6 MONITORING AND SYSTEM ASSESSMENT

Monitoring has three different purposes: validation, or proving that the system is capable of meeting its design requirements; operational monitoring, which provides information regarding the functioning of individual components of the health protection measures; and verification, which usually takes place at the end of the process (e.g. treated wastewater, crop contamination) to ensure that the system is achieving its specified targets.

The most effective means of consistently ensuring the safety of wastewater use in agriculture is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the process, from the generation and use of wastewater to the consumption of the product. This approach is captured in the Stockholm Framework. System assessment and its components are discussed in section 6.2.

The combination of health protection measures adopted in a particular wastewater use scheme requires regular monitoring to ensure that the system continues to function effectively. Monitoring, however, in the sense of observing, inspecting and collecting samples for analysis, is not sufficient on its own. Institutional arrangements must be established for the information collected in this way to provide feedback to those who implement the health protection measures. The responsibility for the monitoring of health protection measures should be clearly defined in the relevant legislation (see chapter 10).

6.1 Monitoring functions

The three functions of monitoring are each used for different purposes at different times. See Table 6.1 for a brief description of each type of monitoring. Validation is performed at the beginning when a new system is developed or when new processes are added and is used to test or prove that the system is capable of meeting the specified targets. Operational monitoring is used on a routine basis to indicate that processes are working as expected. Monitoring of this type relies on simple measurements (e.g. pH, turbidity) that can be read quickly so that decisions can be made in time to remedy a problem. Verification is used to show that the end product (e.g. treated wastewater, crop contamination) meets treatment targets (e.g. microbial quality specifications). Information from verification monitoring is collected periodically and thus would arrive too late to allow managers to make decisions to prevent a hazard break-through. However, verification monitoring can indicate trends over time (e.g. if the efficiency of a specific process was improving or decreasing). The validation and verification targets for effluents presented in the current guidelines are basically similar to what was referred to as recommended effluent standards or guidelines in the previous edition.

6.2 System assessment

The first step in developing a risk management system is to form a multidisciplinary team of experts with a thorough understanding of wastewater use in agriculture. Typically, such a team would include agriculture experts, engineers, water quality specialists, environmental health specialists, public health authorities and food safety experts. In most settings, the team would include members from several institutions, and there should be members from independent institutions, such as from universities.

Effective management of the wastewater use system requires a comprehensive understanding of the system, the range and magnitude of hazards that may be present and the magnitude of related risk levels, and the ability of existing processes and
Guidelines for the safe use of wastewater, excreta and greywater

<table>
<thead>
<tr>
<th>Function</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Validation</td>
<td>Testing the system and its individual components to obtain evidence that it is capable of meeting the specified targets (i.e. microbial reduction targets). Should take place when a new system is developed or new processes are added.</td>
</tr>
<tr>
<td>Operational monitoring</td>
<td>The act of conducting a planned sequence of observations or measurements of control parameters to assess whether a control measure is operating within design specifications (e.g. turbidity following wastewater treatment). Emphasis is given to monitoring parameters that can be measured quickly and easily and that can indicate if a process is functioning properly. Operational monitoring data should help managers to make corrections that can prevent hazard break-through.</td>
</tr>
<tr>
<td>Verification</td>
<td>The application of methods, procedures, tests and other evaluations, in addition to those used in operational monitoring, to determine compliance with the system design parameters and/or whether the system meets specified requirements (e.g. microbial water quality testing for E. coli or helminth eggs, microbial or chemical analysis of irrigated crops).</td>
</tr>
</tbody>
</table>

infrastructure to manage actual or potential risks. It also requires an assessment of capabilities to meet targets. When a new system or an upgrade of an existing system is being planned, the first step in developing a risk management plan is the collection and evaluation of all available relevant information and consideration of what risks may arise during the entire production process. Figure 6.1 illustrates the development of a risk management plan.

The assessment and evaluation of a wastewater use system are enhanced through the development of a flow diagram. Such diagrams provide an overview description of the system, including the identification of sources of hazards, determining factors of associated risks and health protection measures. It is important that the representation of the wastewater use system be conceptually accurate. If the flow diagram is not correct, it is possible to overlook potential hazards that may be significant. To ensure accuracy, the flow diagram should be validated by visually checking it against features observed on the ground.

Data on the occurrence of hazards in the system combined with information concerning the effectiveness of existing controls enable an assessment of whether health-based targets can be achieved with the existing health protection measures. They also assist in identifying health protection measures that would reasonably be expected to achieve those targets if improvements are required.

To ensure accuracy of the assessment, it is essential that all elements of the wastewater use system are considered concurrently and that interactions and influences between elements and their overall effect are taken into consideration.

### 6.3 Validation

Validation is concerned with obtaining evidence on the performance of control measures, both individually and collectively. It should ensure that the system is capable of meeting the specified microbial reduction targets. Validation is used to test or prove design criteria. It should be conducted before a new risk management process is put into place (e.g. for wastewater treatment, wastewater application, produce washing/disinfection, etc.), when equipment is upgraded (e.g. new filter) or when new equipment or processes (e.g. addition of new coagulants) are added. It can also be used to test different combinations of processes to maximize process efficiency. Validation can be conducted at the facility scale or on a test scale. In a waste stabilization pond validation, for example, dye testing would be able to confirm that the design retention time was being achieved in practice.

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Assemble the team to prepare the risk management plan

Document and describe the system

Undertake a hazard assessment and risk characterization to identify and understand how risks can be managed in the system

Assess the existing or proposed system (including a description of the system and a flow diagram)

Identify control measures — the means by which risks can be controlled

Define monitoring of control measures — what limits define acceptable performance and how these are monitored

Establish procedures to verify that the risk management plan is working effectively and will meet the health-based targets

Develop supporting programmes (e.g. training, hygienic practices, standard operating procedures, upgrade and improvement, research and development, etc.)

Prepare management procedures (including corrective actions) for normal and incident conditions

Establish documentation and communication procedures

Figure 6.1
Development of a risk management plan (WHO, 2004a)
The first stage of validation is to consider data that already exist. These will include data from the scientific literature, trade associations, regulation and legislation departments and professional bodies, historical data and supplier knowledge. These data will inform the testing requirements. The second stage of validation is to conduct laboratory or pilot-level evaluations of the components and overall system under conditions that approximate those found at the actual site. A system should be validated for the different types of situations that occur (e.g. hot season vs cold season; dry season vs wet season; winter, spring, summer and autumn). Validation is not used for day-to-day management of wastewater treatment and use; as a result, parameters that may be inappropriate for operational monitoring can be used, and the lag time for return of results and additional costs from measurements can often be tolerated (WHO, 2004a).

6.4 Operational monitoring

Control measures are actions implemented in the system that prevent, reduce or eliminate contamination and are identified in system assessment. They include, for example, wastewater treatment and storage facilities, waste application techniques, use of protective clothing and sanitary conditions in the market or where the food is being prepared and consumed. If collectively operating properly, they would ensure that health-based targets are met.

Operational monitoring is the execution of planned observations or measurements to assess whether the control measures in a wastewater use system are operating properly. It is possible to set limits for control measures, monitor those limits and take corrective action in response to a detected deviation before the contamination passes through the system. Examples of limits are total suspended solids to indicate the level of particulate matter that might be associated with pathogens, turbidity, pH and flow rates. The presence or absence of plants in wastewater irrigation canals is an important indicator, since these may provide suitable habitats for disease vectors or snail intermediate hosts of schistosomes. Operational monitoring should take place around system parameters that indicate the potential for increased risk of hazard break-through. It is facilitated by simple measurements that can be taken quickly. For example, turbidity can be monitored quickly (often in real time) to indicate if a filter is malfunctioning or if a membrane is broken. Operational monitoring parameters are different for high-rate wastewater treatment and low-rate biological treatment systems. Examples of parameters that can be monitored are presented in Table 6.2.

The frequency of operational monitoring varies with the nature of the control measure; for example, checking physical infrastructure integrity (e.g. vegetation on the banks of wastewater treatment ponds) may occur monthly or less frequently, whereas monitoring turbidity in an activated sludge plant may be conducted in real time. If monitoring shows that a limit does not meet specifications, then there is the potential for a hazard break-through. The amount of time needed to correct an action should determine the rate of operational monitoring. For example, with waste stabilization pond systems, operational monitoring for various parameters (see Table 6.2) could take place at regular intervals of several weeks or longer, because the retention time is often long (e.g. 12–20 days). With wastewater treatment systems that have much shorter retention times (e.g. activated sludge), operational monitoring of parameters such as turbidity can take place online in real time.

A variety of physicochemical parameters should be monitored at regular intervals to verify the performance of a wastewater treatment system. Five-day BOD, chemical
oxygen demand, total suspended solids, total dissolved solids, pH, temperature, exposure time and total nitrogen and phosphorus are examples of chemical parameters that are monitored for verification. Most of these parameters are monitored to prevent environmental impacts of wastewater discharge and to meet regulatory requirements for quality of wastes to be discharged. However, some may also be used as proxies for hazardous substances. For example, Jiménez & Chávez (1998) found a direct correlation between total suspended solids and intestinal helminth concentrations. It is easier to measure total suspended solids than to directly determine the concentration of helminth eggs, which requires a trained parasitology technician and suitable laboratory facilities.

In most cases, operational monitoring will be based on simple and rapid observations or tests, such as turbidity or structural integrity, rather than complex microbial or chemical tests. The complex tests are generally applied as part of validation and verification activities rather than as part of operational monitoring.

Monitoring needs to be conducted in such a way that it provides statistically meaningful information (e.g. sample duplicates), is directed at controlling the most important hazards and can inform changes to health protection measures. A monitoring programme should be designed in such a way that it can be performed within the technical and financial resources of any given situation. The objective is timely monitoring of control measures with a logically based sampling plan, to minimize negative public health impacts (WHO, 2004a).

### 6.5 Verification monitoring

Verification is the use of methods, procedures or tests in addition to those used in operational monitoring to determine if the performance of the wastewater/excreta use system is in compliance with the stated objectives outlined by the health-based targets and/or whether the system needs modification and revalidation.

For microbial reduction targets, verification is likely to include microbial analysis. In most cases, it will involve the analysis of faecal indicator microorganisms; in some circumstances, it may also include assessment of specific pathogen densities (e.g. helminth ova). Verification of the microbial quality of wastewater may be undertaken by local public health agencies.

Approaches to verification include testing of wastewater after treatment or wastewater at the point of application or use. Verification of the microbial quality of the wastes often includes testing for *E. coli* or thermotolerant coliforms. While *E. coli* is a useful indicator, it has limitations; the absence of *E. coli* will not necessarily indicate the absence of other pathogens. Under certain circumstances, it may be desirable to include more resistant microorganisms, such as *Ascaris* or bacteriophages (viruses that infect bacteria), as indicators for other microbial groups.

If wastewater is suspected to contain sizable industrial discharges, then periodic monitoring of the wastewater for heavy metals and chlorinated hydrocarbons may be warranted. Also, if crops with particular sensitivities (e.g. boron sensitivity) are being grown, then it will be important to monitor those chemicals that could have an impact on agricultural productivity (see Annex 2).
Table 6.2 Validation, operational monitoring and verification monitoring parameters for different control measures

<table>
<thead>
<tr>
<th>Control measure</th>
<th>Validation requirements</th>
<th>Operational monitoring parameters</th>
<th>Verification monitoring parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater treatment</td>
<td>Effectiveness of treatment processes at inactivating/ removing pathogens and indicator organisms (E. coli, helminth eggs) System design (e.g., retention time, short-circuiting in waste stabilization pond by conducting dye testing) Analytical procedures for detecting indicators and/or pathogens (including measuring viability) Effectiveness of treatment in removing locally important toxic chemicals Analytical procedures and capabilities for detecting chemicals in wastewater, excreta or pond water</td>
<td>Low-rate biological systems: Flow rates BOD (loading rates may need to vary during colder periods) Algal concentrations and species types Dissolved oxygen at different pond depths (facultative and maturation ponds) High-rate processes: BOD Turbidity pH Organic carbon Particle counts Membrane integrity (pressure testing) Chlorine residual</td>
<td>E. coli Helminth eggs (including Schistosoma spp., where appropriate) Locally important toxic chemicals</td>
</tr>
<tr>
<td>Health and hygiene promotion</td>
<td>Testing of promotional materials with relevant stakeholder groups</td>
<td>Local programmes in operation Promotional materials available Promotion included in school curriculum</td>
<td>Increased awareness of health and hygiene issues in key stakeholder groups Improved practices</td>
</tr>
<tr>
<td>Chemotherapy and immunization</td>
<td>Effectiveness of different vaccine/drugs in preventing or treating locally important infections</td>
<td>Numbers of people vaccinated/treated Villages/schools targeted near wastewater use areas Frequency of campaigns</td>
<td>Reduced prevalence and intensity of infections Fewer disease outbreaks in targeted areas</td>
</tr>
<tr>
<td>Product restriction</td>
<td>Survey of product consumers to identify species always eaten after thorough cooking Analysis of marketability of different species/crops Economic viability of growing products not for human consumption</td>
<td>Types of crops grown in wastewater use areas</td>
<td>Water quality testing of wastewater to ensure that water used for unrestricted irrigation meets WHO microbial reduction targets</td>
</tr>
</tbody>
</table>
Table 6.2 (continued)

<table>
<thead>
<tr>
<th>Control measure</th>
<th>Validation requirements</th>
<th>Operational monitoring parameters</th>
<th>Verification monitoring parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste application/timing</td>
<td>Test the amount of time needed for pathogen die-off under different climatic conditions and for different pathogens/indicators between waste application and crop harvest to ensure minimal contamination.</td>
<td>Monitor waste application timing and time to harvest.</td>
<td>Analyse plant contamination.</td>
</tr>
<tr>
<td>Produce washing, disinfection, cooking foods</td>
<td>Research on which methods are most effective in reducing contamination, pathogen inactivation. Testing of educational materials among relevant stakeholders.</td>
<td>Inspection by food safety authorities to ensure that proper procedures are being used at markets or restaurants where products are prepared.</td>
<td>Periodic microbial testing of the hygiene of food preparation spaces in markets and restaurants, product testing to investigate where contamination occurs. Inspection of markets to assess availability of safe drinking-water for product washing/freshening.</td>
</tr>
<tr>
<td>Access control, use of personal protective equipment</td>
<td>Testing access control measures for effectiveness in preventing public exposures to wastewater. Identifying which personal protective equipment is available at low cost that workers will wear. Testing the effectiveness of the personal protective equipment in preventing exposure to hazards.</td>
<td>Visual inspection of wastewater use areas for warning signs, fences, etc. Visual inspection of workers to ensure that they are wearing the appropriate personal protective clothing.</td>
<td>Public health surveillance of workers to document reductions in skin diseases, schistosomiasis (where relevant) and hookworm.</td>
</tr>
<tr>
<td>Intermediate host and vector control</td>
<td>Test system to evaluate its effect on insect vector breeding and/or survival and growth of relevant snail species. Test control measures such as the reduction of emergent vegetation and its impact on the breeding of disease vectors or snail intermediate hosts. Check for obstructed drains, seepage and a rise in groundwater levels that can result in pools of standing water.</td>
<td>Visual inspection of facilities to observe vegetative growth in irrigation canals or treatment ponds. Inspection of waters for relevant insect larvae or snail intermediate hosts.</td>
<td>Public health surveillance to document vector-borne diseases or schistosomiasis in workers and local communities.</td>
</tr>
</tbody>
</table>

*Chemotherapy and immunization are considered to be supplementary health protection measures and should not be used instead of other health protection measures such as wastewater treatment.*
6.6 Small systems

Validation, operational monitoring and verification monitoring are important steps to identify and eventually mitigate public health issues that might be associated with wastewater use in agriculture. However, in some situations, the use of wastewater in agriculture can be difficult to monitor (e.g. in urban areas or in informal small-scale operations). Additionally, much of the wastewater use in agriculture that is practised is indirect and informal (e.g. irrigation with faecally contaminated surface waters) and thus harder to plan and control. Countries and local authorities may have limited budgets for validation and monitoring and thus will need to develop validation and monitoring programmes based on the most important local public health issues, the availability of professional staff and access to laboratory facilities.

When many small-scale wastewater irrigation operations exist, the national health or food safety authority may choose to validate health protection measures at a central research site and then disseminate information to relevant stakeholders (e.g. through the development of guidelines, through public health outreach workers, through agriculture extension workers or through local stakeholder workshops).

Operational monitoring should focus on visual inspections and safety audits without requiring difficult or expensive laboratory testing. For example, visual inspection of a facility will indicate the types of crops being grown or if workers are using boots and gloves. Similarly, food markets can be quickly inspected visually to detect unhygienic conditions or lack of safe water for product washing/freshening.

Verification monitoring may be easier to conduct at a central point (e.g. a wastewater discharge point or a market). Data from public health surveillance for faecal-oral diseases, schistosomiasis, intestinal helminth infections and other locally important diseases should be used to adjust health protection measures as necessary.

6.7 Other types of monitoring

6.7.1 Food inspection

Periodically, the microbial and chemical contamination of wastewater-irrigated crops should be tested. Products should be tested for E. coli or thermotolerant coliforms and helminth eggs where they are a hazard. The concentrations of heavy metals that may pose a health risk (e.g. cadmium, lead) should also be tested to ensure that they are within the safety limits specified by the Codex Alimentarius Commission.

6.7.2 Public health surveillance

Direct measurement of specific health outcomes (e.g. intestinal helminth infections, schistosomiasis and vector-borne diseases, such as filariasis) is possible and should be conducted periodically in exposed populations. This is discussed in the context of the Stockholm Framework in chapter 2.