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Development of a toolbox to assess microbial contamination risks in small water systems

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ABSTRACT

Individual and small water systems account for the majority of waterborne disease outbreaks recorded in the United States each year. To address this problem a project was undertaken to develop a comprehensive self-assessment toolbox that could be used by small water system personnel to determine where their system has the greatest potential risks from microbial contamination. The toolbox components consist of: (1) a survey that asks specific questions; (2) a ranking tool that computes numerical scores for water system components based on survey answers; (3) comments and results from the ranking tool; (4) a guidance document to help the user understand why certain conditions may represent a risk; and (5) instructions for using the toolbox. A unique feature of the ranking tool is the ability to input expert opinion in the form of scores for each answer and weighting factors. Weighting factors are derived using ranked, pairwise comparisons, and then used to determine numerical scores for system components. Toolbox administrators are allowed to modify weighting factors used by the ranking tool application, thus allowing input of expert opinion.

Key words | drinking water, microbial contamination risk, small water systems

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INTRODUCTION

While most drinking water supplies in the United States are safe for human consumption, waterborne disease outbreaks continue to occur, resulting in both illness and occasionally death (Lee *et al*. 2002; Craun *et al*. 2002). The latest release of waterborne disease surveillance data by the Centers for Disease Control and Prevention for the period from 1999 to 2000 (Lee *et al*. 2002) reported 39 outbreaks associated with drinking water resulting in 2,068 illnesses and two deaths. Of the 39 total recorded outbreaks, 11 were associated with community water systems (CWS, serve year-round residents and have 15 or more service connections or 25 or more residents), 11 with non-community water systems (NCWS, serve the general public and have 15 or more connections or serve an average of 25 people or more) and 17 with individual systems. In the period from 1971 to 1998, it was reported by Craun and Calderon (2001) that there were 619 recorded outbreaks in public water systems, 294 from CWS and 325 from NCWS. The above data indicate that the majority of waterborne disease outbreaks occur in small, non-community and individual water systems. A review of selected outbreak case descriptions in Appendix A of the most recent surveillance report (Lee *et al*. 2002) reveals that small water systems (those that serve less than 3,300 people) were involved in a majority of the outbreaks associated with public water systems.

For the period from 1991 to 1998, most outbreaks occurred because of poor or no treatment of groundwater, contamination of stored water or contamination within the distribution system (Craun *et al*. 2002). A large number of distribution system associated outbreaks were caused by contamination of stored water, cross-connections and corrosion of pipe (allowing intrusion of pathogens from outside the pipe). Because of these problems, Craun *et al*.

(2002) recommended more frequent sanitary surveys and increased monitoring as an important step in prevention of microbial contamination.

Small systems are at particular risk for microbial contamination. Small systems typically have the same types of microbial risk as large utilities. These risks may arise from the source water and include protozoan cysts and oocysts in surface water, virus and other pathogen contamination in poorly constructed wells and groundwater under the influence of surface water. Additionally, distribution issues that may contribute to microbial risk include regrowth, back siphons, cross connections, poorly maintained storage tanks and deteriorating buried pipelines. As opposed to large systems, however, the inability of small systems to adequately address microbial risks is compounded by limited financial and operations/management resources, lack of in-house expertise and a simple lack of knowledge of what constitutes a risk. The National Drinking Water Advisory Council's Small Systems Implementation Working Group concluded that 'Many small water systems lack the technical, managerial, and/or financial capacity to comply with standards and provide quality service' (USEPA 2000). Consequently, small systems struggle with making rational choices regarding which improvements or technologies should be considered to ensure that microbial risks for their communities are minimized without compromising their ability to meet other regulatory requirements.

Because of their lack of resources, a critical need exists for tools to help small utilities understand, react to and subsequently manage microbial contamination risk system-wide. This paper presents the background and development of a set of tools (toolbox) designed to address this need. The primary goals for toolbox development were: (1) to help small system operators/managers determine where their risks for microbial contamination exist; and (2) to assist them in making sound decisions on where to invest time, sampling, capital improvements or operational changes. When operators/managers understand the real problems and risks they can work towards good solutions in a cost effective manner rather than investing large sums of money on advanced treatment techniques that may or may not address the areas that pose the greatest potential risk.

TOOLBOX DEVELOPMENT

Five major objectives were selected for development of the toolbox for assessment of potential microbial contamination risks. These were to:

1. Determine toolbox concept and components
2. Identify and enrol small water systems in the project
3. Create an initial survey and get participating small systems to complete it
4. Perform limited monitoring of raw and distribution water quality from each system
5. Develop toolbox components

The fifth objective was further defined by a set of three basic requirements that tools be:

1. Comprehensive and relatively easy to use
2. Capable of providing feedback based on their implementation
3. Capable of being adjusted using expert opinion

The following paragraphs summarize the toolbox development efforts.

Toolbox concept and components

The initial concept for the toolbox involved a series of algorithms that would be used to determine where potential risks might exist. After further investigation of this method it was decided that the concept would become too complex and difficult to use and interpret. An alternative concept was developed based on a numerical scoring and ranking scheme that is commonly used when a high degree of uncertainty exists (Saaty 1980; Canter 1996). The concept, shown schematically in Figure 1, was used to develop a 'ranking tool'.

The concept consists of asking pre-designed questions and, based upon the response to the questions, computing a numerical score ranging from 0 to 1. To determine a numerical score for a group of questions within a single subject, weighting factors (or importance factors) are used to develop a numerical score for the entire group of questions.

Once the basic concept shown in Figure 1 was established, the components of the toolbox were developed

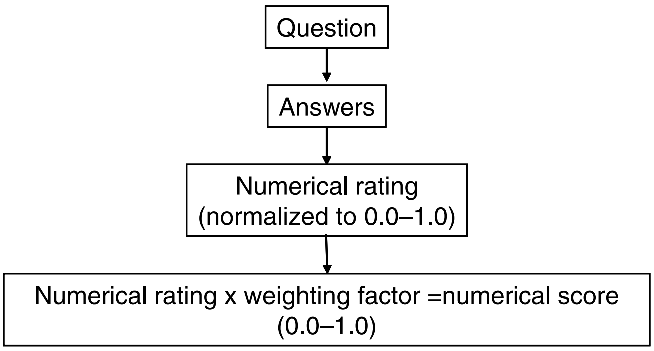


Figure 1 | Schematic showing concept for development of ranking tool.

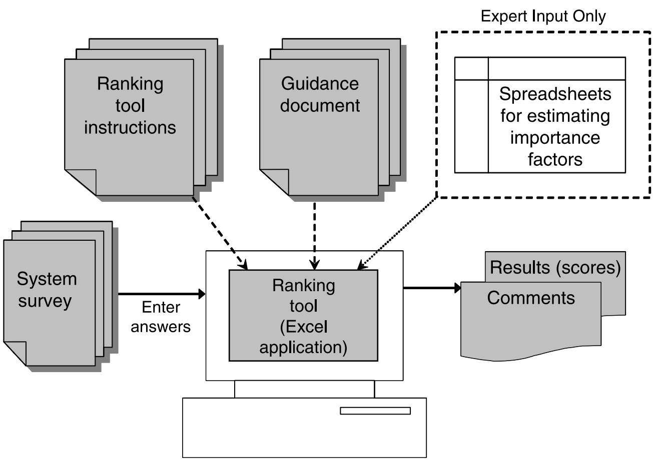


Figure 2 | Components of the assessment toolbox.

(Figure 2). The basic components are the system survey, ranking tool (Microsoft® Excel based application), ranking tool instructions, guidance document, output from the ranking tool (comments and results), and spreadsheets for estimating importance factors. Each of these components will be described in more detail below.

Participating water systems

Five small water systems participated in development of the toolbox. These water systems were selected to represent a variety of different water source types, treatment and size. Table 1 presents some basic information about the water systems that participated. The systems provided information for the project via the initial survey. Data from the initial survey were used to focus the survey's questions, and to test and validate the final tools. Both raw and distribution system water quality were monitored once a month for 6 months. Water quality data provided information used to help assess the validity of results from the toolbox.

Initial survey

The tools to be developed had to be sufficiently comprehensive to cover the wide variety of system components found in small water systems. To accomplish this goal the major water system categories listed in Table 2 were

Table 1 | Selected characteristics of participating small water systems

System ID	Type	Population served	Source	Treatment	Storage	Distribution system
MSU-1	CWS	1,450	1 spring	Cl2 disinfection	None	Asbestos cement, PVC
			2 wells	No treatment for wells		
MSU-2	CWS	650	2 wells	No treatment	3 Hydro-pneumatic tanks	PVC
MSU-3	CWS	1,650	2 springs	Cl2 disinfection	1 above-ground steel	PVC, CI
MSU-4	CWS	700–1,000[a]	2 small rivers	Conventional treatment	1 below-ground concrete; 1 above-ground steel	Lined DI, PVC
MSU-5	TNCWS	20–1,000[a]	2 springs	Cl2 disinfection	1 above-ground concrete	Lined DI

[a]Population served varies with season

CWS: community water system; TNCWS: transient non-community water system; CI: unlined cast iron; DI: ductile iron, lined

Table 2 | Survey and ranking tool categories and sub-categories

System category	Sub-categories
Water source	Surface water – lake or impoundment
	Surface water – river or stream
	Groundwater – wells
	Groundwater – springs
Water treatment	Surface water – disinfection/corrosion control only
	Surface water – filtration/disinfection/corrosion control
	Groundwater – disinfection/corrosion control only
	Groundwater – other treatment types
Pumping facilities	
Storage facilities	
Transmission pipelines	
Distribution system	
Water quality monitoring	

selected. Sub-categories were established within several of the major categories to cover different aspects (Table 2). For example, within the category 'water source' there are four sub-categories designed to address the most predominant sources of water: surface water from a lake or impoundment, surface water from a river or stream, groundwater from wells and groundwater from springs. Similar sub-categories were created in the water treatment category (Table 2).

The initial survey was created based upon the investigators' experience, reviews of the participating water systems and questions asked of their operators, review of sanitary surveys and training materials for several states, and incorporation of deficiencies noted in the literature and surveillance summaries (Craun and Calderon 2001; Lee *et al*. 2002). Staff from each of the five participating water systems completed the initial survey.

Water quality monitoring of systems

Water quality data for the participating systems were collected to supplement monitoring data and provide a basis for checking the validity of the ranking tool output. Raw water prior to treatment and water from the distribution system were sampled once per month for approximately 6 months. Samples were brought to the investigators' lab and analysed according to standard protocols. Table 3 lists the water quality parameters that were monitored.

Development of toolbox components

All toolbox components shown in Figure 1 are for the 'user' of the tools with one exception. Spreadsheets for estimating importance factors are used only by persons qualified to provide 'expert opinion', someone with sufficient knowledge and experience to compare various system components for their potential microbial contamination risks. As will be discussed below, importance factors are an integral part of the ranking tool and cannot be modified by the 'user' of the tools.

Survey and ranking tool application (user)

Development of toolbox components was performed keeping in mind the requirements in objectives 5a–c.

Table 3 | Water quality parameters and methods for small system monitoring

Parameter	Method
Heterotrophic plate count (HPC)	Spread-plate method, R2A medium, incubation for 7 days at room temperature
Total coliforms	Membrane filtration technique, incubation on mT7 media for 24 hours at 35°C
Total coliforms/*E. coli*	Colilert® presence/absence
Virus	20-l sample, filtration (142 mm CUNO ViroSorb 1MDS membrane), double agar plating method
Chlorine residual (field measurement)	DPD colorimetric method
Nitrates	HACH cadmium reduction method

Results of the initial survey were carefully reviewed to determine what questions were important, how the questions could be changed to improve their clarity without losing the ability to gather important information, and what new questions were required to adequately address a topic felt important to the overall assessment. Coinciding with development of the final survey was development of the ranking tool application. The spreadsheet program Microsoft® Excel was selected because it was easily adapted to meet the needs of the ranking tool concept. Microsoft's Visual Basic for Applications was utilized to create an application that could be used without having any basic knowledge of Excel.

Figure 3 shows an example of how the assessment tool is organized. The goal of the assessment is to determine the potential for microbial contamination for the category in question (a well in Figure 3). The potential is determined based on a numerical score from 0 to 1, with 1 representing the greatest potential and 0 the least. For each category or sub-category there exists a series of components or question groups. Questions regarding the specific component are used to create a rating or numerical score for that component. An example of the logic used to create a rating or score for a component is presented in Figure 4. The survey questions for the items in Figure 4 were answered as follows:

Check the box next to the one item that applies to this water source.

4. Source water protection or wellhead protection programme (detailed management programme to protect the water quality in this well)

a. ☐ Programme is in place and actively followed

☑ b. ☐ Programme completed but not implemented by water system

c. ☐ Programme being developed

d. ☐ Development of the programme has not yet started

In the ranking tool application the user places a '1' in the cell next to the answer that was checked (4b in the example). Each answer is given a potential score. Derived from decision analysis techniques (Canter 1996), the basic concept is to give the answer that would indicate the least risk a score of '10'. All other answers represent greater degrees of risk and are scored in relation to the least risk question (4a), with the highest score being 100. In the example shown in Figure 4 the score for item 4c is 50, meaning it was viewed as five-times greater risk than the least risk question. In this example the rating or score for the component was simply calculated by dividing the score (50) by the greatest potential score (100), thereby normalizing the value to between 0 and 1. If the answer to

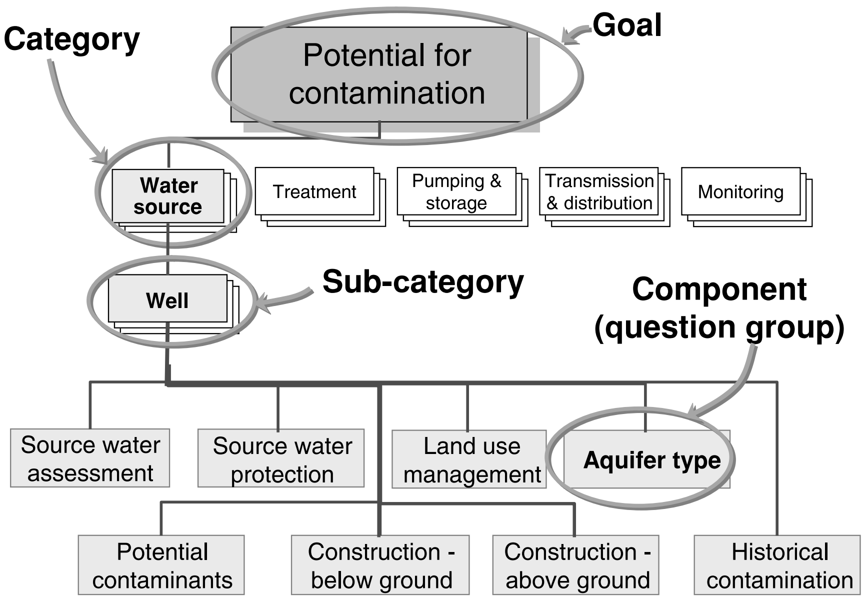


Figure 3 | Example organization for 'water source – wells' showing the category (water source), sub-category (well) and the components associated with the sub-category.

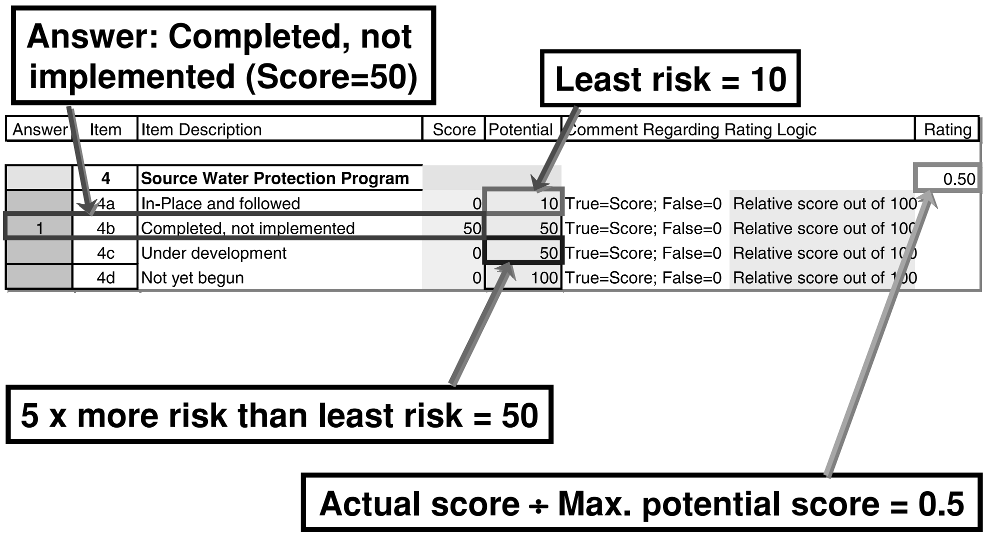


Figure 4 | Example logic used to score a component of a category or sub-category.

the question had been 4a, the least risk answer, then the rating would have been 0. This example represents the least complicated logic used in determining a rating. Within many components there are several options for answering the question and the resulting rating logic accounts for all possibilities, including anticipated user errors such as not answering all of the questions even though the survey asks that certain questions be answered.

All of the scoring and rating calculations are protected and hidden from the user. However it is important to note that the potential scores given the answers are the first option for expert opinion to be input to the model. Potential scores can be altered only by those authorized to change the tool. Users cannot access the potential scores or importance factors.

Ranking tool instructions (user)

The ranking tool instructions document presents detailed information on how to use the toolbox components, and in particular the ranking tool application. Information on how to interpret and use the results is presented.

Guidance document (user)

An important purpose of the toolbox is to help the user understand where potential microbial contamination risks exist and why they are deemed a risk. The guidance document helps to explain survey questions and why they are important. A good example involves air vent and drain lines on air/vacuum relief valves. These valves are found in pump stations, treatment plants and on many buried pipelines. If the air vent/drain line terminates below the rim of a floor drain in a treatment plant or pump station then there is a risk of a cross-connection if the floor drain should have water in it at the same time the air/vacuum valve is operating. When an air/vacuum valve is installed on a buried pipeline another issue is the point of termination of the air vent/drain line. Often, the air vent/drain line terminates in a buried box installed around the valve, resulting in a cross-connection if the box were to become full of water (which happens in many cases because there is no logical place for the box to drain). These situations can be brought to the attention of an operator in the course of answering the questions. The guidance document provides the necessary explanation of why a certain condition like that described above could be a risk. The guidance document can always be updated or amended by experts.

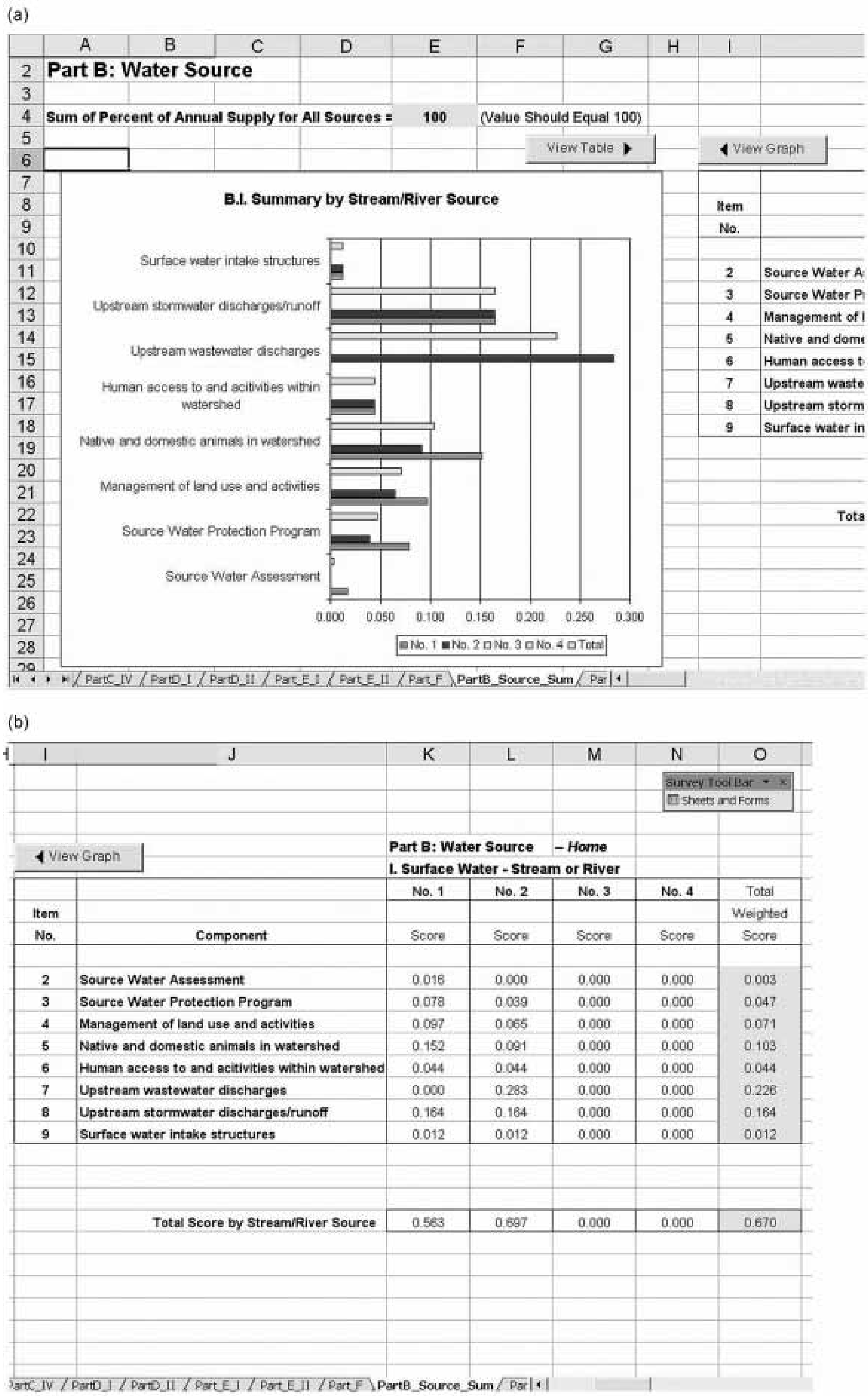
Ranking tool output (user)

The ranking tool application can provide two basic forms of output for the user, comments and results.

- Comments are generated by the ranking tool application as the questions are answered. Comments are suggestions for ways in which certain specific areas that have potential for contamination can be addressed. The comments can be viewed within the ranking tool's answer sheets or printed by the user. Comments, combined with the guidance document, help the user to understand where potential risks may occur.
- Results are presented both graphically and in tabular form (see Figure 5). It should be pointed out that the ranking tool can handle up to four similar facilities within a category: for example, there can be four wells or four wells and four springs, etc. The ranking tool weights each facility based upon the percentage of the total annual water supply that it provides, treats or pumps. The exception to this rule is for storage facilities where the weighting is based on the percentage of total storage volume provided by the facility. Therefore, one can see in the graphs and tables the numerical score for up to four different facilities, such as for four different wells, and a total score for the category or sub-category.

Importance factors (expert opinion)

Importance factors are intended to be changed only by a person qualified to provide expert opinion and not by the user of the toolbox. Since each component of a category or sub-category results in a score ranging from 0 to 1, the numerical score given the sub-category or category can be determined using importance factors (or weighting factors); the sum of all importance factors for a category or sub-category must equal 1. Determination of importance factors can be accomplished in several ways. The person determining the factors can simply look at all of the components of a category or sub-category and give each one a weight, making sure they all add up to 1. Other commonly used techniques are the nominal-group process and the use of unranked, pairwise comparisons (Canter 1996). A technique referred to as ranked, pairwise comparisons (Saaty 1980) results in more consistent importance factors. A component of the toolbox that is not available to users contains Excel spreadsheets for each of the ranked, pairwise comparisons used in the ranking tool application.



Part B: Water Source – *Home*

I. Surface Water - Stream or River

Item No.	Component	No. 1 Score	No. 2 Score	No. 3 Score	No. 4 Score	Total Weighted Score
2	Source Water Assessment	0.016	0.000	0.000	0.000	0.003
3	Source Water Protection Program	0.078	0.039	0.000	0.000	0.047
4	Management of land use and activities	0.097	0.065	0.000	0.000	0.071
5	Native and domestic animals in watershed	0.152	0.091	0.000	0.000	0.103
6	Human access to and acitivities within watershed	0.044	0.044	0.000	0.000	0.044
7	Upstream wastewater discharges	0.000	0.283	0.000	0.000	0.226
8	Upstream stormwater discharges/runoff	0.164	0.164	0.000	0.000	0.164
9	Surface water intake structures	0.012	0.012	0.000	0.000	0.012
	Total Score by Stream/River Source	0.563	0.697	0.000	0.000	0.670

Figure 5 | Example of (a) graphical and (b) tabular results (numerical scores) from the ranking tool application.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
14	Survey Item No.	Importance Factor	Source Water Assessment	Source Water Protection	Management of land use / Influe	Aquifer type	Potential microbial contaminants	Well construction - below grounc	Well construction - above groun	Historical Microbiological Contai				Consistency Ratio (< 0.10 desirable)	Importance Factor
15	3	Source Water Assessment	1	-5	-4	-3	-4	1	2	-6				0.059	0.042
16	4	Source Water Protection		1	-2	1	-2	3	4	-4					0.114
17	5	Management of land use / Influence a			1	-3	-3	4	5	-3					0.124
18	6	Aquifer type				1	-2	4	5	-3					0.145
19	7	Potential microbial contaminants					1	5	6	-2					0.206
20	8	Well construction - below ground						1	4	-4					0.053
21	9	Well construction - above ground							1	-4					0.031
22	10	Historical Microbiological Contamination								1					0.286
23															
24															
25															
26															1.000
27															
28															

B-I-Ranked / B-II-Ranked / B_III-Ranked / B_IV-Ranked / C-I-Ranked / C-II-Ranked / C-

Figure 6 | Screen-shot of Excel worksheet for estimating importance factors using ranked, pairwise comparisons.

Figure 6 presents a screen-shot of one of the worksheets for ranked, pairwise comparisons. Each row factor is compared with a column factor using a scale from 1 to 9 as defined in Table 4 (Saaty 1980). When the row factor (e.g. source water assessment) is compared with itself as the column factor, the two are given an equal ranking, so the number 1 is placed in the box or cell at the intersection of the two. Next the row factor is compared with the second column factor (source water protection). The column factor 'source water protection' in the example shown in Figure 6 was determined to be 'definitely more important' than the row factor 'source water assessment,' therefore a negative 5 was entered into the intersecting cell. If the opposite had been true, the row factor more important than the column factor, the ranking value would have been positive.

Once all row–column comparisons are made, the spreadsheet shows the calculated importance (or weighting) factor for each item. The sum of all the importance factors is 1, as shown in the figure. The importance factors are determined by first completing the matrix with the inverse values for those above the diagonal and then determining the eigenvector associated with the largest eigenvalue (see Saaty 1980 for details of the concept and

Table 4 | Scale for pairwise ranking of importance factors

Scale value	Definition
1	Equal
2	Barely more important
3	Weakly more important
4	Moderately more important
5	Definitely more important
6	Strongly more important
7	Very strongly more important
8	Critically more important
9	Absolutely more important

calculations). A significant advantage of using the ranked, pairwise comparison approach is that a consistency ratio can be calculated (Saaty 1980). The consistency ratio provides an indication to the person making comparisons of any reverse ranking that may have been made. If the consistency ratio remains below 0.1 it can be assumed that the user has made no reverse rankings. By correcting any reverse rankings more consistent estimates of the importance factors are achieved.

Features to assist the user

In Figure 5b it can be noted that there exists in the upper right-hand corner of the screen a toolbar titled 'Survey Tool Bar'. This toolbar opens a dialog box that provides the user with options for moving between sheets, printing results, printing comments, clearing worksheet values and checking to see if the percentage values for a category such as water source add up to 100%. Figure 7 shows this dialog box as an example of the other dialog boxes available to the user for the purpose of making the ranking tool more user-friendly.

APPLICATION OF THE TOOLBOX COMPONENTS

The microbial contamination risk toolbox is intended to be a self-assessment tool for small water system operators and managers, designed to help them determine where their water system may have its greatest risks for potential microbial contamination. This survey tool is not intended to take the place of a sanitary survey or formal vulnerability assessment for risks from bioterrorism.

Interpretation of results

Results can be used to look at specific components of a facility, combined scores for a water system category or for the total water system by major category. Numerical ranking scores are presented in Figure 5 for two surface water stream or river sources. Based upon the ranking scores for Source No. 1 it is seen that component numbers 4-'Management of land use and activities', 5-'Native and domestic animals within watershed' and 8-'Upstream stormwater discharges/runoff', have much greater scores than the other components. The greater the numerical score, the greater the potential risk of microbial contamination.

In this example it is likely that implementation of a program to proactively manage land uses and activities within the watershed could reduce potential risks. Those risks are more clearly illustrated in the scores for 'Native and domestic animals within watershed' and 'Upstream stormwater discharges/runoff'. If the water system cannot manage or influence land uses and activities, perhaps it can focus more attention on the other two items that can be managed to a certain degree, particularly domestic animals grazing along a river or stream and knowing how a point discharge of stormwater is being treated and development of communication with the community responsible for the discharge. The goal would be to address those component with the highest risks and that can be addressed given current resources.

Using the results

The primary use of the results is to determine areas where there is a greater potential for microbial contamination.

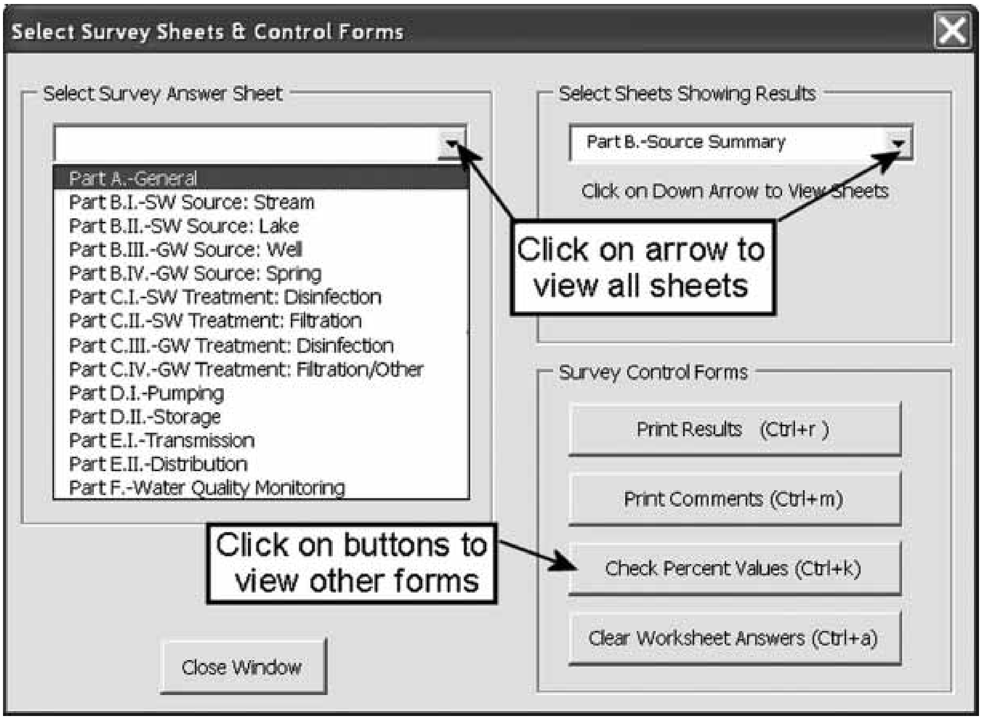


Figure 7 | Dialog box for selection of survey sheets and control forms.

However, often, knowing and acting on that knowledge will require resources in terms of staff time and/or capital. For a small water system with limited resources it is helpful if there is a way to prioritize needs. One use of the ranking tool results can be to demonstrate where greater need exists. The results can be presented to an oversight committee or town council when discussing staff and capital needs. The results can help to show that a problem might exist and explain what would be needed to improve the situation.

When the user is working with any of the answer spreadsheets of the ranking tool, results can be viewed by bringing up a window showing the results graph (see Figure 5a). This feature can be used to view what would happen to scores if an answer could be changed. For example, maybe the water system currently does not have a source water protection plan in place and would like to assess how the scores would change if the plan were completed and implemented. Some users may find the tool helpful in preparation for a formal sanitary survey. Using the comments and scores, the user can look in the 'guidance document' for an explanation of certain items, and can then go to other information sources as required. The objective would be to correct as many items as possible before they become an issue on a sanitary survey, and in doing so reduce potential contamination risks.

As with any tool or model, improper application can lead to erroneous or confusing results. Therefore, results from the ranking tool should be carefully reviewed to determine their validity for a particular system.

TOOLBOX VALIDATION

Information gathered from the five participating small water systems was used to verify that the toolbox was working properly. Importance factors for this phase of the work were obtained from rankings performed by the investigators. Answers to survey questions came from the

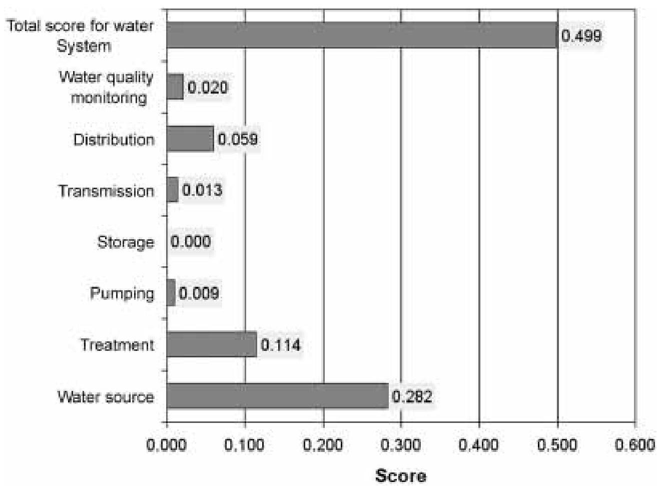


Figure 8 | Summary of numerical scores by category for water system MSU-1.

initial surveys, knowledge of the water system gained during the course of the project, and water quality results from the water samples. Results from two systems will be discussed within this paper, but similar validation was performed for each water system.

System MSU-1

Table 1 presents the basic characteristics of system MSU-1. Briefly, the source of water for the system was one spring supply that received chlorination and two deep wells that received no treatment. There is no storage for the system and the distribution system consisted of asbestos cement and PVC pipe.

Figure 8 presents results by category for the entire water system. The two categories where MSU-1 showed increased potential risks were water sources and treatment. An examination of the results by component for the two well sources (Figure 9) indicates four areas that appeared to present greater potential risk: (1) aquifer type, (2) management of land use, (3) source water protection, and (4) potential contaminants. The aquifer is unconfined and consists of coarse materials, thus increasing risks of

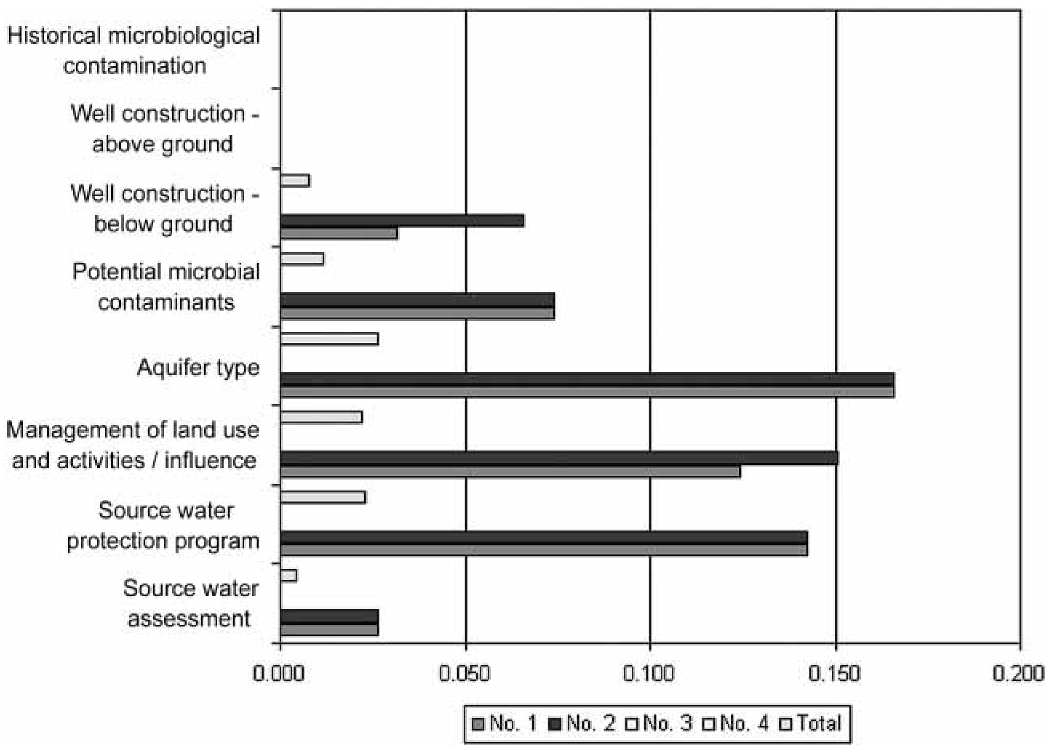


Figure 9 | Results by component for two well sources, MSU-1.

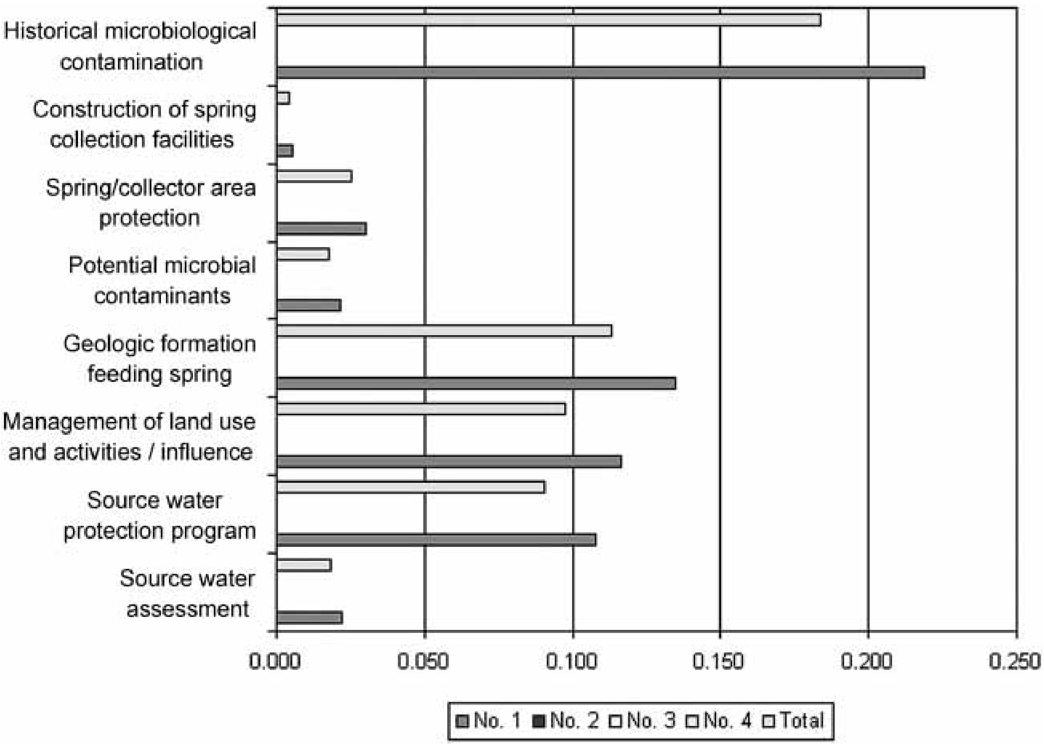


Figure 10 | Results by component for the spring source, MSU-1.

contamination from the surface. An active source water protection programme and management of land use and activities around the wells could reduce contamination risks. The comments indicated that, because the water from the two wells was not treated, and they pumped directly into the distributions system, there was potential risk if any microbial contamination of the well water were to occur. The only disinfection would be mixing within the distribution system with water from the spring already containing chlorine. The two well sources combined accounted for only 16% of the water supply, so their contribution to the total score was not great, even though they both present certain risks.

The spring source was the major contributor to the water source score because it provides 84% of the annual water supply. The components of the spring that resulted in higher scores (Figure 10) were historical contamination, geologic formation, management of land use and source water protection. Positive total coliform results measured by the project team were taken into account when answering questions regarding historical contamination. Springs are typically shallow in nature and as such are prone to surface contamination. The water system owned very little land around the spring and relied upon the surrounding landowners to manage land uses. A proactive source water management programme could help to reduce contamination risks for the spring.

Treatment of the spring water consisted of addition of chlorine for disinfection at a remote site. Items presenting risk with respect to treatment were cross-connections (no vacuum breakers on hose bibs, irrigation connections without backflow devices), lack of alarms and monitoring that would notify an operator if there was a problem at the remote facility, and a generally low disinfectant residual. Distribution system chlorine residuals dropped below 0.2 mg l^{-1} on three occasions, indicating that the chlorine dose should be adjusted more carefully. Also, the time when low chlorine residuals were measured also coincided with peak water demands when unchlorinated well water was being added to the system and reducing overall

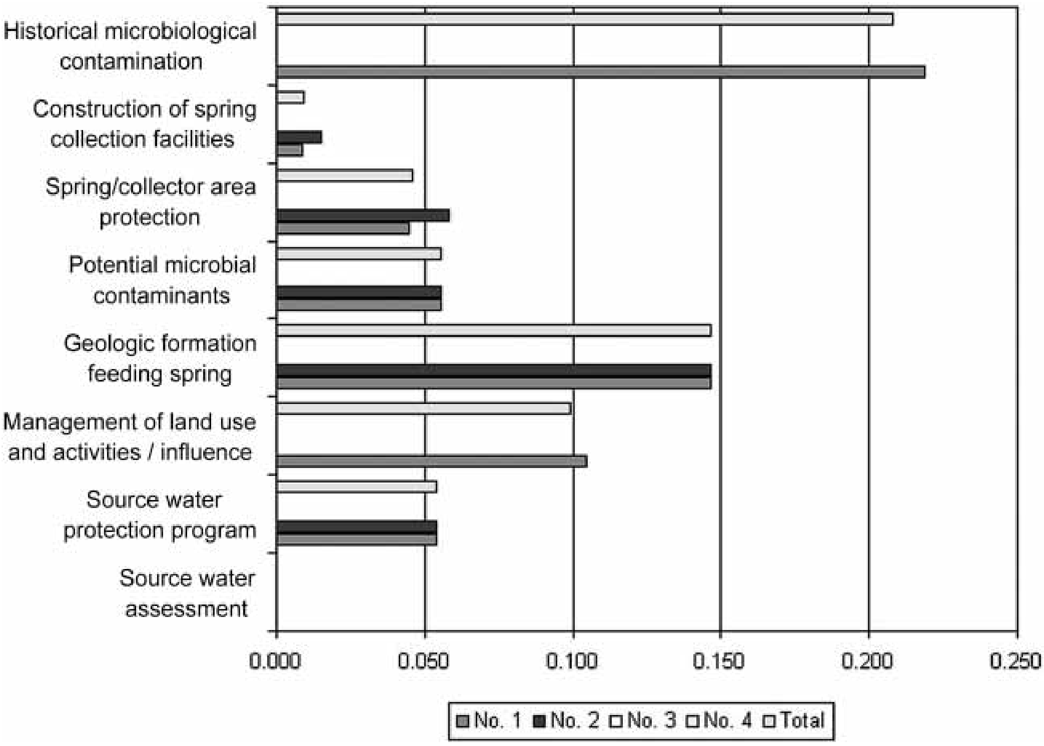


Figure 11 | Results by component for spring water supply sources, MSU-3.

system residuals. This could create a dangerous situation since the system relies upon the chlorine residual in the distribution system to disinfect the well water. Any situation where untreated and treated water are mixed in a system leads to high scores for the untreated sources.

System MSU-3

Table 1 presents the basic characteristics of system MSU-3. The source of water was two spring supplies that received chlorination. A single above-ground steel tank provided storage and the distribution system consisted of PVC and cast iron pipe. System categories that had the highest score were water source and treatment.

Results by component are presented in Figure 11 for the two spring sources. Only the major spring source (No. 1 in Figure 11) was sampled and positive total coliform and virus results were noted. This resulted in a high numerical score for 'historical microbial contamination' for the spring. The spring's collection facilities are located on an island in a river. There are cattle around the spring area but more importantly cattle can be found along the river upstream of the collection facilities. The geologic formation in which the spring is located would appear to be susceptible to surface contaminants, as are most springs. The water system indicated that a source water management plan was in place for the springs, otherwise the scores would have been much higher.

An issue of concern for water treatment (see Figure 12) was that during a power outage water would continue to go to the community but without disinfection. A similar concern was also noted for MSU-1. An apparent lack of telemetry to notify operators in case of a malfunction or power outage was noted. A gravity fed transmission line connected the primary spring source with the system, and had potential to flow partially full if there was an extremely high demand or line break, leading to possible intrusion of contaminants from the surrounding soil/ water matrix. A control system could minimize potential

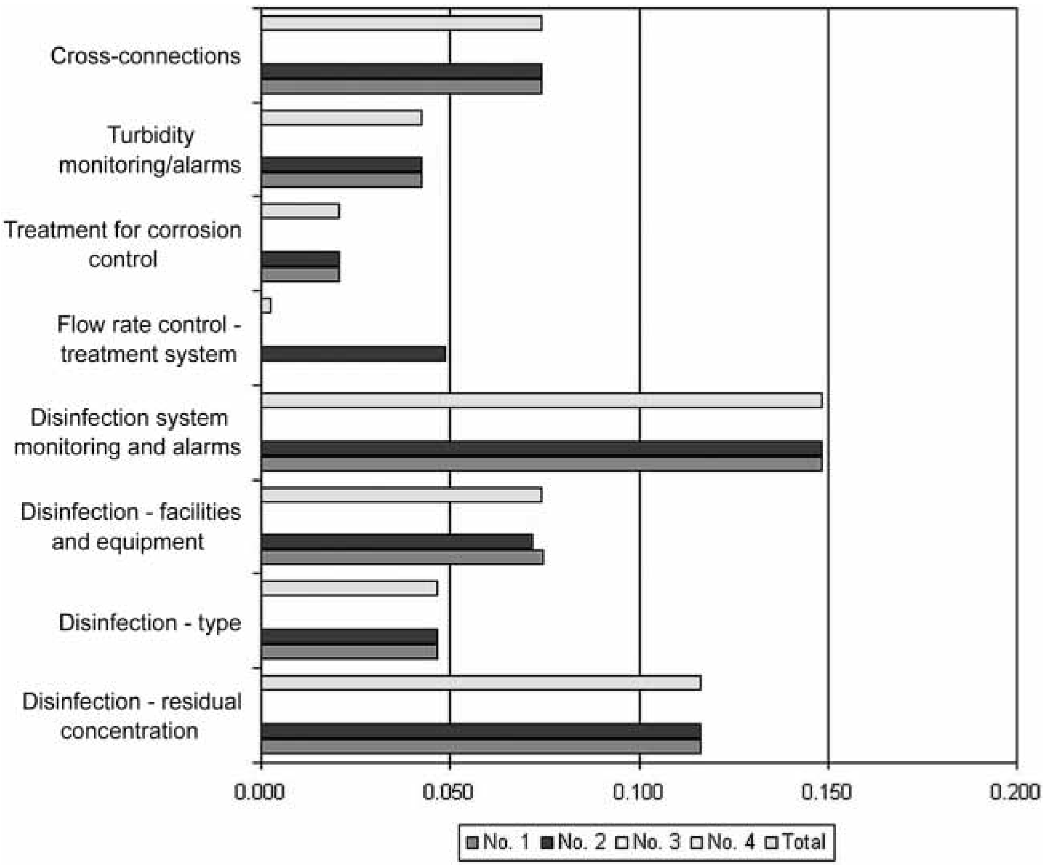


Figure 12 | Results by component for water treatment, disinfection of spring sources, MSU-3.

risks for the transmission pipeline. It was also noted that chlorine residuals were relatively low leaving the spring facility and there were distribution system residuals that were less than 0.2 mg l^{-1}.

CONCLUSIONS

The toolbox that has been developed to assess microbial contamination risks is flexible, comprehensive and relatively easy to use. Application of the toolbox can indicate where certain facilities or water sources are at greater risk for potential microbial contamination. The ranking tool application provides comments that, with the assistance of a guidance document, can inform the user of specific areas that represent a risk and why the risk occurs. Numerical scores are provided for each major category and its components, providing the user with both graphical and tabular output. Results can be used to help prioritize possible remedial actions, demonstrate to management the need for those actions, or provide a check on system condition prior to a sanitary survey. Certain actions may require major changes while others can be implemented with little time or cost involved. The ranking tool application can be adjusted using expert opinion as appropriate. Using the components of the toolbox can help a water system in the never-ending task of reducing potential microbial contamination risks.

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