, on site criteria of the water source, and other factors. Two lists of determinands are then presented. Those that are checked are the ones for which an analysis is recommended. The user can then modify the list. Once the determinands for anaysis are identified, the user can then go on to consult the laboratory determinand test interpreter and water treatment advisor.

Below is the basic sequence of questions asked, with possible answers appearing in italicised text within brackets:

What is the source of the water ? (*Surface water, ground water, spring, other*)

What smell does the water have ?
(Select one item only from those presented: *Ammonia, antiseptic, bad eggs or sulphurous, petroleum, muddy, none noticed, other.*)

What visual characteristics, effects or impact does the water have ?
(Select one item only from those presented: *blackish stains, curds, reddish-brown stains,* etc.)

What best describes the taste of the water ?
(Select one item only from those presented: *Acidic, astringent, bitter-sweet,* etc.)

What is in the vicinity, upslope of the water source ?
(Select one or more items from the list presented: *abattoir, kraals, pit latrines*, etc., or else select the bottom item of the list: *None of those listed above*.)

Two lists of determinands are then presented. The items recommended for analysis are checked (i.e. marked for inclusion). If no items were positively identified in previous questions, then the default items are checked. These default items are dependent on the source type of the water.

Because there is likely to be a need to break a consultation at the point where the checked items are displayed, buttons are available on the screen which enable a user to exit at this point, and the user can then later run the software and go straight to the determinand lists, check relevant items, and proceed to enter the analytical results. If, later, the user selects the option to bypass this component (the laboratory test selection aid), the two lists of determinands are presented first. At least one item on each list should be checked before continuing to the analytical data input screens.

Laboratory determinand toxicity interpreter and water treatment advisor

The ability to cost-effectively treat raw water to make it suitable for potable purposes is believed to be partly dependent on the extent of the need to treat the water for constituents exceeding aesthetic and health-related guideline limits, and the need to incorporate into the treatment process chain those treatment options which will produce water of the required quality at acceptable overall cost.

The laboratory determinand test interpreter takes the checked items on the lists which conclude the task assigned to the laboratory test selection aid, and then uses these to present screens which ask for the individual analytical results relevant to each checked item.

Given laboratory test results, this component then presents comments and /or identifies potentially suitable options regarding:

X the likely toxic effects of drinking the water taking into account the concentration of each contaminant in the water, assuming no treatment of the water for that specific contaminant occurs;

X likely aesthetic (i.e. visual, smell and taste) problems assuming the contaminants in question are not removed by treatment;

X the applicable prescribed drinking water limits for each contaminant in question;

- X potentially suitable treatment options applicable for each contaminant identified.

- X protective measures for the water user assuming negligible treatment of the contaminants in question occur;

- X relevant warnings on disposal problems regarding disposal of treatment plant residues;

An example a report produced by this component is included in the appendix.

The two sequential components of the laboratory determinand test selection aid, toxicity interpreter and water treatment advisor are depicted together in the simplified “Toxicity Advice and Treatment Options” flow chart (See **Figure 5**).

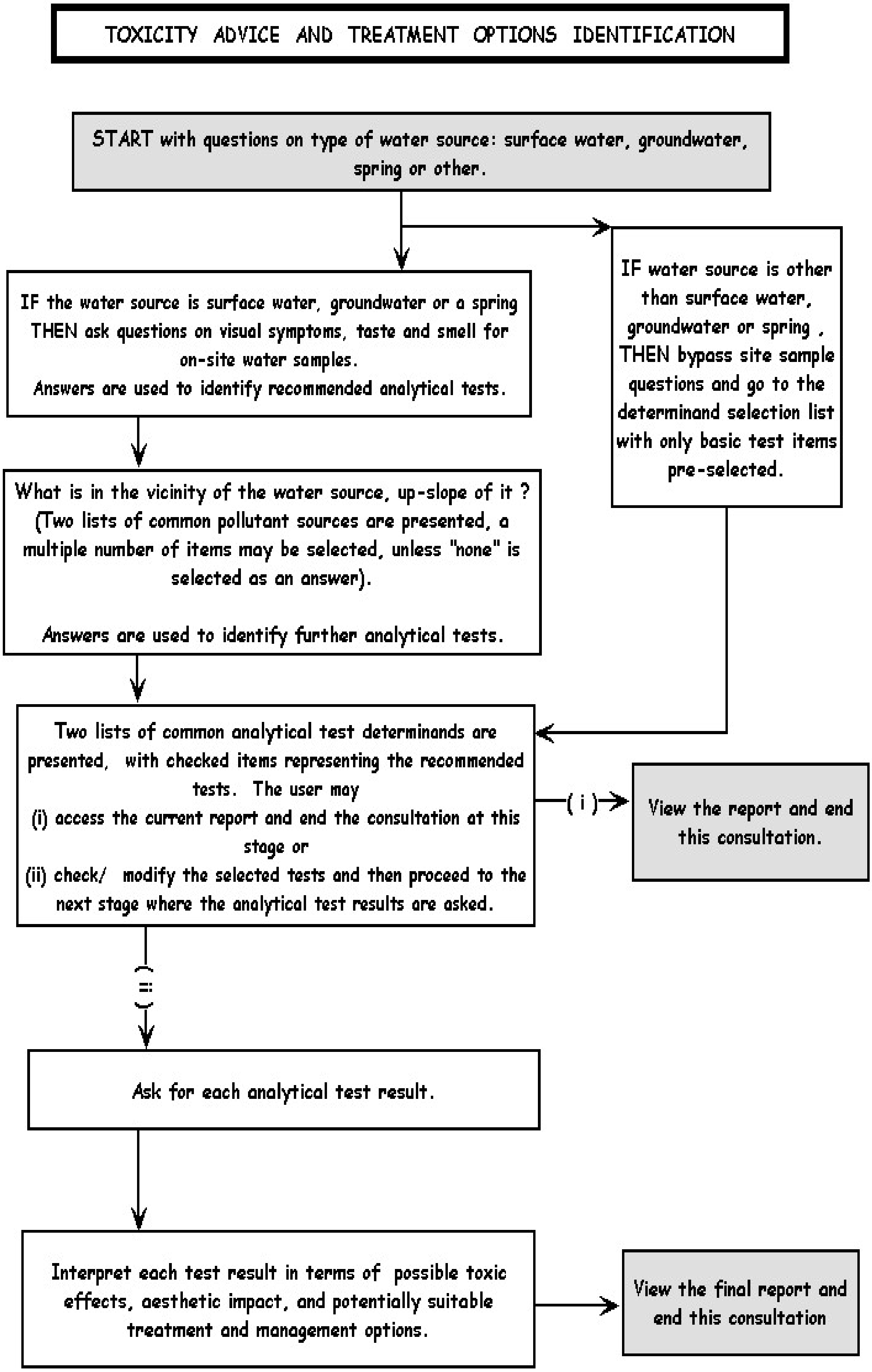

Figure 5: Toxicity Advice and Treatment Options Identification Flow Chart.

5 Water Treatment Option Suitability Assessment Aid

The selection of potentially suitable treatment components taking into account multiple criteria is not an easy undertaking. The conventional way of treating water (screening, sedimentation, precipitation, coagulation/flocculation, precipitation, filtration, chlorination and stabilization) is a universally accepted approach to treating water for domestic supply, and usually produces acceptable results. However, for small-scale water supplies this can be costly and require highly trained personnel and sophisticated equipment, making some of the components in the process not feasible to use.

The ability to cost-effectively treat raw water to make it suitable for potable purposes is believed to be partly dependent on how easy or cost-effective it is to treat the water for major contaminant categories taking into account process reliability, process compatibility with other components in the treatment chain, as well as process treatment effectiveness for the contaminant category in question and the need for upgrading.

Compatibility between treatment components relates to

(i) the extent to which a treatment component, suitable for treating one constituent present in water, may also be suitable for treating other constituents present in the water, and

(ii) the extent that a specific treatment (e.g. chlorination) is compatible with other components in the treatment system.

Suitably trained personnel who are able to run water treatment facilities are scarce. Hence decision-support tools which are able to help in the selection of cost-effective treatment options for different types of water, and which take into account operational and community requirements should help to provide potable water for small communities at acceptable cost to the water service providers with a lower requirement for highly trained personnel.

A computer-based decision-aid, the Treatment Option Ranking Aid, has been developed to help in the selection of water treatment components which are to form a part of a water treatment process chain. The software consists of a rank-ordering algorithm which is applied to two lists of objects. These objects first have values ascribed by a weighting-and-rating algorithm, and then they are ranked.

The water treatment option suitability ranking aid is designed to assist in the identification of potentially important water treatment options, given the following criteria:

(1) The need for restrictions on annualised life-cycle costs (Martin and Martin, 1991) which are essentially the sum of capital costs and maintenance costs divided by the number of years of expected useful life, and the result is added to annual running costs;

(2) the relative importance of operational simplicity, of process reliability and of expected performance, the ease of upgrading the facility (the latter, should it be required), the ability to treat water which varies in flow rate and quality, and the need for the water to be pre-treated (essentially for turbidity).

(3) the need for effective reduction of pathogens, potentially toxic contaminants, and constituents which present aesthetic problems.

The weighting and rating methodology used in this software component is based on a relative assessment of water treatment process components for the above criteria. The treatment components considered in this study are:

Slow sand filter
Pressure sand filter
Dual media filter
Chemical precipitation and filtration
Flocculation
Granular Activated Carbon
Packed Tower Aeration
Ozone treatment
Ultra violet light treatment
Chlorination
Membranes
Ion exchange resins

Each treatment component was rated over twelve criteria in accordance with values ascribed to them by the US Environmental Protection Agency (1990), Martin and Martin (1991), Vigneswaran and Visvanathan, (1995) and the American Water Works Association, (1991).

Criteria considered in this study are:

Reliability
Cost
Expected performance
Operational simplicity
Flow variation adaptability
Dissolved Natural Organic Matter (DNOM) reduction
Pathogen reduction
Inorganics reduction
Organic chemicals reduction
Ease of upgrading
Flow quality change adaptation
Pretreatment independency

Treatment Type	Reliability	Cost	Expected performance	Operational simplicity	Flow variation adaptation	DNOM reduction	Pathogen reduction	Inorganics reduction	Organic chemicals reduction	Ease of upgrading	Flow quality change adaptation	Pretreatment dependency
Slow sand filtration	7	7	8	6	7	4	6	3.5	5	2	8	6
Pressure sand filter	5	8	6.5	7	5	3	2	2	1	8	5	2
Dual media filter	6	7	8	7	5	4	3.5	2	1	5	8	4
Chemical precipitation and filtration	8	6	8	2	7	3	4	5.5	2	8	8	8
Flocculation	8	5	8	3.5	7	4	4	5	2	5	8	8
Granular activated carbon	8	5.5	6.5	5	8	6	5	2	8	2	2	2
Packed tower aeration	8	9	8	5	5	2	2	2	3.5	2	8	2
Ozone treatment	6	8.8	6.5	2	4	4	7	1	6	2	8	2
Ultra violet light treatment	8	8.9	5	5	2	1	6.5	0	1	2	3	2
Chlorination	8	9.5	7	3	5	3	9	1	2	2	8	5
Membranes	7	1	8	5	3	4	5	7	3	8	8	5
Ion exchange resins	5	6.5	6.5	3.5	8	1	3.5	7	2	8	6	3

Table 3: Treatment Component Versus Criteria Ratings (US Environmental Protection Agency 1990; Martin and Martin, 1991; Vigneswaran and Visvanathan, 1995 and the American Water Works Association, 1991)

Table 3 shows the ratings assigned to the components for each criterion, where ratings range from 0 (minimum possible) to 9 (maximum possible). The values in the table were derived from assessments in the literature (US Environmental Protection Agency 1990; Martin and Martin, 1991; Vigneswaran and Visvanathan, 1995, and the American Water Works Association, 1991) The numbers in each column represent relative values assigned to various treatment components for each of the criteria listed above. The values are only relevant within each criterion, and not between criteria. The accuracy of the values for criteria vary, with the least accurate being ascribed to the column headed DNOM (dissolved natural organic matter reduction) due to lack of sufficient data, whereas probably the most accurate being pathogen reduction and possibly, cost (due to an abundance of data in the literature). It should be noted, however, that cost data will be biased as, for example, construction costs will be higher for the United States than for South Africa.

In this study, the aim is to rank treatment components from most suitable to least suitable, given the criteria listed above. Doing a relative comparison of criteria is not easy (nor is it reliable) for criteria that are dissimilar. However, it should be possible to do a relative comparison of the importance of criteria for a specific community, or for a specific place.

The evaluation method used is based on a summation of products of importance weights (input by the computer user) and component ratings (derived from **Table 3**), for each of the twelve treatment components considered. The components are then ranked and ordered, so that the first component has the highest score, the second has the second highest score and so on. The last component then has the lowest score. The treatment component with the highest score is potentially the most suitable component. However, precaution is needed when using these results.

It is not often that a single component will perform sufficiently well for all the important criteria. When two or more components are to be selected, importance should be considered for a component while taking into account the effect that other components will have on it or the effect that it will have on other components. For example:

a. If the water is to be chlorinated in order to reduce pathogens and a further treatment component is now being considered, then for the new component, importance in terms of pathogen reduction should be given a value of low or none.

b. If the effect of a change in water quality is to be addressed by an upstream treatment component (e.g. a change in turbidity is to be addressed by pre-treatment), and a further treatment component is being considered, then the importance of change in water quality when considering downstream components should be given a value of low or none.

c. If robustness of the treatment chain is important, and one of the components selected is not robust, if it should fail then the effect of its failure on the system needs to be considered.

Even using relative importance in the weighting and rating methodology, the results are not considered accurate as the weightings given to the criteria categories assume a standard base reference point across categories and a similar spread of values within each category.

For cases such as those presented above, it is worthwhile to have access to a list of pros and cons of the treatment components, where the pros and cons relate to performance capability of a component under specific conditions (e.g. effect of turbidity on the disinfection capability of UV radiation) as well as the “side-effects” of the treatment component on the water (e.g. the effect of chlorination on the pH of water). Some pros and cons of potentially suitable treatment components are presented in the software, on a screen accessible from the final screen.

One useful approach to selecting potentially suitable components in a treatment chain is presented as follows:

> For the first run, all the criteria are ascribed levels of importance by the user and the highest ranked treatment options are noted. Then for each successive run one of the potentially important criteria are ascribed a value of "high importance" and the rest are ascribed values of "no importance". The process is repeated for the other important criteria. A printout of the ranked values is obtained for each run, and the results compared. One treatment component is selected from those most highly rated, for each run. Components most favoured for selection are those which rank highly for the most important criteria, appear the most times over the runs, and which complement each other in accounting for the range of important criteria.

There is scope for improvement and extension of the functionality of this tool. One possibility is to include decision support for defining further weights for the relative contribution of each criterion to the overall score, the need for which is highlighted by the following statement (as an example):

> “*Cost* has X times as much contribution to make to the component selection outcome as does *reliability*”, where X represents a numeric value which is to be evaluated. The analytical hierarchy process (AHP) or similar evaluation methodology may be useful here.

For each criterion presented to the computer user, the user may select one of four qualitative values for importance: “None”, “Low”, “Medium” and “High” (where None = 0, Low = 2, Medium = 5.5 and High = 9). Once all the values have been entered, the user is presented with a table of equivalent numeric values for review. The user can then either return and change some values, or else start the evaluation process. If the latter is done, a graph, a table of values and a simple report are presented.

The questions presented to the user are shown below, together with descriptions and comments.

(a) How important are cost restrictions for water treatment ?

> For water treatment projects that do not have the required financial resources to support the development and operation of a sophisticated treatment system, there are alternative treatment system options which could be adequate for the

treatment objectives required. If financial resources are severely limited, then cost restrictions are important and a high value should be selected.

(b) How important is the reliability of the water treatment system ?

A reliable process is one whose performance does not get markedly worse as a result of lack of regular attention. Therefore if the treatment system is required to operate with minimal attention, this should have high importance. If the component is to comprise part of a larger treatment system, so that its failure will not markedly affect the overall reliability of the system, then Medium or Low can be selected.

If the quality of the source water is high enough so as to require only minimal treatment, the importance will depend on the type of treatment needed. For example, if the water source is surface water, reliability regarding disinfection may still be considered to have high importance.

(c) How important is operational simplicity for the facility ?

Operational simplicity refers to low operational, monitoring and ongoing maintenance requirements of the treatment works and where electrical and mechanical controls exist, there is a requirement for simple adjustments in order to operate the treatment system.

The more simple a treatment system is to monitor, operate and maintain, the easier it is to manage. The high costs of training and maintaining human resources normally needed for a more complex system are therefore saved. Further, should existing human resources not be available at any point in time, it should not take long to train a stand-in. Fewer people are required to operate simple systems.

The greater the need for operational simplicity, the greater its importance.

(d) How important is the capability of treating flows that are variable ?

If the water flow rate through the treatment works is likely to change significantly over short periods of time, the importance rating should be High.

If the flow rate at the water source is likely to fluctuate, a large water storage tank or reservoir may be built to help overcome this problem.

For smaller communities, due to a highly variable water demand, the water supply flow rate is likely to fluctuate significantly. If water storage tanks at the user end cannot be built to overcome this problem, for such situations a high importance weight is normally recommended.

If the water flow through the treatment plant is likely to stop at times, a high importance weight is normally recommended.

(e) How important is the treatment of dissolved natural organic matter (DNOM) in the water supply ?

DNOM is normally found in water which drains from land covered in fallen leaves or in dried out vegetation. Those waters, which have little or no turbidity, are often amber coloured. DNOM is difficult to treat and does not usually represent a risk to health when present in drinking water.

Removal of DNOM from clear amber-coloured water often causes the water to become corrosive. Such waters usually need stabilisation after DNOM treatment (Loewenthal et al, 1986).

If there is a great need for efficient DNOM reduction, this issue is normally considered to have high importance.

(f) How important is adaptation to change in water quality ?
For water sources whose quality is likely to change from time to time, it is important that the treatment system performs adequately.

If the water source quality is likely to remain constant (e.g. a perennial spring or groundwater), this aspect is not important, and so a low importance may be selected.

If water quality is likely to change for periods of time, this aspect is important and depends to some extent on whether storage facilities are able to "smooth out" the changes in quality by the time the water reaches the treatment plant.

As an example, if the source is a stream that drains from a built-up area or from an area subject to soil erosion, this issue is normally considered to have a high importance.

(g) How important is it that the treatment facility be easily upgraded when the need arises ?

If the population is expanding, for example, the water treatment works may need to start off small and then be expanded as the need arises. Those types of treatment process that can be upgraded at minimal extra cost and disruption to the treatment system could then be more suitable.

The more often or likely upgrading will be required, the higher the importance of this aspect.

(h) How important is the expected performance capability of the facility ?

Expected performance is the expected production of water whose quality is good enough for drinking water purposes.

This usually requires a high importance weight unless it is to be accompanied by pre treatment and/or post treatment. In the latter case, the importance could be Medium or Low (as the importance of this issue depends on expected performance of the other treatment options selected).

(i) How important is the facility's capability for removing inorganic contaminants ?

If the source water is likely to contain trace elements such as arsenic, selenium, lead, mercury, cadmium, zinc, copper, nickel, manganese and fluorides at concentrations that are of concern in drinking water supplies, then the need for treatment/ reduction of these normally needs a high importance weight.

(j) How important is the need for pre-treatment of the raw water supply ?

As pathogens and certain types of pollutant adhere to suspended particles in water, the degree of turbidity can be an indication of the potential pathogen and pollutant content of a water source. It is therefore highly important that water for domestic supply be effectively treated for turbidity.

Some treatment processes are able to treat turbid water satisfactorily without the need for pre-treatment, whereas others are not.

If the raw water has very low turbidity (less than 1 NTU), and is not polluted, pre-treatment (other than screening) should not be required, and so this will receive low importance, or maybe even none.

Water with a slightly higher turbidity (1 - 5 NTU) but still unnoticeable, and is not polluted, may not need pre-treatment. A low importance or medium importance value may be assigned to this. If no treatment besides chlorination is to be considered, then medium or high importance values should normally be selected for domestic water supplies.

Water with turbidity above 5 NTU (the water appears "cloudy") and polluted water often requires pre-treatment. In this case, if the downstream treatment processes are to treat water for turbidity and the identified contaminants, and then the water is then to be chlorinated heavily, this issue may be given a low value. Otherwise give this issue a medium or high importance.

If on the other hand, the object of the exercise is to identify suitable treatment options that will complement each other in a treatment chain, and turbidity treatment is not a current concern, then give this issue low importance (or even none).

(k) How important is the capability of the facility to remove organic chemicals from the water ?

Organic chemicals are manufactured by man. Many of them, such as pesticides, are toxic. Many others, such as PCBs and vinyl chloride, are carcinogenic.

Both groundwater and surface water resources can be polluted by organic chemicals. This can happen directly as result of poor management of industrial processes and incorrect disposal of industrial and municipal wastes and effluents. Organic chemical pollution can also happen as result of certain agricultural activies.

If a water source is likely to be, or else known to be, contaminated by organic chemicals, then give this issue high importance.

(l) How important is the pathogen removal capability of the facility ?

The capability of a treatment or disinfection process to remove or effectively reduce pathogens in a water supply system is an important factor in identifying a potentially suitable water treatment process. The more efficiently a treatment system removes pathogens, the less chance there is of disease spreading to people who drink the treated water. If a disinfectant is to be added to the treated water, then the importance of pathogen reduction is determined by:

(a) the reliability of the continual addition of disinfectant and
(b) regular monitoring of residual disinfectant levels in the water supply system.

For flows of high variability in quality, optimum levels of residual disinfectant in the water supply system will be difficult to maintain, and for certain water sources, there is an increased risk that high concentrations of pathogens will reach the end users. This risk is reduced if pathogens are effectively removed by a water treatment process, so such a process should have a high importance rating for pathogen removal.

If there is a great need for efficient pathogen reduction, especially when flows are variable or water quality is variable, then the importance of this issue would normally be high.

A flow chart of the process used in the water treatment option suitability ranking aid is shown in the figure: "Treatment Options Suitability Assessment Flow Chart" (See **Figure 6**).

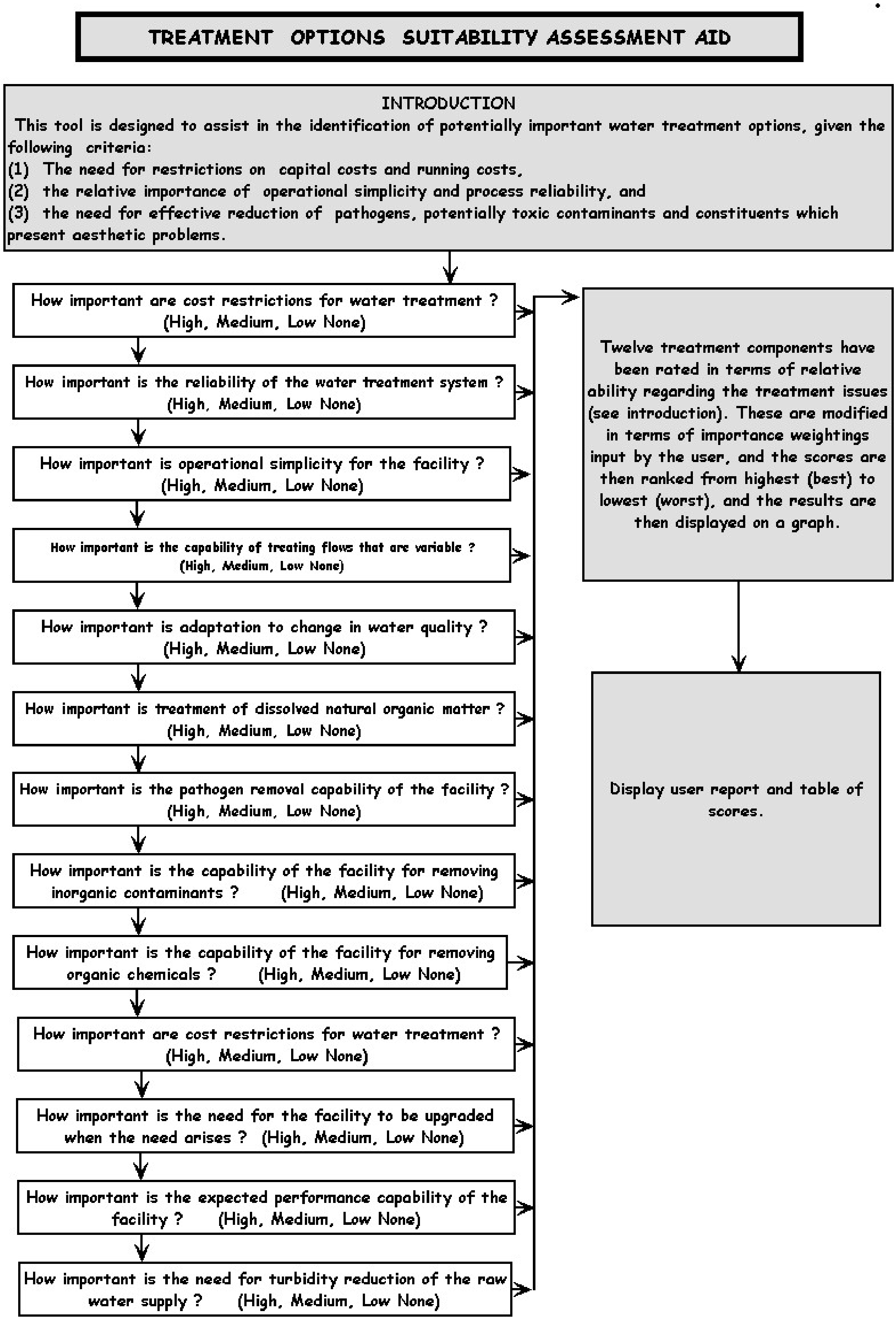

Figure 6: The Treatment Options Suitability Assessment Flow Chart.

6 Drinking Water Contaminant Limits Exceedance Tool.

The ability to cost-effectively treat raw water to make it suitable for potable purposes is believed to be dependent on:

(1) the extent to which constituents exceed aesthetic and health-related guideline limits

(2) how easy or cost-effective it is to treat the water for each constituent to bring it to within acceptable limits (Martin and Martin, 1991).

(3) to what extent a suitable treatment process for one constituent is compatible with that selected for another constituent (Martin and Martin, 1991; US Environmental Protection Agency, 1990).

This decision aid estimates the extent to which constituents exceed or else satisfy upper-end health related guideline limits. The resultant information may be used to help assess the importance of specific treatment process options in terms of the need for treatment of potential contaminants.

The concentration of a water constituent may be compared with various limits. For drinking water purposes, there are limits that represent its Target Water Quality Range (TWQR), defined by upper and lower Target Water Quality Limits (TWQL) (Department of Water Affairs and Forestry, 1996). For certain potentially problematic constituents, another limit is defined: the Maximum Recommended Limit (MRL) (Department of Water Affairs and Forestry, 1996). For contaminant reduction purposes in this software tool, only the upper limits are considered.

The importance of a specific treatment option for contaminants depends on the extent to which a constituent concentration falls below or above the upper TWQR limit, and the extent to which it falls below or above the MRL. (Martin and Martin, 1991)

For potentially toxic constituents, the upper TWQL indicates the level of concentration above which some health and/or aesthetic effects could start to occur. The MRL indicates the concentration level above which the risk associated with health or aesthetic effects would normally be considered unacceptable for domestic purposes. (Department of Water Affairs and Forestry, 1996)

This tool is believed to be potentially useful even though it has limited rule-based logic incorporated into it. The constituents addressed include aluminium, arsenic, cadmium, hexavalent chrome, copper, fluorides, iron, mercury, potassium, manganese, sodium, lead, selenium, vanadium, zinc, nitrate-N and sulphates. There is scope for expansion to include other potential contaminants as well as the capability to address lower limits, the latter (for example) may be used to address lower limits for residual free chlorine in drinking water supplies. The procedure used in this tool is shown as a simple flow chart entitled “Target Water Quality Limits Exceedance Flow Chart” (See **Figure 7**).

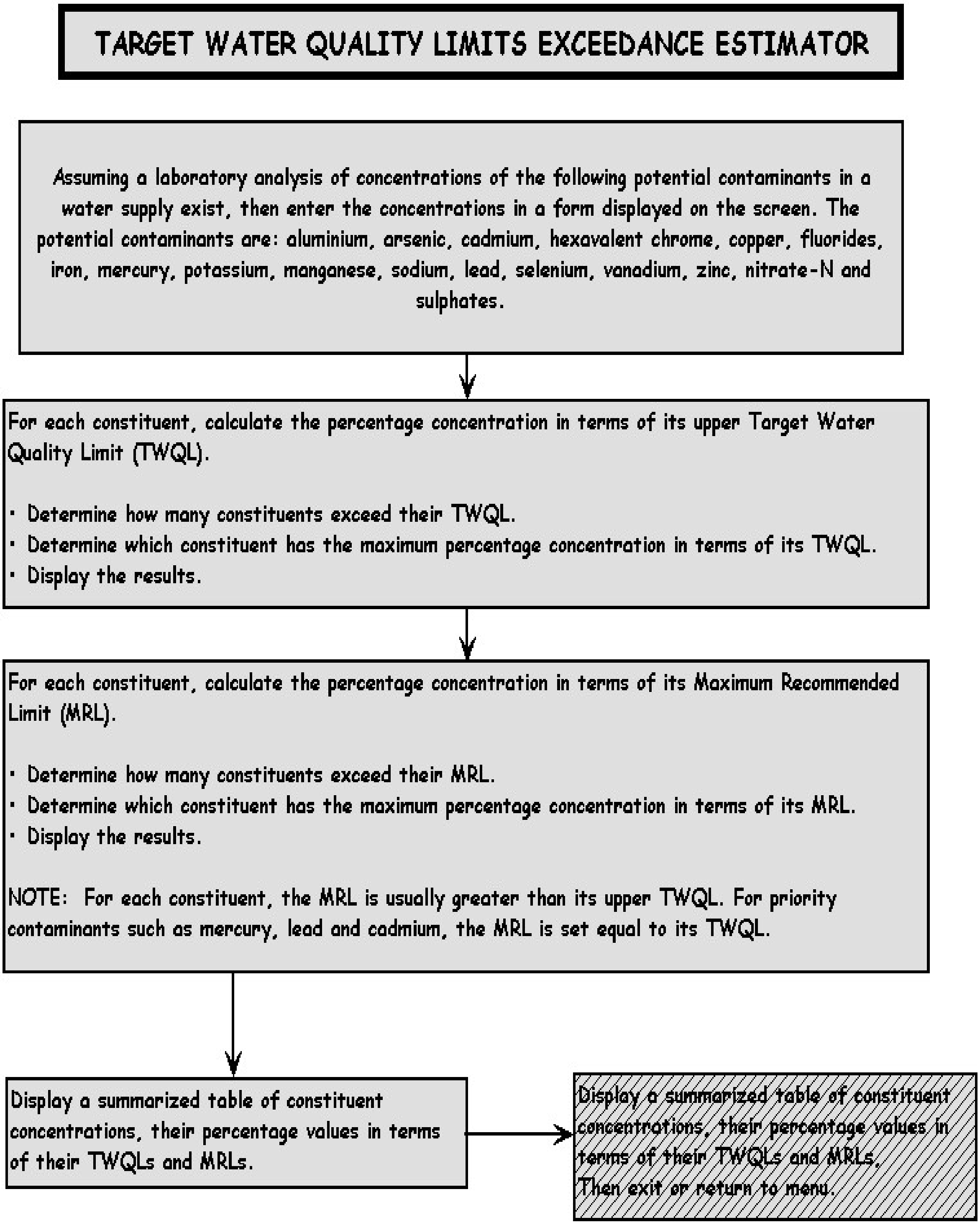

Figure 7: The Target Water Quality Limits Exceedance Flow Chart.

7 Water Hardness, Corrosivity and Aggressiveness Tendency Advisor.

For water supply distribution systems delivering potable water to a community, normally the following analytical data are required for identifying the possibility of the water having potential aggressiveness tendencies in terms of high chloride and sulphate concentrations and having potential problems associated with water hardness. The water-analysis data are:

- On-site pH;
- On-site temperature;
- Electrical conductivity (EC);
- Alkalinity
- Magnesium concentration;
- Calcium concentration;
- Calcium hardness;
- Chloride concentration;
- Sulphate concentration.

This software component does the following:

(1) It calculates the total hardness of the water and then interprets this in terms of its effect on:
   (i) washing with ordinary soap and
   (ii) human health (when used for drinking).
   (Department of Water Affairs and Forestry, 1996.)

(2) It calculates the corrosion ratio and uses this to estimate the likelihood of corrosion in metal pipes and containers as result of high concentrations of sulphates and chlorides in relation to the alkalinity of the water (Loewenthal et al, 1986; US Environmental Protection Agency, 1990).

(3) For concrete/ asbestos-cement pipes and storage tanks, it first calculates the Agressiveness Index and from this it indicates the possibility of corrosion on such pipes and storage tanks. Then, based on the concentration of sulphates in the water, it indicates the likelihood of deterioration of the inner surfaces of concrete/ asbestos-cement pipes and storage tanks (Loewenthal et al, 1986; US Environmental Protection Agency, 1990).

(4) Finally, it presents relevant mitigation measures which include possible treatment options and suggested changes to pipe and water container materials (Loewenthal et al, 1986),.

A flow chart of the logic used in the water corrosivity and aggressiveness tendency advisor is shown in **Figure 7**.

Note: This software does not conduct a corrosion and scaling tendency assessment of water on metals in terms of the calcium-carbonate precipitation potential, as the latter is effectively addressed by STASOFT computer software (Loewenthal, Ekama and Marais, 1988). STASOFT is recommended for this purpose, and the Windows version is currently obtainable from the Water Research Commission for a fee.

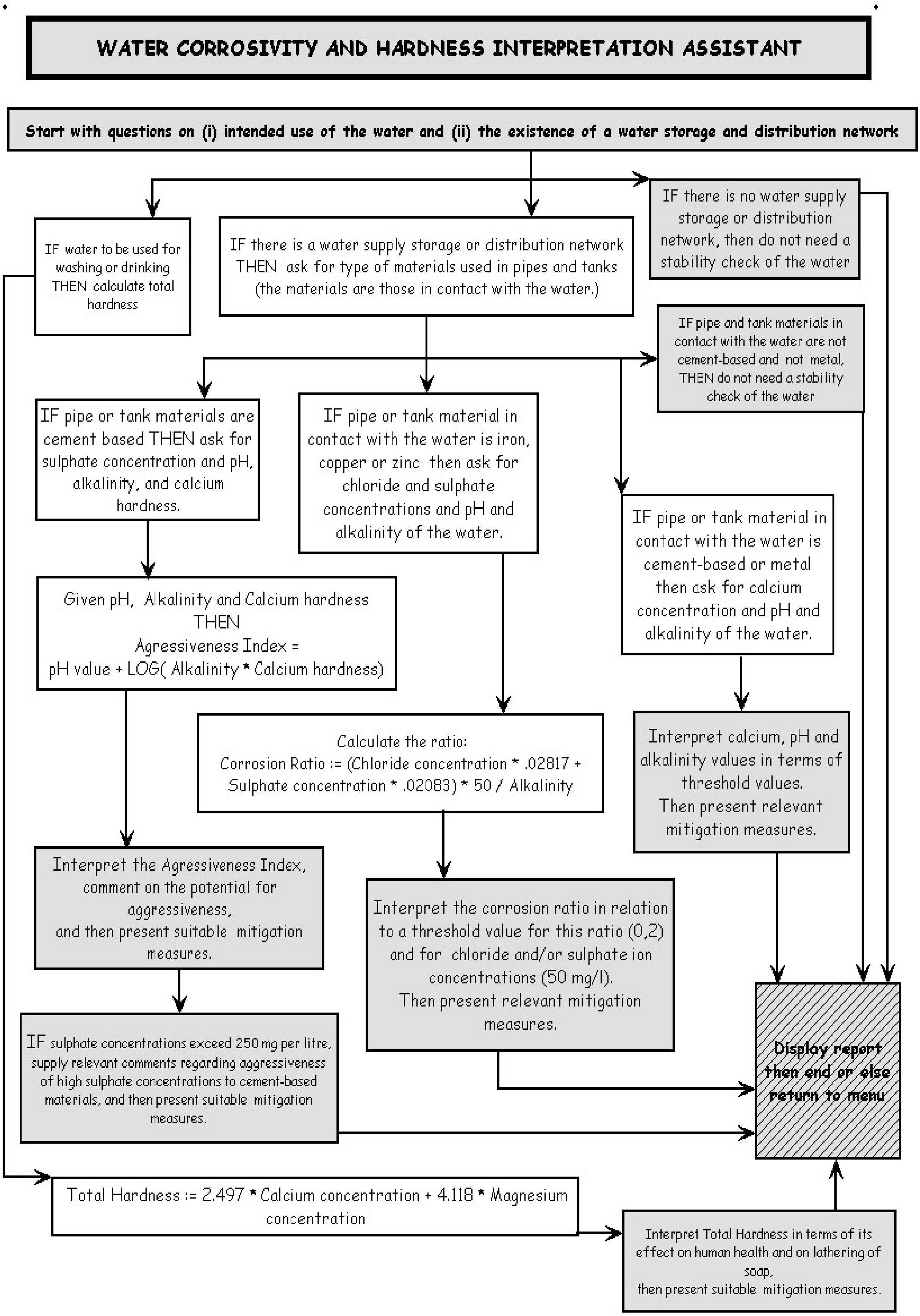

Figure 8: The Water Corrosivity and Hardness Interpretation Flow Chart.

8 Water Source Protection Advisor

In many instances in rural areas, untreated water is collected directly by users from water sources. Perhaps the most practical way of protecting population health then is to protect the water source from contamination and to present simple, cost-effective methods to the community for disinfecting the collected water before it is used for drinking, for preparing food or for personal hygiene.

This module, the water source protection advisor, is designed to give advice on protection of water sources for rural domestic supply, with the principal aim being to protect the health of the population who obtain water from the source, in terms of reducing or preventing microbial contamination of the water source. Much of the information contained herein in simplified form is derived from Sani, (Department of Water Affairs and Forestry, 1997), the World Health Organisation guidelines (World Health Organisation, 2000 b), and other guidelines documents (Cave and Kolsky, 1999; Foster and Hirata, 1991). Due to the lack of practical guidelines relating to on-site protection of water sources other than springs, boreholes and wells, these have not been addressed. The World Health Organisation recommends that river water be assumed contaminated and that it should be at least disinfected (preferably by chlorination) before use for drinking or food preparation. Instructions for chlorination of water collected from rivers and ponds are included in the water source protection advisor and they also appear in the appendix.

This module is designed to address issues relating to:

- The type of source,
- protection of the source and access routes,
- the population size and type of sanitation facilities in the area (pit latrines/ septic tanks/other) and their position in relation to the source,
- the ground type and the depth to groundwater where the sanitation facilities are located.

The above issues and the associated decision-making procedure are presented in the water source protection advisor flow chart (See **Figure 8**).

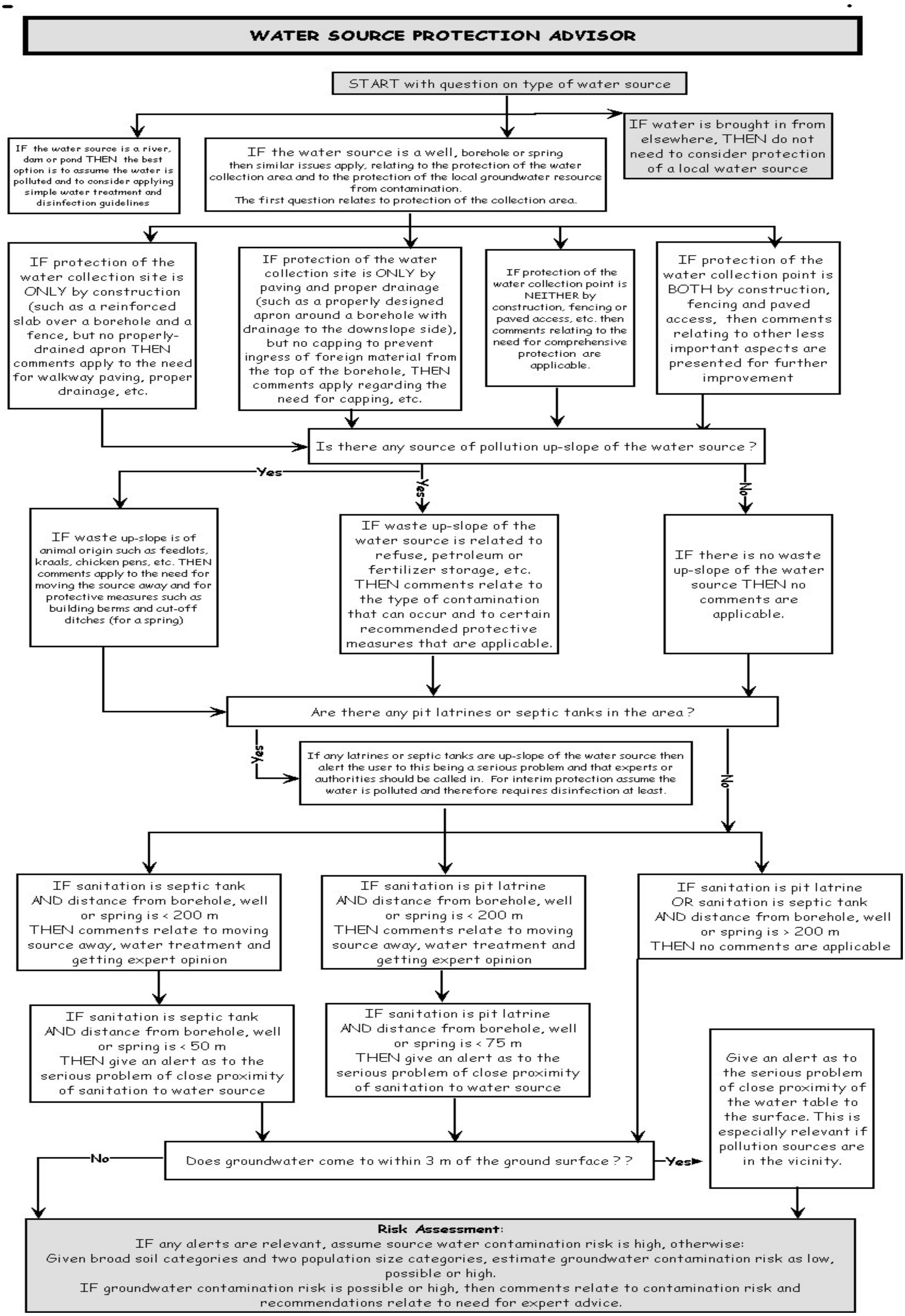

Figure 9: The Water Source Protection Advice Flow Chart.

9 Summary and conclusion

9.1 Summary

In the development of WATTREAT, guidelines, “rules-of-thumb” and some methodologies were derived from literature and then incorporated into rule-based logic and set up as expert system models. The models were incrementally tested, built-up and modified. Development and testing involved setting up “demonstration” versions of expert systems to test preliminary rule sets, methods (e.g. ranking and ordering), question displays, form displays and report generators. Validation was done by comparing results from the software with literature and with experts (The exception to some extent being the water treatment option ranking tool, the results of which need further validation). User acceptance tests were done by holding demonstrations and where possible getting potential users to test the software on a trial basis. Once the expert systems were giving believable results, they were assembled under the control of the main menu, the latter being a single user interface from which all the components could be run.

The functions of these components are summarised below.

Microbial sampling and chlorination disinfection advisor.

This is a simple system designed to give advice on microbiological sampling and chlorination of a community's water supply, where a water storage and/or water reticulation system exists. It is split into two modules.

- One module addresses when and where chlorine disinfection is done and the minimum residual chlorine concentrations in a community's water supply
- The other module addresses how often microbial sampling should be done, what microbes should be tested for, and the need for re-sampling when any tests are positive.

The water determinand test selection aid and the treatment identification and toxicity advisor

This is designed to identify preliminary water quality test determinands based on site evidence and then to present toxicity and water treatment advice.

(I) Given visual symptoms, taste and smell characteristics for on-site water samples and potential pollution sources in the vicinity of the water source, this module then identifies criteria for laboratory analysis.
(II) Given specific contaminant concentrations in a water supply, this component is designed to:

- give comments on potential problems, toxic effects or impacts relating to the contaminant in terms of its concentration;

- give recommendations and warnings regarding the treatment process;
- identify relevant treatment options for the contaminant in question.

Water treatment option ranking aid

This module is designed to aid in selection of water treatment options.

It aims to assist in the identification of potentially important water treatment options, given the following criteria:

(1) The need for restrictions on costs,
(2) the relative importance of operational simplicity and process reliability, and
(3) the need for effective reduction of pathogens, potentially toxic contaminants and constituents which present aesthetic problems.

The drinking water limits assessment tool

This decision aid estimates the extent to which constituents exceed or satisfy upper-end health related guideline limits.

The ability to cost-effectively treat raw water to make it suitable for potable purposes depends on:

(1) the extent to which constituents exceed aesthetic and health-related guideline limits
(2) how easy or cost-effective it is to treat the water for each constituent to bring it to within acceptable limits
(3) to what extent a suitable treatment process for one constituent is compatible with that selected for another constituent.

This information may be used to help assess the importance of specific treatment process options in terms of the need for treatment of potential contaminants, and so can be profitably used with the water treatment option ranking aid and the treatment identification and toxicity advisor.

Water supply network corrosion and aggressiveness assessment aid

This module is designed to give advice on water hardness, corrosivity and aggressiveness, the latter two principally in terms of chlorides and sulphates. In other words, it is designed to advise on:

(1) the potential aggressiveness of water on cement-based materials and potential corrosivity of water on metals, due mainly to high chloride and sulphate concentrations;

(2) corrosivity of water on cement and metals given calcium, pH and alkalinity values in terms of threshold values;
(3) the hardness of the water and the potential affect of this on human health and on washing.

The water source protection assistant

This module is designed to give advice on protection of water sources for rural communities, where the community collects its water directly from the source, with the principal aim being to protect the health of those who use the water for domestic purposes.

Given the type of water source, existing facilities used to protect the source, the type of sanitation in the vicinity, the proximity of sanitation facilities to the source, the existence of other potential sources of pollution up-slope of the source, the depth of the groundwater table and the type of ground in the area, it then does the following:
(1) It determines the degree of risk of contamination of the water source,
(2) It identifies the need to get expert advice;
(3) It identifies appropriate mitigation measures.

9.2 Conclusion

Six decision-support software components that make up WATTREAT have been presented. The logic used in them has been discussed and instructions on how to use the software has been included in the individual chapters
WATTREAT is designed to run under the Windows 3.1, '95 and '98 operating systems, to take up little computer memory, and to be capable of being uninstalled by deleting the WATTREAT directory and associated screen icons without leaving behind "shreds of evidence" such as registry files. WATTREAT can be run from the D drive by copying the directory and its software to that drive, and running the batch file named WatrtDdrive.
Although WATTREAT appears to function properly under Windows 2000, some of the text display and numeric input boxes are not presented with their original colours, making the text and numbers difficult to read.

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APPENDIX

Guidelines for chlorination and microbial sampling and water source protection

Chlorination and Microbial Sampling Guidelines

General principles

Water to be chlorinated should be clear and not alkaline (i.e. the water should have a pH of less than 8). Residual chlorine attaches readily to suspended solids and to dissolved organic contaminants, resulting in the need for higher chlorine doses and the impartation of objectionable tastes to drinking water. Residual chlorine is more effective in low to medium pH waters. (World Health Organisation, 2000a; McGowan, 1988).

The residual chlorine concentration in chlorinated water (as milligrams per litre) after a 30 minute contact time should not be assumed to be equal to the quantity of chlorine added to each litre of water being dosed. On average for clear water, 8 mg per litre of chlorine is required to produce about 2 mg per litre residual chlorine in water (Tebbutt, 1992).

Water should preferably not be used for drinking or food preparation purposes within 30 minutes of chlorination, because:

- pathogens may still be viable (World Health Organisation, 2000a) and
- residual chlorine may still be too high and so impart an objectionable taste to the water (Department of Water Affairs and Forestry, 1996)

Do not chlorinate water upstream of a slow sand filter system, as the latter requires a layer of bacteria (schmutzdecke) on the sand to help treat the water. Chlorine will have a negative effect on the performance of the schmutzdecke. If disinfection must be done upstream of a slow sand filter, ozone is the disinfectant of choice. (American Water Works Association, 1990)

Chlorination may be done upstream of an activated carbon filter. If activated carbon filters are used as part of the treatment system, it may be preferable that there be residual chlorine in the water reaching the filter so as to prevent too large a build-up of microbial biomass in the latter (biomass tends to grow fast in a carbon filter due to the presence of carbon which is needed by microbes as a food source). (Martin and Martin, 1991)

Some principles for water supply distribution systems

Regular sampling / monitoring of water supplies for residual disinfection levels and for pathogens is highly important, especially after disinfectant dosing (after at least a 30 minute contact time) and in those parts of distribution systems where water remains for a long time after dosing, as residual chlorine disappears after a period of time, allowing re-contamination by pathogens. Residual chlorine concentrations of below 0,2 mg per litre in water supply distribution systems are an indication that the original chlorine dosing is too low or is irregular, or else that booster chlorine dosing is required within the distribution network. A sudden drop in residual chlorine concentrations in the distribution network would be indicative of contamination in the network and may warrant investigation. The average and minimum requirements for residual free chlorine in water leaving reservoirs into a distribution network is 1 and 0,5 mg per litre respectively. (World Health Organisation, 2000a; Thompson, 2000)

If sampling of water supplies for pathogens downstream of a chlorination treatment point reveals that viable pathogens are present, then an immediate solution is to increase the chlorine dose strength. However some types of pathogen survive chlorination, and if found to be present, an alternative has to be sought to remove them. Amoebic cysts (for example) survive chlorination, but they can be removed through filtration. (World Health Organisation, 2000a)

Chlorination after stabilisation treatment:

High strength chlorination (resulting in more than 1 mg per litre free chlorine after 30 minutes of contact time) is not suitable for potentially aggressive and corrosive waters that have been stabilised prior to distribution. High strength chlorination after stabilisation will result in a decrease of the pH values (which is unwanted). Therefore, high strength chlorination needs to take place, with sufficient contact time, prior to stabilisation treatment, with minimal dosage after stabilisation (Loewenthal et al, 1986).

Some guidelines for disinfection of household water

The following are alternative ways of disinfecting household water:

- Heat the water to boiling point for at least 20 minutes.
- Filter the water using an approved ceramic filter or slow sand filter.
- If the water is clear and there is abundant sunlight, fill a clear glass or clear plastic bottle with the water and lay it flat in the full sun, preferably on a dark surface such as black plastic, for at least one day prior to use.

The preferred disinfection method follows:

If the water to be disinfected is cloudy, let the water stand for a while in a container to give time for suspended solids to settle, then decant the water from the top, then chlorinate the water according to the following guidelines:

- It is important to know that chlorine, if added to water in the right quantities, not only kills the germs but also remains in the water to kill other germs that come into contact with the water after the chlorine was added.

- It is important to know the volume of water to be treated, because the amount of chlorine needed depends on the volume of water to be treated.
- It is important to reduce the quantity of suspended solids in water before chlorination. This can be done by filtering or leaving the water to stand for a while, so that sediments settle to the bottom.
- Care should be taken when handling substances which contain chlorine (e.g. Jik, HTH). Such substances should be stored in well sealed non-metal containers. Metal spoons, cups or tins should not be used to dispense it. Plastics are preferable.
- Contact with skin and prolonged exposure to the fumes should be avoided;
- Water that has been treated with chlorine should be allowed to stand for at least 30 minutes before use to allow time for the treatment to be effective.
- A large plastic fizzy drink bottle (e.g. coke bottle) holds 2 litres; a plastic medicine spoon holds 5ml; a normal household teaspoon holds 2,5ml
  (World Health Organization, 2000a)

To chlorinate household water:

(1) Make up a 1 % chlorine solution (dosing solution) for water disinfection purposes.

Ten grams of chlorine in one litre of water gives a 1% solution.

For HTH giving 70 % of its mass as chlorine, use 14 g or one heaped tablespoon to a litre of water to make the dosing solution.
For laundry bleach with 5 % of its volume available as chlorine, use 200 millilitres (one fifth of a litre) to make up one litre of dosing solution.

(2) Use the dosing solution to disinfect household water as follows:

Use between 0,6 and 0,8 mg/l (12 to 16 drops) of dosing solution to disinfect one litre of water. (World Health Organization, 2000a**)**
After addition, stir the drinking water and allow it to stand for at least 30 minutes. Disinfect ten litres (one bucketful) of clear drinking water by adding a plastic medicine measure (or two metal teaspoonfuls) of chlorine solution, then stir and stand for at least 30 minutes.
Be careful when using metal spoons for dosing as chlorine is likely to react with the metal. Rinse medicine measures and dosing spoons immediately after use.
(Skinner B and Shaw R, 1998)

Water Source Protection Guidelines

General principles

Any potential source of pollution upslope of a spring, well or borehole represents a contamination threat to the water source. As the source is in the vicinity it should be fairly easy to identify and in most cases, to control.
In the case of a river or stream, the potential sources of pollution can be a long way off from where the water is being abstracted, and so are usually difficult to identify or else control. Generally such waters need treatment, and at the minimum this would mean disinfection (World Health Organisation, 2000b).

In the case of a spring, borehole or well, potential sources of pollution can be controlled by :
(1) Physically protecting the water source at and around the water collection area and
(2) controlling or preventing contamination by various means at the source of contamination.

Physically protecting the water source.

Use fencing, walls and enclosures to prevent unauthorised access to the site by animals and people who may want to use the site for other purposes.

Investigate ways that access routes can:
- be protected with concrete slabs, cemented stones, wooden platforms or other materials,
- be made more attractive to use.

Consider the use of paving at the water collection point or else consider the use of platforms and the construction of shelves or special areas where water containers can be conveniently placed while being filled, etc;
Help to ensure the water resource is used only for water collection (through education, etc.)

Controlling or preventing contamination by various means at the source of contamination:

If there are septic tanks or pit latrines in the vicinity of the water source and

- the groundwater table comes to within 3 metres of the ground surface or
- the soils are sandy gravely or very shallow or
- a sanitation facility is upslope of the water source
- a sanitation facility is close to the water source (within about 50 to 75 metres of the source then

assume the water source is polluted, obtain expert advice and disinfect the water until the results of an expert assessment are available.

For other potential sources of contamination such as feedlots, animal kraals, chicken pens, rubbish dumps upslope of a water source or in the vicinity and

- the groundwater table comes to within 2 metres of the ground surface or

- the soils are sandy gravely or very shallow or
- the pollution source is upslope of the water source
- the pollution source is close to the water source then

assume the water source is polluted, obtain expert advice and disinfect the water until the results of an expert assessment are available.

Potentially suitable mitigation measures include:

(1) Re-design and raise septic tank soakaways (under guidance of a sanitation expert), so that they form mound systems with an impermeable barrier (such as a plastic sheet lining) at the base.

(2) Re-design and raise pit latrines and their pits and seal the pits (under guidance of a sanitation expert).

(3) Consider changing to an alternative (e.g. shallow, dual-pit system) sanitation option.

(4) Move each offending pollution source further away from the water source and not upslope of it, preferably more than 200 metres away and make sure that it is situated on relatively impermeable soils or on an impermeable barrier and establish other protective measures such as cut off drains down-slope of the pollution source, etc.

(5) Disinfect the water source as an interim measure.