WHO GUIDELINES FOR THE

SAFE USE OF WASTEWATER, EXCRETA AND GREYWATER

VOLUME III

WASTEWATER AND EXCRETA USE IN AQUACULTURE

World Health Organization

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LIST OF ACRONYMS AND ABBREVIATIONS

BOD	biochemical oxygen demand
CFU	colony forming unit
CI	confidence interval
DALY	disability adjusted life year
DDT	dichlorodiphenyltrichloroethane
FAO	Food and Agriculture Organization of the United Nations
HACCP	hazard analysis and critical control points
HIA	health impact assessment
MDG	Millennium Development Goal
MPN	most probable number
OR	odds ratio
PCB	polychlorinated biphenyl
PRISM	Project in Agriculture, Rural Industry Science and Medicine (Bangladesh)
QMRA	quantitative microbial risk assessment
TDE	1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane
WHO	World Health Organization
WTO	World Trade Organization

PREFACE

The United Nations General Assembly (2000) adopted the Millennium Development Goals (MDGs) on 8 September 2000. The MDGs that are most directly related to the use of wastewater and excreta in aquaculture are "Goal 1: Eliminate extreme poverty and hunger," as fish raised in waste-fed systems is a main source of protein in many parts of Asia; and "Goal 7: Ensure environmental sustainability." The use of wastewater and excreta in aquaculture can help communities to grow more food and make use of precious water and nutrient resources. However, it should be done safely to maximize public health gains and environmental benefits.

To protect public health and facilitate the rational use of wastewater and excreta in agriculture and aquaculture, in 1973 the World Health Organization (WHO) developed guidelines for wastewater use in agriculture and aquaculture under the title *Reuse of effluents: Methods of wastewater treatment and health safeguards* (WHO, 1973). After a thorough review of epidemiological studies and other information, the guidelines were updated in 1989 as *Health guidelines for the use of wastewater in agriculture and aquaculture* (WHO, 1989). These guidelines have been very influential, and many countries have adopted or adapted them for their wastewater and excreta use practices.

Wastewater and excreta use in aquaculture is increasingly considered a method combining water and nutrient recycling, increased household food security and improved nutrition for poor households. Recent interest in wastewater and excreta use in aquaculture has been driven by water scarcity, lack of availability of nutrients and concerns about health and environmental effects. It was necessary to update the guidelines to take into account recent scientific evidence concerning pathogens, chemicals and other factors, including changes in population characteristics, changes in sanitation practices, better methods for evaluating risk, social/equity issues and sociocultural practices. There was a particular need to conduct a review of both risk assessment and epidemiological data.

In order to better package the guidelines for appropriate audiences, the third edition of the *Guidelines for the safe use of wastewater, excreta and greywater* is presented in four separate volumes: *Volume 1: Policy and regulatory aspects*; *Volume 2: Wastewater use in agriculture*; *Volume 3: Wastewater and excreta use in aquaculture*; and *Volume 4: Excreta and greywater use in agriculture*.

WHO water-related guidelines are based on scientific consensus and best available evidence and are developed through broad participation. The *Guidelines for the safe use of wastewater, excreta and greywater* are designed to protect the health of farmers (and their families), local communities and product consumers. They are meant to be adapted to take into consideration national sociocultural, economic and environmental factors. Where the Guidelines relate to technical issues — for example, wastewater treatment — technologies that are readily available and achievable (from both technical and economic standpoints) are explicitly noted, but others are not excluded. Overly strict standards may not be sustainable and, paradoxically, may lead to reduced health protection, because they may be viewed as unachievable under local circumstances and, thus, ignored. The Guidelines therefore strive to maximize overall public health benefits and the beneficial use of scarce resources.

Following an expert meeting in Stockholm, Sweden, WHO published *Water quality: Guidelines, standards and health — Assessment of risk and risk management for water-related infectious disease* (Fewtrell & Bartram, 2001). This document presents a harmonized framework for the development of guidelines and standards for water-related microbial hazards. This framework involves the assessment of health risks prior to the setting of health targets, defining basic control approaches and evaluating the impact of these combined approaches on public health status. The framework is flexible and allows countries to take into consideration health risks that may result from microbial exposures through drinking-water or contact with recreational or occupational water. It is important that health risks from the use of wastewater in aquaculture be put into the context of the overall burden of disease within a given population.

This volume of the *Guidelines for the safe use of wastewater, excreta and greywater* provides information on the assessment and management of risks associated with microbial hazards and toxic chemicals. It explains requirements to promote the safe use of wastewater and excreta in aquaculture, including minimum procedures and specific health-based targets, and how those requirements are intended to be used. This volume also describes the approaches used in deriving the guidelines, including health-based targets, and includes a substantive revision of approaches to ensuring microbial safety — especially with respect to foodborne trematode parasites.

This edition of the Guidelines supersedes previous editions (1973 and 1989). The Guidelines are recognized as representing the position of the United Nations system on issues of wastewater, excreta and greywater use and health by "UN-Water," the coordinating body of the 24 United Nations agencies and programmes concerned with water issues. This edition of the Guidelines further develops concepts, approaches and information in previous editions and includes additional information on:

- the context of overall waterborne disease burden in a population and how the use of wastewater and excreta in aquaculture may contribute to that burden;
- the Stockholm Framework for development of water-related guidelines and the setting of health-based targets;
- risk analysis;
- risk management strategies, including expanded sections on foodborne trematode parasites;
- chemicals;
- guideline implementation strategies.

The revised Guidelines will be useful to all those concerned with issues relating to the safe use of wastewater, excreta and greywater, public health and water and waste management, including environmental and public health scientists, educators, researchers, engineers, policy-makers and those responsible for developing standards and regulations.

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EXECUTIVE SUMMARY

This volume of the World Health Organization's (WHO) *Guidelines for the safe use of wastewater, excreta and greywater* describes the present state of knowledge regarding the impact of waste-fed aquaculture on the health of product consumers, workers and their families and local communities. Health hazards are identified for each group at risk, and appropriate health protection measures to mitigate the risks are discussed.

The primary aim of the Guidelines is to maximize public health protection and the beneficial use of important resources. The purpose of this volume is to ensure that waste-fed aquacultural activities are made as safe as possible so that the nutritional and household food security benefits can be shared widely in affected communities. Thus, the adverse health impacts of waste-fed aquaculture should be carefully weighed against the benefits to health and the environment associated with these practices. Yet this is not a matter of simple trade-offs. Wherever waste-fed aquaculture contributes significantly to food security and nutritional status, the point is to identify associated hazards, define the risks they represent to vulnerable groups and design measures aimed at reducing these risks

This volume of the Guidelines is intended to be used as the basis for the development of international and national approaches (including standards and regulations) to managing the health risks from hazards associated with waste-fed aquaculture, as well as providing a framework for national and local decision-making. The information provided is applicable to intentional waste-fed aquacultural practices but also should be relevant to the unintentional use of faecally contaminated waters for aquaculture.

The Guidelines provide an integrated preventive management framework for safety applied from the point of waste generation to the consumption of products grown with the wastewater and excreta. They describe reasonable minimum requirements of good practice to protect the health of the people using wastewater or excreta, or consuming products grown with wastewater or excreta and provide information that is then used to derive health-based targets. Neither the minimum good practices nor the health-based targets are mandatory limits. The preferred approaches adopted by national or local authorities towards implementation of the Guidelines, including health-based targets, may vary depending on local social, cultural, environmental and economic conditions, as well as knowledge of routes of exposure, the nature and severity of hazards and the effectiveness of health protection measures available.

The revised *Guidelines for the safe use of wastewater, excreta and greywater* will be useful to all those concerned with issues relating to the safe use of wastewater, excreta and greywater, public health, water resources development and wastewater management. The target audience may include environmental and public health scientists, educators, researchers, engineers, policy-makers and those responsible for developing standards and regulations.

Introduction

A number of forces are both negatively and positively impacting the development of waste-fed aquacultural production. Many of the areas where waste-fed aquaculture has been traditionally practised are shrinking due to urbanization, increasing surface water pollution and the development of high-input aquaculture to produce cash crops. Most of the traditional waste-fed aquacultural production has occurred in parts of Asia. Although intentional waste-fed aquaculture is in decline, the unintentional use of contaminated water in aquaculture may be increasing in some areas.

The Stockholm Framework

The Stockholm Framework is an integrated approach that combines risk assessment and risk management to control water-related diseases. This provides a harmonized framework for the development of health-based guidelines and standards in terms of water- and sanitation-related microbial hazards. The Stockholm Framework involves the assessment of health risks prior to the setting of health-based targets and the development of guideline values, defining basic control approaches and evaluating the impact of these combined approaches on public health. The Stockholm Framework provides the conceptual framework for these Guidelines and other WHO water-related guidelines.

Assessment of health risk

Three types of evaluations are used to assess risk: microbial and chemical laboratory analysis, epidemiological studies and quantitative microbial (and chemical) risk assessment. Overall, there are limited data on the health impacts associated with waste-fed aquacultural practices. The evidence suggests that pathogens are often present at significant levels in untreated wastewater and excreta; pathogens can survive long enough in the environment to be transmitted to humans; and waste-fed aquaculture-associated disease transmission can occur.

Foodborne trematode parasites, where they occur, pose significant health risks to consumers of raw or inadequately cooked fish or plants. Priority should be given to implementing control measures against the transmission of foodborne trematode infections, where relevant. Excreta-related pathogens pose health risks to product consumers and people who may have contact with the contaminated water. For product consumers, much of the health risk may be associated with poor fish cleaning practices that lead to cross-contamination between the gut contents and the edible flesh. Thus, improving market hygiene and fish processing/cleaning is an important health protection intervention.

Health-based targets

Health-based targets define a level of health protection that is relevant to each hazard. A health-based target can be based on a standard metric of disease, such as the disability adjusted life year or DALY (e.g. 10^{-6} DALY), or it can be based on an appropriate health outcome, such as the prevention of the transmission of foodborne trematode infection associated with waste-fed aquacultural practices. To achieve a health-based target, health protection measures are developed. Usually a health-based target can be achieved through a combination of health protection measures targeted at different components of the waste-fed aquacultural system. Health-based targets for different waste-fed aquacultural hazards are presented in Table 1.

Table 1. Health-based targets for waste-fed aquaculture

Exposed group	Hazard	Health-based target[a]	Health protection measure
Consumers, workers and local communities	Excreta-related pathogens	10^{-6} DALY	Wastewater treatment Excreta treatment Health and hygiene promotion Chemotherapy and immunization
Consumers	Excreta-related pathogens Foodborne trematodes Chemicals	10^{-6} DALY Absence of trematode infections Tolerable daily intakes as specified by the Codex Alimentarius Commission	Produce restriction Waste application/timing Depuration Food handling and preparation Produce washing/disinfection Cooking foods
Workers and local communities	Excreta-related pathogens Skin irritants Schistosomes Vector-borne pathogens	10^{-6} DALY Absence of skin disease Absence of schistosomiasis Absence of vector-borne disease	Access control Use of personal protective equipment Disease vector control Intermediate host control Access to safe drinking-water and sanitation at aquacultural facilities and in local communities Reduced vector contact (insecticide-treated nets, repellents)

[a]Absence of disease associated with waste-fed aquaculture exposures.

Health protection measures

A variety of health protection measures can be used to reduce health risks to product consumers, workers and their families and local communities.

Hazards associated with the consumption of waste-fed aquacultural products include excreta-related pathogens, foodborne trematodes and some toxic chemicals. The risk from infectious diseases is significantly reduced if foods are eaten after thorough cooking. Cooking has little or no impact on the concentrations of toxic chemicals that might be present. Special considerations for managing trematode parasites (including *Schistosoma* spp.) may be required where they are present. The following health protection measures impact product consumers:

- wastewater and excreta treatment;
- produce restriction;
- waste application withholding periods;
- control of trematode intermediate hosts;
- depuration;
- hygienic food handling and preparation;
- post-harvest processing;
- health and hygiene promotion;
- produce washing, disinfection and cooking;
- produce washing, disinfection and cooking;
- chemotherapy and immunization.

Workers and their families may be exposed to excreta-related diseases, skin irritants, schistosomiasis and vector-borne diseases through waste-fed aquacultural activities or contact with the hazards. Wastewater treatment and excreta treatment are control measures for excreta-related diseases, skin irritants and schistosomiasis but may not have much impact on vector-borne diseases. Other health protection measures include:

- use of personal protective equipment;
- access to safe drinking-water and sanitation facilities at aquacultural facilities;
- health and hygiene promotion;
- chemotherapy and immunization;
- disease vector and intermediate host control;
- reduced vector contact.

Local communities are at risk from the same hazards as workers, especially if they have access to waste-fed ponds. If they do not have access to safe drinking-water, they may use the contaminated water for drinking or for domestic purposes, such as washing clothes, dishes and themselves. Children may also play or swim in the contaminated water. Similarly, if waste-fed aquacultural activities result in increased vector breeding, then local communities can be affected by vector-borne diseases, even if they do not have access to the waste-fed aquacultural facilities. To reduce health hazards, the following health protection measures may be used:

- wastewater and excreta treatment;
- restricted access to aquacultural facilities;
- access to safe drinking-water and sanitation facilities at aquacultural facilities;
- health and hygiene promotion;
- chemotherapy and immunization;
- disease vector and intermediate host control;
- reduced vector contact.

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 to ensure that the system is achieving the specified targets.

The three functions of monitoring are each used for different purposes at different times. Validation is performed 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 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/excreta/pond water; fish or plants) meets treatment targets (e.g. microbial reduction targets) and ultimately the health-based targets. 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. whether the efficiency of a specific process is improving or decreasing).

The most effective means of consistently ensuring safety in waste-fed aquaculture is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in waste-fed aquaculture, from the generation and use of wastewater and excreta to the product consumer. This approach is captured in the Stockholm Framework. Three components of this approach are important for achieving the health-based targets: system assessment; identifying control measures and methods for monitoring them; and developing a management plan.

Sociocultural, environmental and economic aspects

Human behavioural patterns are a key determining factor in the transmission of excreta-related diseases. The social feasibility of changing certain behavioural patterns in order to introduce excreta or wastewater use schemes or to reduce disease transmission in existing schemes can be assessed only with a prior understanding of the cultural values attached to practices that appear to be social preferences, yet which facilitate disease transmission. Closely associated with cultural beliefs is the public perception of wastewater and excreta use.

Excreta and wastewater use schemes, if properly planned and managed, can have a positive environmental impact, as well as produce fish and plants. Environmental improvement may be related to:

- avoidance of surface water pollution;
- conservation or more rational use of freshwater resources, especially in arid and semi-arid areas: fresh water for urban demand, wastewater for aquacultural use;
- reduction in risks of flooding in urban areas, as wastewater-fed canals, ponds and lakes act as a "buffer" during heavy rains;
- reduced requirements for artificial fertilizers, with a concomitant reduction in energy expenditure and industrial pollution elsewhere.

The primary negative environmental impacts are often related to contamination of surface waters or groundwaters in proximity to waste-fed aquacultural facilities. Other impacts relate to general aquacultural practices (e.g. the introduction of non-indigenous species or destruction of mangroves) and are not specifically related to waste-fed aquaculture.

Economic factors are especially important when the viability of a new scheme for the use of wastewater and excreta is being appraised, but even an economically worthwhile project can fail without careful financial planning. Economic appraisal considers whether a project is worthwhile, whereas financial planning looks at how projects are to be paid for. Improvements to existing practices must be paid for in some way and therefore also require financial planning.

Policy aspects

The safe management of waste-fed aquacultural practices is facilitated by appropriate policies, legislation, institutional frameworks and regulations at the international, national and local levels. In many countries where waste-fed aquaculture takes place, these frameworks are lacking.

Policy is the set of procedures, rules, decision-making criteria and allocation mechanisms that provide the basis for programmes and services. Policies set priorities, and associated strategies allocate resources for their implementation. Policies are implemented through four types of instruments: laws and regulations; economic measures; information and education programmes; and assignments of rights and responsibilities for providing services.

In developing a national policy framework to facilitate safe waste-fed aquaculture, it is important to define the objectives of the policy, assess the current policy environment and develop a national approach. National approaches for safe waste-fed aquacultural practices based on the WHO Guidelines will protect public health the most when they are integrated into comprehensive public health programmes that include other sanitary measures, such as health and hygiene promotion, and improving access to safe drinking-water and adequate sanitation. Other complementary programmes, such as chemotherapy campaigns, should be accompanied by health promotion/education to change behaviours that would otherwise lead to reinfection with foodborne trematodes or intestinal helminths.

National approaches need to be adapted to the local sociocultural, environmental and economic circumstances, but they should be aimed at progressive improvement of public health. Interventions that address the greatest local health threats first should be given the highest priority. As resources and new data become available, additional health protection measures can be introduced.

Planning and implementation

Planning and implementation of waste-fed aquacultural programmes require a comprehensive progressive approach that responds to the greatest health priorities first. Strategies for developing national programmes should include elements on communication to stakeholders, interaction with stakeholders and the collection and use of data.

Additionally, planning for projects at a local level requires an assessment of several important underlying factors. The sustainability of waste-fed aquaculture relies on the assessment and understanding of eight important criteria: health, economic feasibility, social impact and public perception, financial feasibility, environmental impact, market feasibility, institutional feasibility and technical feasibility.

1 INTRODUCTION

This volume of the *Guidelines for the safe use of wastewater, excreta and greywater* describes the present state of knowledge regarding possible health impacts of wastewater and excreta use in aquaculture (hereafter referred to as waste-fed aquaculture). This chapter describes the objectives and general considerations related to the Guidelines and their target audience. It presents an overview of what World Health Organization (WHO) water-related guidelines are and how they relate to waste-fed aquaculture. Driving forces that impact waste-fed aquaculture and how and where waste-fed aquaculture is practised in the world are also described.

1.1 Objectives and general considerations

The primary aim of the Guidelines is to maximize public health protection and the beneficial use of important resources. The purpose of this volume of the Guidelines is to ensure that waste-fed aquacultural activities are made as safe as possible so that the nutritional and household food security benefits can be shared widely in exposed communities. To achieve this objective, strategies are needed for minimizing the transmission of wastewater- and excreta-related disease or illness (from both infectious agents and toxic chemicals), vector-borne diseases and diseases caused by trematodes (i.e. both foodborne and schistosomes) to aquaculturists and their families, to local communities and to product consumers. This can be achieved by minimizing human exposure to pathogens and toxic chemicals in the wastewater and excreta or preventing the breeding of vectors or intermediate hosts that may propagate in conditions created by waste-fed aquacultural activities.

These Guidelines review the current knowledge base related to the transmission of infectious diseases and illnesses related to exposures to toxic chemicals associated with waste-fed aquaculture. Information on disease transmission and the effectiveness of different health protection measures is used to derive the guidelines and guideline values. Guidelines are based on the derivation of health-based targets, which establish a goal of attaining a certain level of health protection in an exposed population. This level of health can then be achieved by using a combination of management approaches (e.g. produce restriction, human exposure control) and microbial water quality targets to arrive at the specified health outcome. Thus, guidelines consist of both good practices and microbial water quality specifications and may include:

- a level of management;
- a concentration of a constituent that does not represent a significant risk to the health of members of important user groups;
- a condition under which such exposures are unlikely to occur; or
- a combination of the last two.

The Guidelines provide an integrated preventive management framework (see discussion on the Stockholm Framework in chapter 2) for safety applied from the point of waste generation to consumption of products grown with the wastewater and excreta (see Box 1.1). They describe reasonable minimum requirements of good practice to protect the health of the people using wastewater or excreta or consuming products grown with wastewater or excreta and provide information that is then used to derive numerical guideline values. Neither the minimum good practices nor the numerical guideline values are mandatory limits. In order to define such limits, it is preferable to consider the Guidelines in the context of national environmental, social, economic and cultural conditions.

Box 1.1 What are the Guidelines?

The WHO Guidelines are an integrated preventive management framework for maximizing the public health benefits of waste-fed aquaculture. The Guidelines are built around a health component and an implementation component. Health protection is dependent on both elements.

Health component:

- defines a level of health protection that is expressed as a health-based target for each hazard;
- identifies health protection measures that, used collectively, can achieve the specified health-based target.

Implementation component:

- establishes monitoring and system assessment procedures;
- defines institutional and oversight responsibilities;
- requires system documentation;
- requires confirmation by independent surveillance.

The approach followed in these Guidelines is intended to support the establishment of national standards and regulations that can be readily implemented and enforced and are protective of public health. Each country should review its needs and capacities in developing a regulatory framework. Successful implementation of the Guidelines will benefit from a broad-based policy framework that includes positive and negative incentives to alter behaviour and monitor and improve situations. Intersectoral coordination and cooperation at national and local levels and the development of suitable skills and expertise will facilitate implementation of the Guidelines.

In many situations, it will not be possible to fully implement the Guidelines at once. The Guidelines set target values designed in such a way as to allow progressive implementation. They are to be achieved over time in a orderly manner, depending on the current reality and the existing resources of each individual country or region. The greatest threats to health should be given the highest priority and addressed first. Over time, it should be possible to adjust the risk management framework to strive for the continual improvement of public health.

Ultimately, the judgement of safety — or what is a tolerable level of risk in particular circumstances — is a matter in which society as a whole has a role to play. Each country should make the final judgement as to whether the benefit from applying any of the guidelines and health-based targets as national or local standards justifies the cost in the context of national public health, environment and socio-economic realities and of international trade regulations.

1.2 Target audience, definitions and scope

The revised *Guidelines for the safe use of wastewater, excreta and greywater* will be useful to all those concerned with issues relating to the safe use of wastewater, excreta and greywater, public health and water and waste management. The target audience may include environmental and public health scientists, educators, researchers, engineers, policy-makers and those responsible for developing standards and regulations.

This volume of the Guidelines addresses the use of wastewater and excreta in aquaculture. These Guidelines focus on wastewater consisting of domestic sewage that does not contain industrial effluents at levels that could pose threats to the functioning of the sewerage system, treatment plant, public health or the environment. The ability to use wastewater with significant concentrations of industrial chemicals in aquaculture should be determined on a case-by-case basis. Excreta denotes faeces and urine; for the purposes of these Guidelines, it may also refer to faecal sludge, septage and nightsoil. Definitions of common terms used in this document are presented in the glossary in Annex 4. Sludge derived from the treatment of municipal or industrial wastewater is not included in the scope of this document.

The public health aspects and the health-based targets for aquaculture are applicable to situations where wastewater is used indirectly — for example, discharged into surface waters, which are then used for aquaculture. Management of the health risks in these situations may require approaches that are different from those for the planned use of wastewater or excreta in aquaculture. These are further discussed in chapter 5.

For the purposes of these Guidelines, aquaculture refers to the production of fish, non-molluscan shellfish and aquatic plants. The management of health risks associated with the consumption of filter-feeding molluscan shellfish is complex, because they can concentrate environmental contaminants to very high levels in their flesh and are often eaten raw or partly cooked. These issues are discussed in more detail in other WHO documents and are considered to be beyond the scope of this document.

1.3 Organization of this Guidelines document

The structure of this volume of the Guidelines is presented in Figure 1.1. Chapter 2 provides an overview of the Stockholm Framework. Chapter 3 provides the epidemiological, microbial and risk assessment bases for the Guidelines, which are formally developed in chapter 4 as health-based targets. Chapter 5 reviews the health protection measures that can be used to achieve the health-based targets. Chapter 6 reviews monitoring requirements. Chapter 7 presents the sociocultural and public perception aspects that need to be considered in waste-fed aquaculture. Chapter 8 discusses policy aspects at different levels, and Chapter 9 reviews planning and implementation issues. A waste stabilization pond designed to facilitate waste-fed aquaculture is described in Annex 1, and sections of the Food and Agriculture Organization of the United Nations (FAO) Code of Responsible Fisheries related to aquacultural development are presented in Annex 2. Health impact assessment with regard to wastewater use in aquaculture is discussed in Annex 3. Annex 4 is a glossary of terms used in the *Guidelines for the safe use of wastewater, excreta and greywater.*

1.4 Driving forces affecting wastewater and excreta use in aquaculture

A number of factors may either increase or decrease the use of wastewater and excreta in aquaculture in the future. At the present time, the *intentional* use of wastewater and excreta in aquaculture is declining in many of the areas of the world where it has been traditionally practised. Urbanization and the expansion of urban/periurban areas have made land previously used for aquaculture more valuable for other purposes, such as housing development. Additionally, aquaculturists are shifting to the production of high-value species such as shrimp, which are grown intensively in high-input monoculture systems with the use of artificial feeds. Shrimp and some other high-value species cannot be grown in waste-fed aquacultural systems because they require high-quality water to survive and are particularly susceptible to elevated ammonia levels. Economic development may also impact waste-fed aquaculture. Richer urban populations may be less likely to accept products grown with wastewater or excreta.

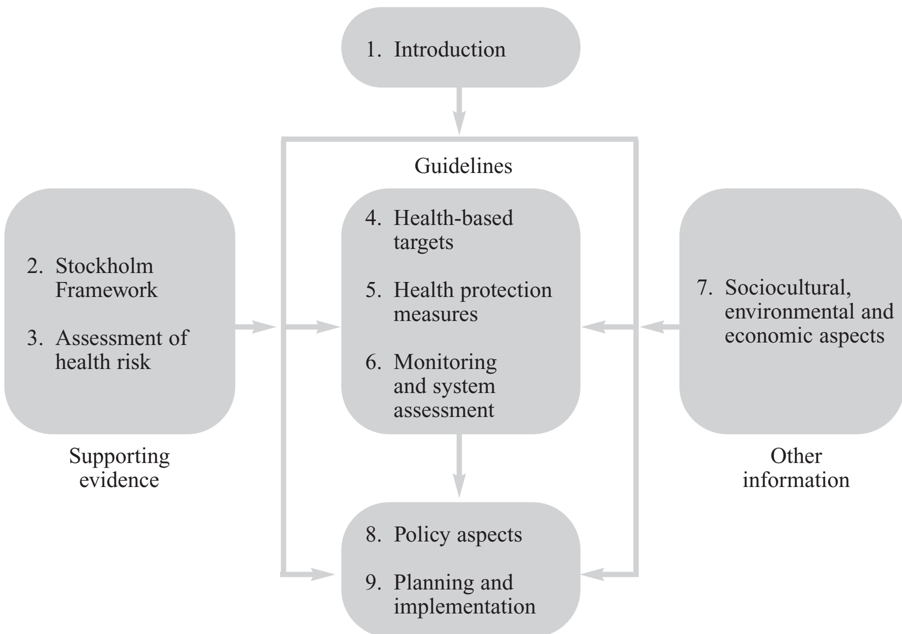

Figure 1.1
Structure of Volume 3 of the *Guidelines for the safe use of wastewater, excreta and greywater*

However, because surface water pollution is increasing in many areas, the *unintentional* use of wastewater and excreta in aquaculture may actually increase. Wastewater and excreta are important sources of nutrients and water, which can be used to increase both fish and plant production. This is more important as fresh water becomes increasingly scarce in a wider range of countries. In many areas, fish and plants are grown in surface waters that are heavily contaminated with wastewater and excreta. As noted above, the growth of urban areas is often detrimental to waste-fed aquaculture, but in some cases it may also increase waste-fed aquaculture — especially in less developed countries where farmers frequently undertake small-scale agricultural and aquacultural activities in cities and their surroundings. Urban areas may provide aquaculturists with a reliable source of water (i.e. wastewater) and offer ready access to markets, minimizing the distance over which perishable products need to be transported before sale.

Waste-fed aquaculture can also be considered as a low-cost wastewater treatment option, as it effectively reduces the organic matter, nutrients and pathogens in the wastewater and excreta. The sale of fish or plants can be used to offset the costs of the wastewater treatment (see chapter 7).

1.5 Historical overview of waste-fed aquaculture

Waste-fed aquaculture has a long history in several countries in East, South and South-east Asia, particularly in China, where the practice is centuries old (Edwards & Pullin, 1990; Edwards, 1992, 2000). Waste-fed aquaculture was mainly developed by farmers and local communities to increase food production. Nightsoil, wastewater, septage and faecally polluted surface water were often used in aquaculture without any pretreatment.

Systems primarily engineered to treat wastewater that incorporated an aquaculture component appeared later. About 90 systems were constructed in Germany between the end of the 19th century and the 1950s. Most have been closed, however, with the notable exception of some fish ponds in Munich, which are now used for tertiary treatment of activated sludge effluent and as a bird sanctuary (Prein, 1996). Sewage-fed fish ponds were developed later in Asia than in Europe — in India in the 1930s, in China from the 1950s onwards and in Viet Nam in the 1960s — but these systems were developed to increase fish production and not as a means of wastewater treatment. Experimental fish culture in engineered wastewater stabilization ponds has been and still is practised in all regions of the world, and a number of country examples are presented below. Although many experimental small-scale waste-fed aquacultural systems have been developed, the practice has not been adopted by commercial aquacultural producers (Edwards, 1992, 2000).

1.6 Current waste-fed aquacultural practice

There is a great diversity of systems currently in use (Table 1.1; Figure 1.2). These systems use wastewater, fresh human excreta or nightsoil and septage. Some common and scientific names of species grown in waste-fed aquaculture are presented in Table 1.2.

Wastewater and excreta used in aquaculture are added directly to ponds to produce fish (mainly carp, catfish and tilapia) or aquatic plants (macrophytes such as lotus, water mimosa or water spinach) for direct human consumption. Less common is indirect use to produce fish seed (fingerlings) or fish and aquatic plants (e.g. duckweed) that are fed to livestock or other fish. Fish may be cultured in pen and cage enclosures and aquatic plants secured by stakes in either ponds or, more commonly, faecally contaminated surface waters. Wastewater may be fed into lakes and reservoirs to culture fish and/or aquatic plants.

A number of different plants are grown in waste-fed aquaculture, including watercress, water chestnut, water spinach and water mimosa. Most of these plants can be grown in aquacultural ponds, wastewater canals, etc., as well as in agricultural soil. When the plants are grown in aquatic environments, any pathogen present in the water is likely also to be present on the plants, in particular on roots and other plant parts in contact with water contact. Consumption of aquatic plants is important for food security in a number of South-east Asian countries.

Table 1.1 Types of waste-fed aquacultural systems

Waste type and delivery system	Aquacultural system	Cultured organism	Examples of where aquacultural system is applied
Nightsoil (overhanging latrine)	Pond	Fish	China, Indonesia, Viet Nam
Nightsoil (overhanging latrine)	Pond	Duckweed	Bangladesh
Nightsoil, septage (cartage)	Pond	Fish	China, Viet Nam
Contaminated surface water (waterborne)	Pond	Fish	Bangladesh, Indonesia, Viet Nam
Contaminated surface water (waterborne)	Pond	Duckweed	China
Contaminated surface water (waterborne)	Cage in river	Fish	Indonesia
Contaminated surface water (waterborne)	Stakes in river, shallow pond	Aquatic vegetables	Widespread in Asia
Sewage (waterborne)	Pond	Fish	China, Germany, India, Viet Nam
Sewage (waterborne)	Pond	Duckweed	Bangladesh

Source: Adapted from UNEP (2002).

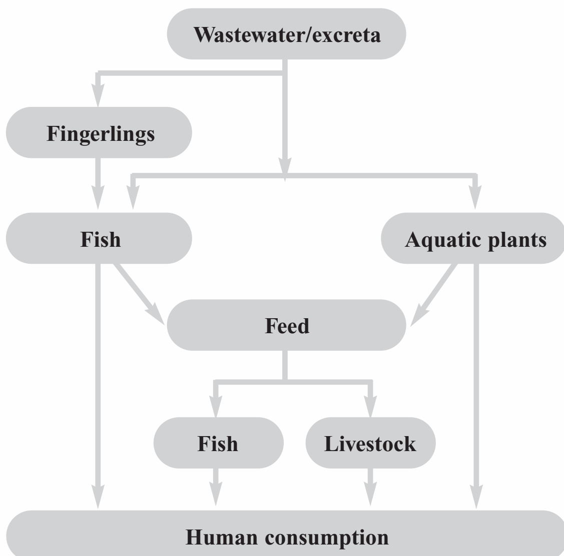

Figure 1.2
Wastewater and excreta use in aquaculture (UNEP, 2002)

Table 1.2 Common and scientific names of fish and plants grown in waste-fed aquaculture

Common name	Scientific name
Fish	
Chinese carp:	
Bighead carp	*Aristichthys nobilis*
Grass carp	*Ctenopharyngodon idellus*
Silver carp	*Hypophthalmychthis molitrix*
Common carp	*Cyprinus carpio*
Indian major carp:	
Catla	*Catla catla*
Mrigal	*Cirrhinus mrigala*
Rohu	*Labeo rohita*
Mandarin fish	*Siniperca chautsi*
Milkfish	*Chanos chanos*
Mozambique tilapia	*Oreochromus mossambicus*
Nile tilapia	*Oreochromus niloticus*
Silver striped catfish	*Pangasius hypophthalmus*
Walking catfish	*Clarias macrocephalus*
Plants	
Aquatic mint	*Mentha aquatica*
Duckweed	*Lemna* spp., *Spirodela polyrhiza* and *Wolffia arrhiza*
Lotus	*Nelumbo nucifera*
Mosquito fern	*Azolla* spp.
Spirulina	*Spirulina* spp.
Water caltrop	*Trapa natans*
Water chestnut	*Eliocharis tuberosa*
Watercress	*Nasturtium officinale*
Water dropwort	*Oenanthe stolonifera*
Water mimosa	*Neptunia oleracea*
Water spinach	*Ipomoea aquatica*
Wild mint	*Mentha pipesota* L.

Most waste-fed aquaculture takes place in Asia, with an almost insignificant level of practice on other continents. Examples are given below of waste-fed aquaculture in selected countries, those where it is an important practice and those where recent attempts have been made to introduce it (UNEP, 2002).

1.6.1 Bangladesh

Unintentional waste-fed aquaculture occurs in Bangladesh. Fish are farmed in low-lying water bodies within the city of Dhaka that contain faecally contaminated water. This practice is now constrained by excessively high organic loadings and rapid urbanization.

PRISM (Project in Agriculture, Rural Industry Science and Medicine) Bangladesh, a nongovernmental organization, operates duckweed wastewater treatment systems at Mirzapur using wastewater from a hospital (Gijzen & Ikramullah, 1999) and at

Khulna with municipal wastewater, with harvested duckweed used to feed fish (Haq & Ghosal, 2000) (see section 5.2.3). A household-level latrine-fed pond system from which duckweed is harvested to feed fish in nearby ponds has been introduced by PRISM Bangladesh in about 50 villages.

1.6.2 China

Nightsoil is used in aquaculture in China, particularly in more remote rural areas, but its use has declined drastically in the major aquacultural areas in the Pearl and Yangtze river basins due to loss of land and rapid economic growth. Improved sanitation has reduced the availability of nightsoil, and increased labour costs favour use of inorganic fertilizers and supplementary and formulated feeds. Furthermore, intensification of aquaculture has led to excess nutrients in ponds from feeds, reducing the need for fertilization.

Nightsoil (and livestock manure) is used to cultivate duckweed to feed grass carp fingerlings up to the size at which they can feed on grass or formulated feed. Although the most common way to culture the high-value, carnivorous mandarin fish is in a carp polyculture system, some farmers culture low-value silver carp fingerlings in nightsoil-fed ponds as live feed for the carnivorous fish.

There has also been a decline in the use of sewage for aquaculture in ponds and lakes, from a peak of 20 000 ha nationally in the 1980s, due to the twin constraints of eutrophication and industrial pollution (Li, 1997). There have been mass fish kills in wastewater-fed lakes due to dissolved oxygen depletion. In China, most domestic sewage is mixed with industrial wastewater, so that fish cultured in waste-fed systems may be contaminated with various chemical substances (e.g. heavy metals, petroleum and phenolic compounds). In addition to being difficult to market because of undesirable odour and taste, more importantly, such fish will be unfit for human consumption from a food safety perspective.

There is no formal ban on waste-fed aquaculture from any level of government, although concerned agencies have advised aquaculturists not to practise this type of aquaculture, especially in periurban areas. However, the practice continues to exist in poor urban and rural areas. With improved living standards, the urban population is increasingly concerned about food safety and may not accept waste-fed aquacultural products.

1.6.3 India

The world's single largest wastewater-fed fish pond complex is in Kolkata, occupying an area of about 3800 ha (Bose, 1944; Strauss & Blumenthal, 1990; Edwards, 1992). It provides considerable environmental benefits (low-cost wastewater treatment, stormwater drainage and a green area as a lung for the city) and social benefits (employment for fish farmers, service providers, such as producers of fish fingerlings, and people involved in fish transport and marketing). However, it is under threat from pressures of urban expansion and has declined in area from about 8000 ha.

Raw wastewater from Kolkata is conveyed in two 27-km canals to the North and South Salt Lake fisheries constructed on the wetlands of East Kolkata. The canals feed into a complex system of secondary and tertiary canals, from which wastewater is fed into the fish ponds stocked with Chinese carps, Indian major carps and tilapia. The ponds are emptied each year in February to remove the bottom mud and are refilled with raw wastewater six to eight weeks later. After a period of two to three weeks to permit the development of phytoplankton, the ponds are stocked with fish, and additional wastewater is slowly fed into them for 5–10 days each month; this slow rate of wastewater introduction avoids deoxygenation of the fish ponds. The fish attain marketable size in five to six months, and mean annual yields for the North and South Salt Lake fisheries are approximately 1400 and 1000 kg/ha, respectively, although well managed farms attain yields of up to 5000 kg/ha.

Some of the fish ponds are leased from the City of Kolkata, some are privately owned and a few are run as cooperatives; they provide employment for the local people at a rate of 7.5 persons/ha. The fish ponds supply 10–20% of the fish consumed in Greater Kolkata (Morrice, Chowdhury & Little, 1998).

Lessons learned from farmers who developed the system over the past few decades have been used to install systems incorporating pretreatment in three municipalities within the Kolkata metropolitan area under the Ganga Action Plan (Ghosh, 1997) and in Kalyani, West Bengal (Jana, 1998). A wastewater treatment system involving duckweed as well as fish ponds has recently been constructed in Cuttack, Orissa (CIFA, undated).

1.6.4 Indonesia

The fertilization of fish ponds with excreta from overhanging latrines is mainly practised in south-eastern West Java. In the four regencies (administrative areas) of Bandung, Ciamis, Garut and Tasikmalaya, where this practice is most common and which have a population of nearly eight million, some 33 000 t of fish, predominantly common carp and Mozambique and Nile tilapia, are produced annually in approximately 10 000 ha of ponds (Djajadiredja et al., 1979).

Strauss & Blumenthal (1990) describe excreta-based fish culture in the village of Cikoneng, which has a population of 3900 and is located 20 km south-east of Bandung. Cikoneng is a typical "pond village": the natural surface drainage from rivulets and streams discharges into 5 ha of ponds (the average pond size is 590 m^2), into which local runoff and water from paddy fields are also directed through bamboo gutters and pipes. The ponds are interconnected, and water flows from the upper to the lower ponds. The ponds are used for washing and bathing by all except the richer families, who have their own wells, and overhanging latrines are constructed in the ponds for excreta disposal and direct fertilization of the fish. Rice bran and chicken manure are also used by some families for fertilization. The ponds are completely drained once a year, and all the fish are caught and sold. Annual fish yields are in the range of 1600–2800 kg/ha. The bottom mud is removed and used in the local rice fields as a soil conditioner and fertilizer. Fish are also caught once a week for local consumption after cooking. In some ponds, water spinach is also grown, and this is eaten as a cooked vegetable.

1.6.5 Viet Nam

In Viet Nam, wastewater and excreta use in aquaculture is widespread, with overhanging fish pond latrines, nightsoil cartage to fertilize fish nursery and production ponds and culture of fish and aquatic vegetables in contaminated surface water and sewage.

The overhanging fish pond latrine is the most common system for nightsoil disposal in the Mekong River delta. A survey conducted by the Institute of Hygiene and Public Health in Ho Chi Minh City in 1989 showed that 65% of all toilets in the delta were overhanging fish pond latrines, with an estimated total of 360 000 units, each used by an average of 4–5 families. The major fish species, Sutchi catfish, feeds directly on human excreta. Most units have connections to nearby canals or rivers with some exchange of pond water due to tidal changes in water level. The overhanging fish pond latrine system provides benefits such as food and income from fish, a sanitation system free of smell, absence of problems with breeding of flies and no handling of nightsoil.

As an example of nightsoil cartage, fresh nightsoil from Bac Ninh, a town in the Red River delta in northern Viet Nam, is bought by specialized traders who transport it by bicycle to nursery farms producing fish fingerlings. Up to 1 t of fresh nightsoil per hectare per week is loaded into ponds as the primary fertilizer, on a contract basis. The high value of nightsoil is indicated by its scarcity and price, as it is up to five times more expensive than pig manure (Little & Pham, 1995).

Ho Chi Minh City has a unique system of tilapia seed production in about 500 ha of ponds batch fed with faecally contaminated surface water. The area is the main source of tilapia fingerlings for southern Viet Nam. Farmers typically have two ponds and alternate production of fingerlings with production of lotus and water mimosa for human consumption.

In several cities, especially in northern Viet Nam, use of sewage and contaminated surface water in aquaculture (and agriculture) is the only means of treatment. The largest system is in Hanoi, where untreated sewage flows out of the city in rivers into a low-lying area, Thanh Tri district, fertilizing almost 500 ha of fish ponds (Vo, 1996). The major species are rohu, silver carp and tilapia raised in polyculture either alone in ponds or in combination with rice for part of the year. Mean fish yields range from 4.7 t/ha in rice/fish culture to 5.6 t/ha in fish-only culture during a 10-month growing season. Privatization of land has made it difficult to supply wastewater to some areas, resulting in about a 35% decline in area due to breakdown of the communal wastewater distribution system. Rapid urbanization in Hanoi is leading to a reduction in wastewater-fed aquaculture.

1.6.6 Africa

The intentional use of excreta and wastewater in aquaculture is not a traditional practice in Africa (Larsson, 1994). Fish for human consumption are grown in faecally polluted lakes, however (Demanou & Brummett, 2003). Although experiments have been carried out with fish culture in secondarily treated effluent in wastewater stabilization ponds in Egypt (Khalil & Hussein, 1997) and South Africa (Slabbert, Morgan & Wood, 1989), this does not appear to have led to commercial practice (Hendy & Youssef, 2002).

1.6.7 Europe

In addition to the experience of Germany, outlined in section 1.5, a sewage-fed system was introduced in Hungary at Fonyod that did progress from experimental to commercial practice (Olah, 1990). It no longer operates, however, because the owners lost interest in the technology under changing economic conditions in the country (L. Varadi, personal communication, 2002).

1.6.8 The Americas

There appears to be only a single example of commercial waste-fed aquacultural practice in Latin America, in Lima, Peru (J.M. Cavallini, personal communication, 2002). A project sponsored by the United Nations Development Programme and the World Bank successfully demonstrated the culture of the fish tilapia in tertiary treated effluent at the San Juan wastewater treatment facility in Lima to produce food and employment as well as to improve the efficiency of water use in a desert environment

(Cavallini, 1996; UNEP, 2002). Tilapia grew well, attaining a marketable size of 250 g in four months. The pond carrying capacity was 4 t of fish per hectare without use of supplementary feed. Wastewater-fed fish were acceptable to Lima city consumers, even though they were aware of the origin of the fish.

Following the completion of the research at the San Juan facility, the Aquaculture Unit was increased in area and operated by the Peruvian government as a full-scale operation for 12 years, with fish traders eventually buying the 5 t annual tilapia harvest from the pilot demonstration unit for sale to mainly Asian restaurants. A new aquaculture demonstration unit has been built in another Lima district, Villa El Salvador. Although the objective of the research at San Juan was to develop a wastewater-fed aquacultural system for application in other countries in the region, attempts to introduce wastewater-fed aquacultural practice in other Latin American cities have failed (J.M. Cavallini, personal communication, 2002).

1.6.9 Western Pacific

There does not appear to be direct waste-fed aquacultural practice in the region (D. Sharp, personal communication, 2002). In Nauru, milkfish are cultured in a brackish water lagoon; although wastewater is not deliberately introduced, water quality analyses have indicated significant contamination with sewage. Waste-fed aquaculture is considered an underutilized option for Pacific Island countries, and its introduction could help to reduce the pollution of groundwater and coral reef ecosystems.

2
THE STOCKHOLM FRAMEWORK

The Stockholm Framework is an integrated approach that combines risk assessment and risk management to control water-related diseases. Although it was developed for infectious diseases, it can be applied to diseases and illnesses resulting from water-related exposures to toxic chemicals. This chapter contains a summary of the components of the Framework and how it applies to assessing and managing risk associated with the use of wastewater and excreta in aquaculture. Specific components of the Framework are discussed in more detail in other chapters.

2.1 A harmonized approach to risk assessment/management

Following an expert meeting in Stockholm, Sweden, WHO published *Water quality: Guidelines, standards and health — Assessment of risk and risk management for water-related infectious disease* (Fewtrell & Bartram, 2001). This report provides a harmonized framework for the development of health-based guidelines and standards in terms of water- and sanitation-related microbial hazards. The Stockholm Framework involves the assessment of health risks prior to the setting of health-based targets and the development of guideline values, defining basic control approaches and evaluating the impact of these combined approaches on public health (Figure 2.1; Table 2.1).

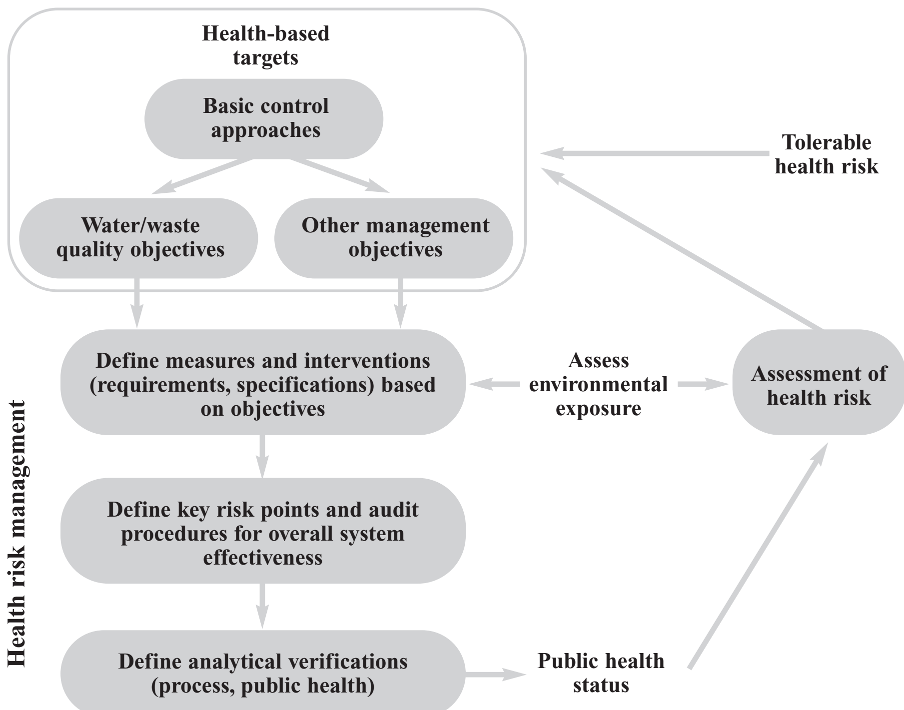

Figure 2.1
The Stockholm Framework for developing harmonized guidelines for the management of water-related infectious disease (adapted from Bartram, Fewtrell & Stenström, 2001)

Table 2.1 Elements and important considerations of the Stockholm Framework

Framework component	Process	Considerations
Assessment of health risk	Epidemiological studies QMRA	Best estimate of risk — not overly conservative Health outcomes presented in DALYs facilitate comparison of risks across different exposures and priority setting Assessment of risk is an iterative process — risk should be periodically reassessed based on new data or changing conditions Risk assessment (QMRA) is a tool for estimating risk and should be supported by other data (e.g. outbreak investigations, epidemiological evidence and studies of environmental behaviour of microbes) Process dependent on quality of data Risk assessment needs to account for short-term underperformance
Tolerable health risk/health-based targets	Health-based target setting linked to risk assessment	Needs to be realistic and achievable within the constraints of each setting Set based on a risk–benefit approach; should consider cost-effectiveness of different available interventions Should take sensitive subpopulations into account Reference pathogens should be selected for relevance to contamination, control challenges and health significance (it may be necessary to select more than one reference pathogen) Health-based targets establish a desired health outcome
Health risk management	Define water/waste quality objectives Define other management objectives Define measures and interventions Define key risk points and audit procedures Define analytical verifications	Health-based targets should be basis for selecting risk management strategies; exposure prevention occurs through a combination of good practices (e.g. hygienic fish processing, use of personal protective equipment, etc.) and appropriate water quality objectives (e.g. absence of viable trematode eggs) Risk points should be defined and used to anticipate and minimize health risks; parameters for monitoring can be set up around risk points A multiple-barrier approach should be used Risk management strategies need to address rare or catastrophic events Validation of the effectiveness of the health protection measures is needed to ensure that the system is capable of meeting the health-based targets; validation is needed when a new system is developed or additional barriers/technologies are added Monitoring — overall emphasis should be given to periodi inspection/auditing and to simple measurements that can b rapidly and frequently made to inform management

Table 2.1 (continued)

Framework component	Process	Considerations
Health risk management *(continued)*		Analytical verifications may include testing wastewater and/or plants for *Escherichia coli* or trematode eggs/infective metacercariae to confirm that the treatment processes are working to the desired level
		Verification data can be used to make necessary adjustments to the risk management process to improve safety
Public health status	Public health surveillance	Need to evaluate effectiveness of risk management interventions on specific health outcomes (through both investigation of disease outbreaks and evaluation of background disease levels)
		Public health outcome monitoring provides the information needed to fine-tune the risk management process through an iterative process; procedures for estimating the burden of disease will facilitate monitoring health outcomes due to specific exposures
		Burden of disease estimates can be used to place water-related exposures in the wider public health context to enable prioritization of risk management decisions

Source: Adapted from Carr & Bartram (2004).

The Framework encourages countries to take into consideration their local social, cultural, economic and environmental circumstances and compare the wastewater- and excreta-associated health risks with risks that may result from microbial exposures through other water and sanitation routes and additional exposures (e.g. through food, hygienic practices, etc.). This approach facilitates the management of infectious diseases in an integrated, holistic fashion and not in isolation from other diseases or exposure routes. Disease outcomes from different exposure routes can be compared by using a common metric, such as disability adjusted life years (DALYs), or normalized for a population over a time period (see Box 2.1).

Box 2.1 Disability adjusted life years (DALYs)

DALYs are a measure of the health of a population or burden of disease due to a specific disease or risk factor. DALYs attempt to measure the time lost because of disability or death from a disease compared with a long life free of disability in the absence of the disease. DALYs are calculated by adding the years of life lost to premature death to the years lived with a disability. Years of life lost are calculated from age-specific mortality rates and the standard life expectancies of a given population. Years lived with a disability are calculated from the number of cases multiplied by the average duration of the disease and a severity factor ranging from 1 (death) to 0 (perfect health) based on the disease (e.g. watery diarrhoea has a severity factor ranging from 0.09 to 0.12, depending on the age group) (Murray & Lopez, 1996; Prüss & Havelaar, 2001). DALYs are an important tool for comparing health outcomes, because they account not only for acute health effects but also for delayed and chronic effects — including morbidity and mortality (Bartram, Fewtrell & Stenström, 2001).

When risk is described in DALYs, different health outcomes (e.g. cancer vs giardiasis) can be compared and risk management decisions can be prioritized.

WHO water and sanitation-related guidelines have been developed in accordance with the principles of the Stockholm Framework. The third edition of the WHO *Guidelines for drinking-water quality* (WHO, 2004a) and Volumes 1 and 2 of the WHO *Guidelines for safe recreational water environments* (WHO, 2003a, 2005a) have both incorporated a harmonized approach to risk assessment and management, as outlined in the Stockholm Framework. The following sections describe the individual elements of the Stockholm Framework, as illustrated in Figure 2.1, and how they specifically relate to the use of wastewater and excreta. Some of the elements related to waste-fed aquaculture are discussed in more detail in subsequent chapters of this document.

2.2 Assessment of environmental exposure

The assessment of environmental exposure is an important input to both risk assessment and risk management. Environmental exposure assessment is a process that looks at the hazards in the environment and evaluates different exposure routes to human (or animal) populations. Table 2.2 describes the hazards associated with the use of wastewater and excreta in aquaculture, the primary hazards being pathogens, some vectors of parasites and viruses and certain chemicals. Treatment of wastewater and excreta to varying degrees can significantly reduce the concentrations of some contaminants (e.g. excreta-derived pathogens and some chemicals) (see chapter 5) and thus the risk of disease transmission. Other strategies are necessary to prevent the transmission of vector-borne diseases.

Table 2.2 Examples of hazards associated with waste-fed aquaculture

Hazard	Exposure route	Relative importance	Comments
Excreta-related pathogens			
Bacteria (*E. coli, Vibrio cholerae, Salmonella* spp., *Shigella* spp.)	Contact Consumption	Low–medium	Concentrations of bacteria are always high in the gut. Cross-contamination from gut contents to edible flesh during cleaning is the greatest risk. Hygienic processing and cooking reduce the risk. Poor personal hygiene after wastewater/excreta contact will increase the risk of infection/disease.
Helminths			
- Soil-transmitted (*Ascaris*, hookworms, *Taenia* spp.)	Contact Consumption	Low–high	Risk depends on how wastewater and excreta are handled, if shoes are worn, etc. Risks are probably higher for plant producers or consumers than for fish producers or consumers.
- Trematodes (*Clonorchis, Opisthorchis, Fasciola, Schistosoma*)	Contact Consumption	Nil–high	Foodborne trematodes and schistosomes are present only in certain geographic regions and require suitable intermediate hosts. Foodborne trematodes present risk where they are endemic and fish or plants are often eaten raw. Animals may serve as reservoirs, and thus they can be difficult to eliminate. Schistosomiasis is transmitted through water contact in endemic areas.

Table 2.2 (continued)

Hazard	Exposure Route	Relative Importance	Comments
Protozoa (*Giardia intestinalis, Cryptosporidium, Entamoeba* spp.)	Contact Consumption	Low–medium	Same comments as for bacteria.
Viruses (hepatitis A virus, hepatitis E virus, adenovirus, rotavirus, norovirus)	Contact Consumption	Low–medium	Same comments as for bacteria.
Skin irritants	Contact	Medium–high	Skin diseases such as contact dermatitis (eczema) have been reported after heavy contact with untreated wastewater. Cause has not yet been determined but is likely due to a mixture of microbial and chemical agents. May also be caused by cyanobacterial toxins in some situations.
Vector-borne pathogens (*Plasmodium* spp., dengue virus, *Wuchereria bancrofti*)	Vector contact	Nil–medium	Limited to geographic areas where disease is endemic and suitable vectors are present. No specific risk associated with aquaculture, but certain culicine vectors of filariasis breed in organically polluted water.
Chemicals			
Antibiotics (chloramphenicol)	Consumption	Nil–low	Antibiotics are not usually used in waste-fed aquaculture.
Cyanobacterial toxins (microcystin-LR)	Contact Consumption	Low–medium	Risk from fish consumption is thought to be low. Toxin-producing cyanobacteria can contaminate blue-green algae *(Spirulina)* grown for human nutritional supplements. May cause skin irritation or breathing difficulties when inhaled or contacted — probably rare in relation to waste-fed aquaculture.
Heavy metals (arsenic, cadmium, lead, mercury)	Consumption	Low	Mercury may bioaccumulate in long-lived carnivorous fish, but most fish produced in waste-fed aquaculture are harvested young. Pond water quality typical of waste-fed systems also reduces the uptake of mercury by fish and plants. Other heavy metals also may accumulate in fish or aquatic plants but rarely to levels considered unsafe.
Halogenated hydrocarbons (dioxins, furans, PCBs)	Consumption	Low	Dioxins and similar substances may accumulate in fish (as for mercury described above), but risk from waste-fed aquaculture is estimated to be low.
Pesticides (aldrin, DDT)	Contact Consumption	Low	Risk is related to agricultural practices. Wastewater and excreta generally do not contain high concentrations of these substances.

Sources: WHO (1995, 1999); Chorus & Bartram (1999); Gilroy et al. (2000); van der Hoek et al.(2005).

Raw wastewater contains a variety of human pathogens (see chapter 3). The concentrations of pathogens vary from region to region and over time. Pathogen concentrations will be at the highest levels in areas where faecal–oral disease is widely endemic. If excreta-related disease outbreaks occur, then concentrations of the causative pathogen may also reach higher levels in the wastewater and excreta.

Many pathogens are capable of survival (and sometimes multiplication) in the environment (e.g. water, sediments, plants) for periods long enough to allow transmission to humans. However, other factors influence their die-off, including temperature, moisture, exposure to ultraviolet radiation, absence of appropriate intermediate hosts, time, type of plant, etc.

Trematodes (both foodborne and schistosomes) and vector-borne pathogens (e.g. causing malaria, dengue, filariasis, Japanese encephalitis) may also be hazards, but are often present only in limited geographic areas and their vector require specific ecological conditions for their propagation. Only certain *Culex* species transmit lymphatic filariasis in certain parts of the world, where their breeding is associated with organically polluted water bodies (see section 2.7 and chapter 3).

Toxic chemicals may pose a risk, especially if industries also discharge into the sewers/drains (see Table 2.2). Concentrations of toxic chemicals will be highest where industries discharge wastes directly into the sewer system without prior treatment.

The primary routes of exposure to contaminants associated with waste-fed aquaculture arise from:

- human contact with the wastewater or excreta (or contaminated fish or plants) before, during or after use (farmers, their families, vendors, local communities);
- consumption of contaminated products (either directly contaminated by the excreta or wastewater or indirectly contaminated through cross-contamination from the fish gut contents);
- consumption of animal products (e.g. beef or pork) that have been contaminated with pathogens or chemicals through exposure of animals to wastewater or excreta (e.g. through feeding and drinking).

2.3 Assessment of health risk

Assessing the risk associated with human exposure to hazards associated with waste-fed aquaculture can be carried out through epidemiological studies and by means of quantitative microbial risk assessment (QMRA).

Epidemiological studies aim to assess the health risks associated with the use of wastewater or excreta by comparing the level of disease in the exposed population (which uses wastewater or excreta or consumes products raised or grown with wastewater or excreta) with that in an unexposed or control population. Epidemiological studies can determine either the excess prevalence of infection (as measured by the proportion of infected or seropositive individuals) in an exposed group compared with that in a control group or the excess prevalence or incidence of disease (over a period of time) in an exposed group compared with that in a control group. The difference in disease levels may then be attributed to the practice of using the wastewater/excreta, provided that the two populations compared are similar in all other respects, including socioeconomic status and ethnicity. Potential confounding factors and bias that affect results would need to be addressed in the study by careful selection of the study population groups. In the context of these Guidelines, individuals eating fish or aquatic plants, working (or playing) in or near waste-fed aquacultural ponds or living near such ponds are potentially exposed groups, and those not meeting any of these criteria are control groups.

QMRA can be used to estimate the risk to human health by predicting infection or illness rates given densities of particular pathogens, assumed rates of ingestion and appropriate dose–response models for the exposed population. QMRA provides a technique for estimating the risks from a specific pathogen associated with a specific exposure pathway. It is a sensitive tool that can estimate risks that would be difficult and costly to measure and therefore provides an important complement to epidemiological investigations, which are less sensitive and more difficult to perform. QMRA consists of four steps, which are outlined in Table 2.3. QMRA has not been used specifically to estimate the risks from eating fish or plants grown in waste-fed aquaculture, but QMRAs developed for wastewater use in agriculture and risk assessment models for accumulation of toxic chemicals may give an indication of the level of risk from certain practices.

Table 2.3 Risk assessment paradigm for any human health effect

Step	Aim
1. Hazard identification	To describe acute and chronic human health effects associated with any particular hazard, including pathogens or toxic chemicals
2. Hazard characterization	Dose–response assessment, to characterize the relationship between various doses administered and the incidence of the health effect, including underlying mechanisms and extrapolation from model systems to humans
3. Exposure assessment	To determine the size and nature of the population exposed and the route, amount and duration of the exposure
4. Risk characterization	To integrate the information from exposure, dose–response and hazard identification steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty

Source: Adapted from WHO (2003a).

2.4 Tolerable risk

The management of risk is context specific; there is no universally applicable risk management formula. In setting guidelines for waste-fed aquaculture, it would be logical to ensure that the overall levels of health protection were comparable with those for other water and excreta exposures (e.g. through drinking-water or recreational water contact and through inadequate sanitation). This would require comparison of very different adverse health outcomes, such as cancer, diarrhoea, etc. Significant experience has now been gained in such comparisons, especially using the metric of DALYs (see Box 2.1) (WHO, 2003a).

For carcinogenic chemicals in drinking-water, guideline values have been set at a 10^{-5} upper-bound estimate of risk (WHO, 2004a). This is approximately equivalent to one excess case of cancer per 100 000 of the population ingesting drinking-water that contained the chemical at the guideline concentration over a lifetime. The disease burden associated with this level of risk and adjusted for the severity of the illness is approximately 1×10^{-6} DALY (1 µDALY) (WHO, 2004a). This level of disease burden can be compared with a mild but more frequent illness, such as self-limiting diarrhoea caused by a microbial pathogen. The estimated disease burden associated with mild diarrhoea (e.g. with a case fatality rate of $\sim 1 \times 10^{-5}$) at an annual disease risk of 1 in 1000 (10^{-3}) (~1 in 10 lifetime risk) is also about 1×10^{-6} DALY (1 μDALY) (WHO, 2004a).

2.5 Health-based targets

Health-based targets should be part of overall public health policy, taking into account status and trends and the contribution of waste-fed aquaculture to the transmission of disease (i.e. excreta-related, vector-borne and illnesses related to chemical exposures), both in individual settings and within overall health management. The purpose of setting targets is to mark milestones to guide and chart progress towards a predetermined health goal. To ensure effective health protection and improvement, targets need to be realistic and relevant to local conditions, including sociocultural, economic, environmental, technical and institutional factors (WHO, 2003a). This normally implies periodic review and updating of priorities and targets and, in turn, that norms and standards should be revised to take account of these factors and changes in available information (WHO, 2004a).

A health-based target uses the tolerable risk of disease as a baseline to set specific performance targets that will reduce the risk of disease to meet the health-based target. Exposure to different hazards through waste-fed aquacultural practices or through consumption of contaminated products is associated with a certain level of risk. Barriers that reduce exposures to hazards will reduce health risks. Multiple barriers are better than single barriers, because performance of any one barrier will vary over time, and multiple barriers will better protect against barrier failure, especially during unusual events.

Health-based targets can be specified in terms of combinations of different components or single parameters, including:

- *Health outcome:* as determined by epidemiological studies, public health surveillance or QMRA (DALYs or levels of risk);
- *Wastewater and excreta quality:* e.g. trematode eggs and/or *E. coli* concentrations;
- *Exposure to wastewater and excreta:* e.g. time and type of exposure;
- *Performance:* e.g. a performance target for removal of microbial or chemical contaminants (e.g. a percentage removal of pathogens through a combination of treatment requirements, water quality standards and exposure control techniques; see chapter 4). Performance may be approximated by other parameters: retention time in ponds and different latrine types; turbidity; suspended solids; lack of vector breeding sites or intermediate hosts, etc.
- *Specified technology:* specified treatment process, etc.

For example, a health-based target could be the absence of clonorchiasis due to waste-fed aquaculture in an exposed population. Several options could be used to arrive at this outcome. Option one might consist exclusively of wastewater and excreta treatment to inactivate *Clonorchis sinensis* eggs (see chapters 4 and 5). If wastes could not be treated to achieve this quality target, then option two might include produce restriction — that is, ensuring that fish or plants are thoroughly cooked prior to consumption. Thoroughly cooking fish will inactivate any infective *Clonorchis* metacercariae. Option three could be to process the fish or plants by drying them or marinating them in an acidic solution for a suitable time (see chapter 5) before they were consumed. Each of these options, in theory, could result in the same outcome — the prevention of *Clonorchis* infections in consumers.

2.6 Risk management

After health-based targets have been defined, risk management strategies can be developed. Measures and interventions will be different depending on local aquacultural practices. Performance targets to achieve exposure reductions for aquaculture will vary. For example, it may be determined that a certain reduction in exposure to pathogens is needed to achieve the health-based target for aquaculture. This target could be met by a combination of wastewater/excreta treatment and wastewater/excreta withholding periods (plus exposure prevention for workers and local communities) (see Figure 2.2). Control of vector and intermediate host populations is also an important intervention to reduce transmission risks of vector-borne diseases and trematode infections.

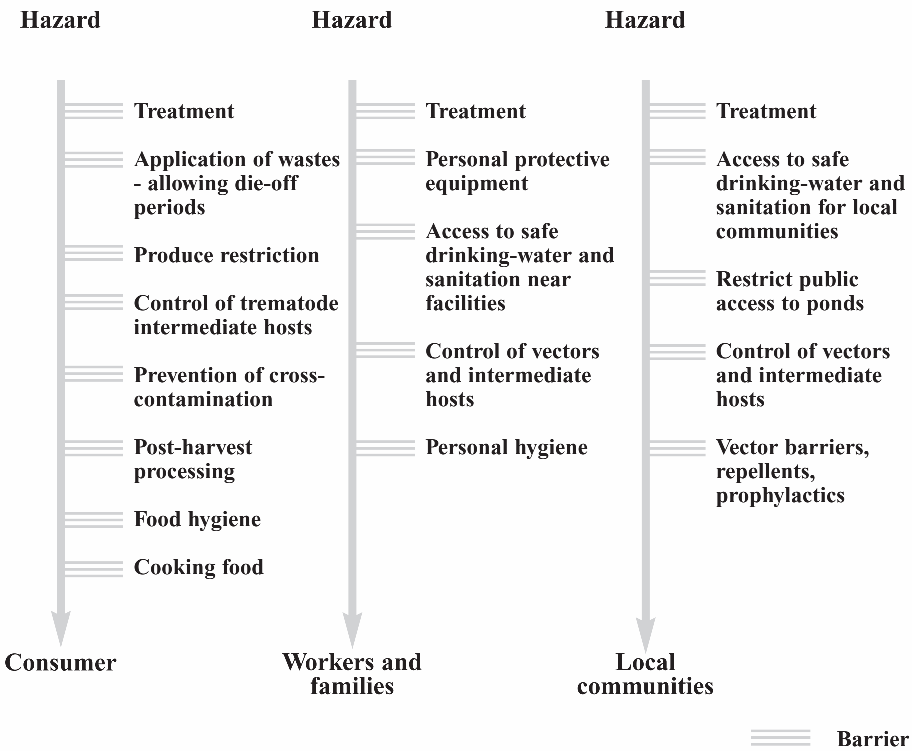

Figure 2.2
Examples of hazard barriers for waste-fed aquaculture

Figure 2.2 shows risk management strategies for wastewater and excreta use in aquaculture to prevent exposures to pathogens and toxic chemicals by constructing multiple barriers (additional strategies are discussed in chapter 5). They may include combinations of the following:

- *Wastewater treatment:* to remove pathogens and toxic chemicals to a level that presents a tolerable risk or that can be combined with other measures to achieve the health-based target;
- *Produce restriction:* growing fish or plants that either are not for direct human consumption or are always processed (cooked) prior to consumption;
- *Application:* using wastewater/excreta application techniques that reduce exposures to workers and contamination of products or allowing adequate periods between waste application and harvest to allow pathogen die-off (e.g. batch flow of wastewater into fish ponds, withholding periods, buffer zones) or depuration to clear fish gut contents prior to processing;
- *Exposure control methods:* limiting public access to ponds, workers wearing protective clothing, cooking food properly prior to consumption, good food hygienic practices to reduce cross-contamination from fish gut contents to other foods during cleaning, good personal hygienic practices such as hand-washing with soap to remove contaminants after contact with wastewater and excreta or products contaminated with them.

Information concerning the efficiency of processes in preventing exposures (e.g. withholding periods and other health protection measures) combined with data on the occurrence of pathogens and chemicals in wastewaters and excreta and water quality targets enable definition of operating conditions that would reasonably be expected to achieve those targets (see chapter 4). Information on process efficiency and pathogen occurrence should take account of steady-state performance and performance during maintenance and periods of unusual load. While the indicator systems required to verify adequate performance may call for the use of laboratory-based analytical measures (e.g. for *E. coli* or trematode egg analysis), the greater overall emphasis should be given to periodic inspection/auditing and to simple measurements that can be rapidly and frequently made and can directly inform management (Bartram, Fewtrell & Stenström, 2001).

2.7 Public health status

Section 2.2 identifies different hazards associated with waste-fed aquaculture. The hazards most likely to cause disease are the excreta-related pathogens (including the trematodes), skin irritants and vector-borne pathogens. Risks from most chemicals (with the possible exception of cyanobacterial toxins contaminating *Spirulina* grown for human nutritional supplements; Gilroy et al., 2000) are thought to be low and would be difficult to associate with exposure through waste-fed aquaculture because of the long exposure times required to cause illnesses in most cases (WHO, 1999). Table 2.4 illustrates examples of mortality and morbidity estimates for some diseases of possible relevance to waste-fed aquaculture.

Table 2.4 Global mortality and DALYs due to diseases of potential relevance to waste-fed aquaculture

Disease	Mortality (deaths/year)	Burden of disease (DALYs/year)	Comments
Diarrhoea	1 798 000	61 966 000	99.8% of deaths occur in developing countries; 90% of deaths occur in children
Schistosomiasis	15 000	1 702 000	Found in 74 countries; 200 million people worldwide are estimated to be infected, 20 million with severe consequences
Foodborne trematode infections	NA	NA	Estimated 40 million infections worldwide; 10% of the world's population thought to be at risk
Lymphatic filariasis	0	5 777 000	Causes high morbidity but no deaths; more than 40% of infected people live in India

NA, not available
Sources: WHO (1995, 2002, 2003b, 2003c, 2004b, 2005b).

2.7.1 Excreta-related diseases

Excreta-related infections (see Table 2.5) are communicable diseases whose causative agents (pathogenic viruses, bacteria, protozoa and helminths) are released from the bodies of infected persons (or animals in some cases) in their excreta (faeces, urine). The causative agents eventually reach other people and enter either via the mouth (e.g. when contaminated crops are eaten) or via the skin (e.g. hookworm infection and schistosomiasis). Of particular concern in aquaculture is the transmission of foodborne trematode parasites, because trematode-associated diseases are associated with high morbidity (see section 2.7.2, including Table 2.7, for further discussion of trematode infections associated with waste-fed aquaculture).

Table 2.5 Excreta-related diseases

Agent	Disease
Bacteria	
Campylobacter jejuni	Gastroenteritis, long-term sequelae (e.g. arthritis)
Escherichia coli	Gastroenteritis
E. coli O157:H7	Bloody diarrhoea, haemolytic uraemic syndrome
Leptospira spp.	Leptospirosis
Salmonella (many serotypes)	Salmonellosis, gastroenteritis, diarrhoea, long-term sequelae (e.g. arthritis)
Salmonella typhi	Typhoid fever
Shigella (several serotypes)	Shigellosis (dysentery), long-term sequelae (e.g. arthritis)
Vibrio cholerae	Cholera
Yersinia enterocolitica	Yersiniosis, gastroenteritis, diarrhoea, long-term sequelae (e.g. arthritis)

Table 2.5 (continued)

Agent	Disease
Helminths	
Ancylostoma duodenale and *Necator americanus* (hookworm)	Hookworm infection
Ascaris lumbricoides (roundworm)	Ascariasis
Clonorchis sinensis (liver fluke)	Clonorchiasis
Diphyllobothrium latum (fish tapeworm)	Diphyllobothriasis
Fasciola hepatica and *F. gigantica* (liver fluke)	Fascioliasis
Fasciolopsis buski (intestinal fluke)	Fasciolopsiasis
Opisthorchis viverrini (liver fluke)	Opisthorchiasis
Paragonimus westermani (lung fluke)	Paragonimiasis
Schistosoma spp. (blood fluke)	Schistosomiasis, bilharzia
Taenia saginata and *T. solium* (tapeworm)	Taeniasis
Trichuris trichuria (whipworm)	Trichuriasis
Protozoa	
Balantidium coli	Balantidiasis (dysentery)
Cryptosporidium parvum	Cryptosporidiosis, diarrhoea, fever
Cyclospora cayetanensis	Persistent diarrhoea
Entamoeba histolytica	Amoebiasis (amoebic dysentery)
Giardia intestinalis	Giardiasis
Viruses	
Adenovirus (many types)	Respiratory disease, eye infections
Astrovirus (many types)	Gastroenteritis
Calicivirus (several types)	Gastroenteritis
Coronavirus	Gastroenteritis
Coxsackievirus A	Herpangina, aseptic meningitis, respiratory illness
Coxsackievirus B	Fever, paralysis, respiratory, heart and kidney disease
Echovirus	Fever, rash, respiratory and heart disease, aseptic meningitis
Enteroviruses (many types)	Gastroenteritis, various
Hepatitis A virus	Infectious hepatitis
Hepatitis E virus	Infectious hepatitis
Norovirus	Gastroenteritis
Parvovirus (several types)	Gastroenteritis
Poliovirus	Paralysis, aseptic meningitis
Reovirus (several types)	Not clearly established
Rotavirus (several types)	Gastroenteritis

Sources: Sagik, Moor & Sorber (1978); Hurst, Benton & Stetler (1989); Edwards (1992); National Research Council (1998).

In many countries, excreta-related infections are common, and excreta and wastewater contain correspondingly high concentrations of pathogens. The failure to properly treat and manage wastewater and excreta worldwide is directly responsible for adverse health and environmental effects. Human excreta have been implicated in the transmission of many infectious diseases, including cholera, typhoid, hepatitis, polio, schistosomiasis and infections by helminths, including a variety of trematodes. Most of these excreta-related illnesses occur in children living in poor countries. Overall, WHO estimates that diarrhoea alone is responsible for 3.2% of all deaths and 4.2% of the overall disease burden expressed in DALYs worldwide (WHO, 2004b).

Diarrhoea or gastrointestinal disease is often used as a proxy for waterborne infectious diseases. Mead et al. (1999) estimated that the average person (including all age groups) in the United States of America suffers from 0.79 episode of acute gastroenteritis (characterized by diarrhoea, vomiting or both) per year. The rates of acute gastroenteritis among adults worldwide are generally within the same order of magnitude (Table 2.6). However, children — especially those living in high-risk situations, where poor hygiene, sanitation and water quality prevail — generally have a higher rate of gastrointestinal illness. Kosek, Bern & Guerrant (2003) found that children under the age of five in developing countries experienced a median of 3.2 episodes of diarrhoea per year.

Table 2.6 Diarrhoeal disease incidence per person per year in 2000, by region and age

Region	Diarrhoeal disease incidence, all ages	Diarrhoeal disease incidence, 0–4 years	Diarrhoeal disease incidence, 5–80+ years
Developed regions	0.2	0.2–1.7	0.1–0.2
Developing regions	0.8–1.3	2.4–5.2	0.4–0.6
World average	0.7	3.7	0.4

Souce: Adapted from Mathers et al. (2002).

2.7.2 Foodborne trematodes and schistosomiasis

Trematodiases are important parasitic diseases in various parts of the world (see Table 2.7). Trematodes have a complex life cycle that involves the passage of eggs into a water body in excreta (usually faeces, but urine for one schistosome species); the eggs then hatch and infect a snail. The parasites develop in the snail and are released into the water, where they infect fish or encyst on aquatic plants. Infection results when the fish or plants with viable encysted trematode metacercariae are ingested raw or without adequate cooking. Schistosomes directly infect humans by penetrating the skin in contact with contaminated water.

Although seldom fatal, trematodiases can cause morbidity and complications leading to death. The major genera of importance for human health are *Clonorchis*, *Opisthorchis*, *Fasciola*, *Fasciolopsis* and *Paragonimus*. Overall, foodborne trematodes are thought to infect 40 million people worldwide, and 10% of the global population is at risk of infection (see Table 2.4) (WHO, 1995). Schistosomiasis affects about 200 million people worldwide, 80% of whom live in sub-Saharan Africa, where direct waste-fed aquaculture seldom occurs but indirect waste-fed aquaculture does occur.

Table 2.7 Examples of major trematode infections potentially associated with waste-fed aquaculture

Trematode infection	Country
Clonorchiasis *Clonorchis sinensis* causes human and animal infections. Distribution within endemic countries is associated with snail hosts, particularly *Parafossarulus manchouricus*. Wild and domestic animals may act as reservoirs of the parasite in addition to humans. Larvae are excreted by the hosts and ingested by freshwater snails. After multiplication, free-swimming larval forms of the parasite (known as cercariae) are released from the snails and penetrate and form metacercarial cysts in fish muscle. They can infect a variety of freshwater fish. After ingestion, *Clonorchis* metacercariae excyst in the small intestine and migrate to the bile duct, where they cause clinical disease. The infection has been implicated in recurrent pyogenic cholangitis, cholangiohepatitis and cholangiocarcinoma (WHO, 1995). The metacercariae can persist in fish muscle for a considerable time — for weeks in dried fish and for a few hours in salted or pickled products — but are killed by adequate cooking.	China, Russian Federation, Republic of Korea, Viet Nam
Opisthorchiasis *Opisthorchis viverrini* and *Opisthorchis felineus* cause opisthorchiasis in humans and many other animal hosts. Snail species (genus *Bithyna*), predominantly found in rice fields in endemic areas, are a common first intermediate host. The pathogenicity, treatment and control of the two *Opisthorchis* species are similar to those of *Clonorchis sinensi*. Although the number of fish species that can act as intermediate fish hosts seems lower compared with that for *C. sinensis*, the risk of opisthorchiasis associated with the consumption of aquacultured versus wild-caught fish remains to be assessed.	*O. viverrini*: Cambodia, Lao People's Democratic republic, Thailand *O. felineus*: Kazakhstan, Russian Federation (Siberia), Ukraine
Fascioliasis Fascioliasis is an infection of the bile ducts caused by *Fasciola hepatica* and *F. gigantica* (liver fluke). Although this parasite primarily infects sheep, cattle and other animals, humans can also serve as hosts. In some areas (parts of Bolivia and Peru), humans have become definitive hosts for this parasite. Eggs are passed from infected humans or other animals into water, where they hatch into miracidia and infect snail intermediate hosts; cercariae are then released from the snails and encyst as metacercariae on aquatic plants. Humans become infected when they eat the contaminated plants raw or partially cooked. In human endemic areas, some of the metacercariae float rather than encyst on plants.T his allows their transmission to humans via drinking-water or by contamination of food or cooking utensils washed in the contaminated water. Symptoms of fascioliasis include fever, abdominal pain, anaemia, dizziness, blood in urine, bronchial asthma and severe liver damage. Infection in children is usually accompanied by severe clinical manifestations and can be fatal. The importance of waste-fed aquaculture in the transmission of *F. hepatica* and *F. gigantica* remains to be assessed.	Temperate areas of Africa, Asia, Australia, Europe and Central/South America where ruminants are raised

Table 2.7 (continued)

Trematode infection	Country
Fasciolopsiasis Fasciolopsiasis is an intestinal infection caused by the parasite *Fasciolopsis buski*, which has a life cycle similar to that of other trematode parasites requiring a snail intermediate host. Cercariae are released from the snail and encyst on plants as infective metacercariae. Humans are infected when they eat the plants raw or partially cooked. Most infections with *F. buski* are light and asymptomatic, but heavier infections may exhibit diarrhoea, epigastric pains, nausea, vomiting and oedema of the face, abdominal wall or lower limbs. Severe infections in children can cause death.	Kazakhstan, Lao People's Democratic Republic, Poland, Russian Federation, Thailand, Turkey, Ukraine, Viet Nam
Schistosomiasis Schistosomiasis is an infection by blood flukes of the genus *Schistosoma*, which harbour in the venous systems draining the urine bladder or intestinal tract. The disease is caused by *Schistosoma haematobium*, *S. mansoni*, *S. japonicum*, *S. intercalatum* and *S. mekongi*. Similar to other trematode parasites, the life cycle requires replication in a snail intermediate host. Snails become infected by a larval stage of the parasite, known as a miracidium, which develops from eggs passed out in the urine or faeces of infected people. Cercariae released by the snails penetrate the skin of people in the water. Light infections may be asymptomatic, but heavier infections may lead to enlargement of the spleen or liver, blood loss and bladder cancer, depending on the species.	Endemic in 74 countries; most infections occur in sub-Saharan Africa, but it is also present in the Eastern Mediterranean, parts of Asia and the Americas

Sources: Feachem et al. (1983); Wei (1984); Edwards (1992); Chen et al. (1994); WHO (1995, 1999); De et al. (2003); Huss & Ben Embarek (2003); TDR (2004).

A review of foodborne trematodiases by Keiser & Utzinger (2005) indicated that clonorchiasis infections tripled in China over a 10-year period from 1995 to 2004. Keiser & Utzinger (2005) estimate that 15 million Chinese were infected with *Clonorchis sinensis* in 2004. The increase in foodborne trematode infections is thought to be associated with the exponential growth that occurred in the aquacultural industry during the same time period. Although growth in intentional waste-fed aquaculture during this period in all probability declined, the incidental use of wastewater- and excreta-contaminated water for aquaculture likely contributed to the increase in foodborne trematode infections.

2.7.3 Vector-borne diseases

Vector-borne diseases such as malaria and filariasis, although not specific to the use of wastewater and excreta, should be considered in endemic areas. Prior to the development of water resource management projects (including waste-fed aquaculture), a health impact assessment should be conducted (see Annex 3) (WHO, 2000). As Table 2.8 indicates, activities related to some aquacultural activities could lead to an increase of the population of disease vectors. However, only certain mosquito species can breed in organically polluted water, especially the vectors of filariasis (e.g. *Culex quinquefasciatus*). Additionally, mosquito larvae are often eaten by fish but may survive if emergent vegetation is present where the larvae can be protected from the fish. Algae or plants that cover the water surface may block larvae from breathing air at the surface. A variety of measures to reduce the breeding of vectors in wastewater and excreta use programmes are described in chapter 4.

Table 2.8 Vector-borne diseases of possible relevance to waste-fed aquaculture

Disease	Vector	Relative risk of waste-fed aquaculture	Comments
Dengue	*Aedes aegypti*	Low	Vectors breed in standing water (e.g. tires, cans, bottles, etc.). Present in South-east Asia but not China.
Filariasis	*Culex quinquefasciatus* *Anopheles* spp. *Mansonia* spp.	Medium	*Culex* vectors breed in organically polluted water. Endemic in most countries where waste-fed aquaculture is practised.
Japanese encephalitis	*Culex* spp.	Low	Vectors breed in flooded rice fields. Endemic in many countries where waste-fed aquaculture is practised.
Malaria	*Anopheles* spp.	Low	Vectors breed in uncontaminated water; 90% of malaria cases occur in Africa, where waste-fed aquaculture is not common. *Anopheles* breeding has been reported from serial waste stabilization ponds.

Sources: WHO (1988a); TDR (2004).

2.7.4 Measuring public health status

The impacts of risk management actions can be measured if the baseline health status of the affected population is known or can be approximated.

Similarly, tolerable risk and health-based targets can be set with some knowledge of the types of diseases that may result from the use of wastewater or excreta in the local setting and their incidence and prevalence.

It is important to understand the role that waste-fed aquaculture plays in the transmission of water-related disease in a community. For example, if aquacultural ponds are the sole source of fish consumed in a community and the fish have been infected with trematode metacercariae, then there is a high probability that consumption of raw or inadequately prepared fish may be responsible for much of the trematode infections in a community. Therefore, it would make sense to introduce or require health protection measures such as wastewater/excreta treatment before the wastewater/excreta is used at the facility. However, if the use of wastewater or excreta in aquaculture contributes to only a small percentage of the waterborne illness in a specific community, then investing large amounts of money to reduce that small contribution from waste-fed aquaculture is not cost-effective.

Initial information on background levels of disease in the population might be based on information collected from local health care facilities, public health surveillance, laboratory analysis, epidemiological studies or specific research conducted in a similar or selected community. Seasonal fluctuations in disease incidence, such as during the wet season or cold season (e.g. rotavirus infections peak in the cold season), should be considered. In evaluating the use of wastewater and excreta in a certain area, it would be important to establish baseline disease conditions and then to evaluate disease trends (i.e. whether disease incidence was decreasing or increasing). High background disease levels (e.g. trematode infections) or disease outbreaks (e.g. typhoid) might indicate that risk management procedures were not being implemented adequately and would need to be strengthened or reconsidered.

3
ASSESSMENT OF HEALTH RISK

The use of wastewater and excreta in aquaculture has both negative and positive impacts on public health. Because the intentional use of wastewater and excreta in aquaculture is not widespread, the information on health impacts that is available is fairly limited. The available information is summarized in this chapter.

3.1 Microbial evidence

Microbial evidence can be used to indicate that a hazard exists in the environment. Microbial analysis is an important process for providing data for the assessment of risk. Site-specific information concerning the types and numbers of different pathogens in wastewater and excreta and from waste-fed ponds, fish and produce can be used to quantify risk.

Untreated wastewater and excreta contain a variety of excreted organisms, including pathogens, with types and numbers that vary depending upon the background levels of disease in the population. Table 3.1 shows ranges of concentrations for different excreted organisms that may be found in wastewater and excreta. Because pathogen types and concentrations can vary over a large range, it is helpful to collect local data to evaluate risk and develop risk management strategies. Excreted organisms are removed or inactivated by many wastewater/excreta treatment processes. Removal efficiencies for different types of organisms are further discussed in chapter 5.

Table 3.1 Excreted organism concentrations in wastewater and faeces

Organism	Numbers in wastewater (per litre)	Numbers in faeces[a] (per gram)
Bacteria		
Thermotolerant coliforms	10^8–10^{10}	10^5–10^{11}
Campylobacter jejuni	10–10^4	10^6–10^9
Salmonella spp.	1–10^5	10^4–10^8
Shigella spp.	10–10^4	10^7
Vibrio cholerae	10^2–10^5	10^7
Helminths		
Ascaris lumbricoides	1–10^3	1–10^5
Schistosoma mansoni	ND	1–10^3
Clonorchis sinensis	ND	10^2
Protozoa		
Cryptosporidium parvum	1–10^4	10^7–10^8
Entamoeba histolytica	1–10^2	10^5–10^8
Giardia intestinalis	10^2–10^5	10^5–10^8
Viruses		
Enteric viruses	10^5–10^6	10^4–10^9
Rotavirus	10^2–10^5	10^7–10^{11}

ND, no data

Sources: Feachem et al. (1983); Strauss (1985); Mara & Silva (1986); Oragui et al. (1987); Yates & Gerba (1998); WHO (2002).

[a] Estimated pathogen numbers for infected individuals.

Pathogens are rarely measured directly in wastewater or excreta, because their concentrations vary and analytical procedures are often difficult or expensive to perform. Instead, indicators of faecal contamination, such as *E. coli* and thermotolerant coliforms, have been used as proxies for pathogens with similar properties that may be present in wastewater or excreta. Their presence in water usually (but not always) is related proportionately to the amount of faecal contamination present. For wastewater and excreta, indicators can show how much treatment or natural purification has taken place and thus give a rough estimate of the risk associated with their use. Standardized analytical procedures have been developed for *E. coli* and thermotolerant coliforms and are widely used.

Unfortunately, there is no perfect indicator organism for wastewater and excreta, especially for non-faecal bacterial pathogens, trematodes, viruses and protozoa, as the concentrations of faecal indicator bacteria often do not correspond to concentrations of these organisms. For further discussion of the advantages and disadvantages of different faecal indicators, see WHO (2004a) and Jiménez (2003).

Many of the excreted pathogens can survive in the environment long enough to be transmitted to humans through contact with the excreta or wastewater or consumption of contaminated products grown in the waste-fed ponds (see Table 3.2). Pathogen die-off in fish ponds may be more similar to that observed in the maturation ponds of waste stabilization ponds (i.e. more rapid) than to that observed in other surface waters, because both types of ponds have similar properties (Edwards et al., 1984; Edwards, Polprasert & Wee, 1987; Edwards, 1992). In general, pathogen survival is by and large inversely related to water temperature. If wastewater or excreta are added continuously to a pond or surface waters where aquaculture occurs, however, then there is a high likelihood that viable pathogens will be present in the water constantly.

Pathogens that are concentrated in the fish gut or that infect the fish tissues (e.g. *Clonorchis*, *Opistorchis*) may survive (and in some cases reproduce) until the fish is harvested and eaten (Buras, 1993; WHO, 1995). Trematode metacercariae encysted (e.g. *Fasciola hepatica*) on plants may remain infective for many months and may even survive the winter in temperate climates (Feachem et al., 1983).

Trematodes can multiply in ponds only if the appropriate snail intermediate host is also present, as that part of the trematode life cycle is snail host species specific. Table 2.7 in section 2.7.2 provides information on the main types of trematodes that are of concern to waste-fed aquaculture and the countries where the diseases are endemic.

3.1.1 Microbial pond water quality

Studies of the association between microbial pond water quality and the quality of fish tissues have been conducted in both laboratory environments and waste-fed aquacultural ponds. Fish and plants passively accumulate microbial contaminants on their surfaces. Fish concentrate bacteria, viruses and protozoa found in the water in their guts. In waste-fed aquaculture, they may concentrate microbes pathogenic to humans because they are present in the water. Rarely do pathogens (excluding trematodes) penetrate into the edible fish flesh (muscle). However, if fish are stressed — for example, by overcrowding, poor water quality or other conditions — then bacteria and viruses (there are no data for protozoa) may be able to penetrate into the edible flesh. Research has been conducted to identify a bacterial concentration threshold beyond which muscle penetration occurs (Edwards, 1984; Buras, Duek & Niv, 1985; Buras et al., 1987; Buras, 1990; Fattal, Doan & Tchorsh, 1992). The results are contradictory, however, and seem to relate more to cultural conditions that lead to stressed fish than to the microbial water quality.

Table 3.2 Survival of various organisms in selected environmental media at 20–30 °C

Organism	Survival times (days)	
	Fresh water and sewage	Plants
Viruses		
Enteroviruses[a]	<120 but usually <50	<60 but usually <15
Bacteria		
Thermotolerant coliforms	<60 but usually <30	<30 but usually <15
Salmonella spp.	<60 but usually <30	<30 but usually <15
Shigella spp.	<30 but usually <10	<10 but usually <5
Vibrio cholerae	ND	<5 but usually <2
Protozoa		
Entamoeba histolytica cysts	<30 but usually <15	<10 but usually <2
Cryptosporidium oocysts	<180 but usually <70	<3 but usually <2
Helminths		
Ascaris eggs	Years	<60 but usually <30
Tapeworm eggs	Many months	<60 but usually <30
Trematode eggs[b]	<30	<300[c]

ND, no data available

Sources: Feachem et al. (1983); Strauss (1985); Robertson, Campbell & Smith (1992); Jenkins et al. (2002); Warnes & Keevil (2003).

[a] Poliovirus, echovirus and coxsackievirus.

[b] In these temperature ranges, in well oxygenated water, trematode eggs may hatch quickly into miracidia, which will die within a few hours if they do not find and infect a suitable snail intermediate host. In waters that are colder or anaerobic, trematode eggs may survive for many months.

[c] Encysted metacercariae of *Fasciola hepatica* can remain infective for many months on aquatic plants. In temperate environments, they can survive the winter on plants. Metacercariae in fish flesh can remain infective for the life of the fish.

Methods for detecting trematode eggs in water need to be standardized. Additionally, in warm oxygenated water, trematode eggs may develop rapidly into miracidia. Miracidia need to find a suitable snail host to infect within a few hours or they die (Feachem et al., 1983). These factors can make it difficult to monitor water for trematode parasites. It may be more relevant to identify suitable snail intermediate hosts and the presence of encysted metacercariae in fish flesh or on plants in endemic areas.

Microbial water quality indicators (e.g. *E. coli* or thermotolerant coliforms) are more likely to provide information on health risks incurred by heavy contact with the water (e.g. by workers or other groups with access to the aquacultural facilities; see section 3.2) than to provide information on health risks posed to fish consumers.

3.1.2 Evidence of product contamination: Fish

Pathogenic bacteria, protozoa and viruses are rarely found in edible fish flesh but are almost always found in the digestive tract and the intraperitoneal fluid of the fish at higher than ambient concentrations. They may also be recovered from the skin surface of fish (Edwards, 1992). The microbial flora of a fish seems to reflect the microbial quality of the water from which it is taken (Buras et al., 1987). Limited evidence suggests that some types of bacteria may be able to reproduce in fish digestive tracts.

Salmonella and *E. coli* have been found to survive and multiply in the guts of tilapia and carp grown in waste-fed ponds (Buras, 1993; Fattal et al., 1993). A study in Viet Nam of numbers of presumptive thermotolerant coliforms in fish raised in wastewater-fed ponds (10^6 per 100 ml) and non-wastewater-fed ponds (10^4 per 100 ml) showed no significant difference in presumptive thermotolerant coliform numbers in gut content from the two ponds: common carp (5.3 and 6.2 log geometric means, respectively), Nile tilapia (5.2 and 4.6 log geometric means, respectively) and silver carp (both 4.7 log geometric mean) (Lan et al., in press).

In cases where bacteria and viruses have been detected in edible flesh from fish raised in waste-fed aquacultural facilities, the concentrations are nearly always extremely low. For example, a study in Viet Nam of the microbial quality of fish muscle from waste-fed ponds (10^6 presumptive thermotolerant coliforms per 100 ml) and non-waste-fed ponds (10^4 presumptive thermotolerant coliforms per 100 ml) found zero presumptive thermotolerant coliforms per gram of muscle in the majority of fish, with only a few samples containing 2–3 presumptive thermotolerant coliforms per gram of muscle tissue (Lan et al., in press). Similar findings have been reported by Fattal, Doan & Tchorsh (1992) and Edwards (1984).

Studies of fish flesh microbial quality (bacterial indicators) taken at the point of harvest from the waste-fed aquacultural facility often show low levels of bacterial contamination. However, when waste-fed fish are sampled in the market, they often show much higher levels of bacterial contamination in their edible flesh. This indicates that much of the bacterial contamination of fish flesh occurs during post-harvest cleaning due to cross-contamination with the gut contents or unhygienic facilities.

A study in Viet Nam of the microbial quality of fish muscle from waste-fed ponds (10^6 presumptive thermotolerant coliforms) and non-waste-fed ponds (10^4 presumptive thermotolerant coliforms) showed that fish sampled at the point of harvest had nearly identical levels of bacterial contamination; most samples contained zero presumptive thermotolerant coliforms per gram of muscle tissue, but a few contained 2–3 presumptive thermotolerant coliforms per gram of muscle tissue. Fish from the two sites were harvested and transported alive to a nearby market. After the fish were processed at the market by the vendors, they were purchased and sampled. The edible flesh showed contamination levels of between 800 and 17 000 and between 2800 and 19 000 presumptive thermotolerant coliforms per gram of muscle tissue for the waste-fed and non-waste-fed fish, respectively (there was no significant difference between the two groups). For both types of fish, the contamination level from the point of harvest to the point of sale increased exponentially (Lan et al., in press).

The infective cercariae of trematode parasites (e.g. *Opisthorchis viverrini* and *Clonorchis sinensis*) can penetrate into fish flesh from the water (see Table 2.7 in section 2.7.2). They encyst in fish flesh and can be detected by laboratory analysis. Methods for detecting encysted metacercariae are described in WHO (1995). Many of the fish grown in waste-fed aquaculture can serve as hosts for trematode parasites — especially *Clonorchis*. A study conducted in Viet Nam found 45% of the fish grown in a traditional aquacultural pond were infected with *Clonorchis* metacercariae (Son et al., 1995).

3.1.3 Evidence of product contamination: Plants

Evidence suggests that plants grown in waste-fed ponds can passively accumulate parasites, bacteria and viruses on their surfaces. Infective metacercariae of two types of trematode parasite (i.e. *Fasciola hepatica*, *Fasciolopsis buski*) encyst on water plants. For example, *Fasciola* has been identified on watercress plants, and *Fasciolopsis* has been identified on water caltrop and water chestnut (WHO, 1995). Other aquatic plants harvested and/or cultured for direct human consumption may also be contaminated, such as the widely grown water spinach and water mimosa. Historical descriptive studies carried out in China where nightsoil was added directly to fish ponds indicated that plants grown for human consumption in waste-fed fish ponds had both the snail intermediate host for trematodes and large numbers of *Fasciolopsis buski* cysts on them (Barlow, 1925).

Regarding the use of duckweed as feed, Edwards et al. (1984) found that the level of thermotolerant coliforms on the surface of duckweed was 100 times higher than the concentration in septage-fed fish ponds (trial 1) and in ponds fed with the effluent from a pour-flush water-sealed latrine with a 30-day retention time (trial 2) (Edwards, Polprasert & Wee, 1987). Microbial analyses of fish organs revealed relatively high thermotolerant coliform numbers in guts of fish, with means of 7.9×10^5 and 1.8×10^5 MPN/100 g in trials 1 and 2, respectively. Heterotrophic plate counts in fish muscle were low, 3.5 and 3.0 CFU/g in trials 1 and 2, respectively.

3.2 Epidemiological evidence

Very few epidemiological studies have been conducted on the use of wastewater and excreta in aquaculture. One study has been conducted on skin diseases associated with contact with wastewater/excreta during aquacultural activities, and a single study in Indonesia has investigated the direct health outcomes associated with the consumption of fish or plants grown in waste-fed aquaculture (Blumenthal et al., 1991–1992; van der Hoek et al., 2005). No studies seem to have been conducted on the association between waste-fed aquaculture and risks of human infections by fish- and plant-borne trematodes.

3.2.1 Skin diseases

Research conducted in Phnom Penh, Cambodia, indicated that there may be an association between exposure to wastewater and skin problems such as contact dermatitis (eczema) (van der Hoek et al., 2005). In a survey of households engaged in the cultivation of aquatic vegetables in a lake heavily contaminated by untreated sewage, 22% of the people living in the households reported skin problems. In a survey of similar households living around a lake with no wastewater inputs, only 1% of the people reported skin problems. Skin problems were most likely to be reported on the hands (56%), feet (36%) and legs (34%). The cause of the skin problems was not determined, but it was likely due to a mixture of agents (i.e. both chemical and biological) in the wastewater. Additional studies are needed on skin problems caused by occupational exposure to wastewater.

3.2.2 Product consumption and other exposures

The use of human excreta in aquaculture occurs in parts of West Java, Indonesia, through the use of overhanging fish pond latrines. The ponds are small and used mostly for the domestic supply of fish. Blumenthal et al. (1991–1992) conducted a cross-sectional study of the risk of diarrhoeal disease associated with the use of excreta in exposed populations (total number of study households was 1961, which all had children under the age of five years) (Blumenthal et al., 2000). Exposure to fish pond water was through domestic exposure (through washing or bathing), recreational exposure (through playing or swimming) or consumer exposure (through eating fish raised in fish ponds). Furthermore, people experienced defecation exposure (from use of fish pond latrines for defecation). Three groups (domestic exposure, recreational exposure and defecation exposure) were compared (with variations on exposures except for fish consumption, which they all shared). The geometric mean of thermotolerant coliforms in the pond water was 3.9×10^4/100 ml, with numbers of thermotolerant coliforms ranging from 10^2 to 10^5 CFU/100 ml. When the risk related to consumption of fish was explored separately in the three study areas, there was no association between exposure and diarrhoeal disease in individuals over five years of age. In children under five years, domestic and recreational exposures were associated with a significant increase in diarrhoeal disease (adjusted odds ratio [OR] = 1.65, 95% confidence interval [CI] = 1.13–2.41 for domestic exposure; and adjusted OR = 1.89, 95% CI = 1.14–3.13, for recreational exposure). Moreover, consumption of fish raised in ponds with fish pond latrines was associated with an increase in diarrhoeal disease (not significant at the 95% confidence level) (OR = 1.45; 95% CI = 0.97–2.17). There was some evidence of a greater risk of diarrhoea associated with fish consumption in the control group (OR = 2.35; 95% CI = 1.01–5.29) compared to the exposed group (OR = 1.09; 95% CI = 0.61–1.95), a 1.5-fold increase in the semi-exposed area (not statistically significant) and no increase in the exposed area (Blumenthal et al., 2000).

This study indicated that recreational and domestic contact with water from excreta-fed fish ponds with a mean quality of 3.9×10^4 thermotolerant coliforms per 100 ml can cause an excess risk of diarrhoea in exposed children under five years of age. Consumption of fish from such ponds can be a risk to persons living in areas with no ponds and with less exposure to contamination (Blumenthal et al., 2000). More studies are needed to confirm the findings of this study.

While there is overwhelming evidence for the transmission of intestinal helminths (*Trichuris* spp., *Ascaris* spp. and hookworm) through wastewater use in agriculture, there is very little evidence about the transmission of these parasites through waste-fed aquaculture. Research is needed on risks of helminth infections associated with waste-fed aquaculture, including on survival and human infectivity of helminth eggs when exposed to aquatic wastewater environments (e.g. the ability of hookworm larvae to penetrate skin).

Fattal et al. (1981) conducted a retrospective review of clinical records over a four-year period that indicated that kibbutzim (farming cooperatives) using wastewater effluents in fish ponds had higher rates of clinical enteric disease and laboratory-confirmed cases of salmonellosis than non-effluent-using kibbutzim (Blum & Feachem, 1985).

No epidemiological studies are available on risks of infections by plant- and fish-borne trematodes associated with consumption of produce grown in waste-fed aquaculture. Also, no studies are available on the occurrence and density of trematode metacercariae in waste-fed plants and fish compared with non-waste-fed plants and fish, including wild-caught fish. Epidemiological studies are therefore urgently needed that take into account all relevant risk factors for transmission of the trematode parasites, including the snail intermediate host; role of animal reservoir hosts; and the human host.

3.3 Chemicals

In many areas, municipal wastewater and industrial wastes are discharged into the same drains/sewers. This practice may add toxic chemicals such as heavy metals and chlorinated hydrocarbons to the wastewater. To minimize adverse health and environmental effects from these components, industrial wastes should be adequately pretreated to remove these chemicals or should be treated separately from municipal wastewater and excreta. Wastewater used for aquaculture should not contain significant concentrations of toxic chemicals.

The chemistry and fate of toxic chemicals such as heavy metals and chlorinated hydrocarbons in the aquatic environment are complex. However, concentrations of heavy metals reported in fish raised in aquaculture do not usually exceed levels recommended by the Codex Alimentarius Commission, even in fish harvested from highly polluted water with high metal concentrations (WHO, 1999). This also applies to fish raised in effluents of wastewater stabilization ponds in Egypt (Easa et al., 1995; Shereif & Mancy, 1995), Hong Kong (Sin, 1987) and Peru (UNEP, 2002).

Most heavy metals are precipitated as insoluble sulfides or hydrated oxides in the anaerobic conditions of raw sewage, and further reduction in concentration takes place in the alkaline conditions of wastewater-fed ponds, as metal solubility decreases with increasing pH. Furthermore, metals tend to precipitate in anaerobic fish pond sediments. Although fish readily absorb metals from the water through their gills and from food in their gut, they regulate the concentrations of inorganic heavy metal compounds in muscle tissue. Mercury in the form of methyl mercury, however, is poorly regulated by fish. Generally, long-lived, carnivorous fish bioaccumulate mercury to higher concentrations than relatively young and small fish feeding at low levels of the food-chain.

A study of vegetables and fish from markets in the Kolkata metropolitan area recommended considering the total daily intake of metals from all sources if risks were to be assessed (Biswas & Santra, 2000). Concentrations of cadmium, chromium and lead in fish and vegetables grown in wastewater were much higher than concentrations of these chemicals in crops grown without wastewater. The concentrations were still below Codex Alimentarius Commission standards, however, and were not thought to be associated with negative health impacts.

A study of the accumulation of toxic metals in water spinach grown in untreated mixed urban and industrial wastewater from the city of Hanoi, Viet Nam, found that the concentrations of cadmium and lead in water spinach did not exceed the Codex Alimentarius Commission standards for leafy vegetables, at 0.2 and 0.3 μg/g fresh weight, respectively. Although the concentration of arsenic in water spinach was higher than concentrations of cadmium and lead, it was concluded, based on the Codex Alimentarius Commission standards, that there was no immediate risk to health from eating the water spinach (Jørgensen, 2005).

There are insufficient data to provide a general picture of contamination by chlorinated hydrocarbons, the group of chemicals of most concern to environmentalists and public health officials, in aquacultural produce, because most measurements derive from measurements of wild-caught fish or fish not raised in wastewater/excreta (WHO, 1999). Wastewater is not specifically associated with agricultural chemicals, and fish raised in wastewater usually show only low concentrations of chlorinated insecticides in their tissues (WHO, 1999; Zhou, Cheung & Wong, 1999; UNEP, 2002). The production of polychlorinated biphenyls (PCBs) has now been banned in most developed countries. PCBs were reported at concentrations within Codex Alimentarius Commission acceptable limits in fish raised in wastewater-fed ponds in Egypt (Easa et al., 1995) and Peru (UNEP, 2002). Dioxins and furans are not manufactured but generated as products of combustion or as by-products in the production of other chlorinated chemicals and can therefore be present in wastewater. The qualitative estimate of risk from persistent hydrocarbons in wastewater-fed aquaculture has been judged to be low (WHO, 1999).

Excessive nutrients (primarily nitrogen and phosphorus) in wastewater, sludge and excreta or human-made fertilizers may contaminate surface waters and cause eutrophication. Eutrophication of freshwater sources may create environmental conditions that favour the growth of potentially toxin-producing cyanobacteria. Toxins produced by cyanobacteria can cause gastroenteritis, liver damage, nervous system impairment and skin irritation. Chronic exposure to cyanobacterial toxins has been associated with liver cancer in animals and may cause similar effects in humans (Chorus & Bartram, 1999). Exposure to these toxins has usually been through contaminated drinking-water or recreational contact with the water. However, it is also possible that pond workers and consumers of contaminated freshwater fish might be exposed to these toxins (Chorus & Bartram, 1999).

Experimental work with filter-feeding tilapia and silver carp show that these species avoid ingesting phytoplankton when toxic cells are present (Beveridge et al., 1993; Keshavanath et al., 1994). Prolonged exposure to high concentrations of free microcystins in the water column, such as may occur at the end of a plankton bloom, may lead to the accumulation of these compounds in the livers of freshwater fish (Codd & Bell, 1995). Overall, the balance of evidence suggests that these toxins do not present a significant health threat to consumers of waste-fed fish (WHO, 1999). However, certain species of blue-green algae (*Spirulina*) have been cultivated as nutritional supplements. In some areas where these algae are cultivated, toxin-producing cyanobacteria may also be present (Chorus & Bartram, 1999). Gilroy et al. (2000) found levels of cyanobacterial toxins (microcystins) exceeding 1 µg/g in 72% of the supplement samples tested. This level of microcystin could lead to exposures exceeding the total daily intake for this substance if a 60-kg person consumed more than 2.4 g of the supplement in a day (assuming there were no other contributions from other food or water sources) (WHO, 2004a). Further research is needed to determine if there are adverse health effects associated with the consumption of contaminated blue-green algal supplements.

3.4 Health benefits

The use of wastewater and excreta in aquaculture may lead to better nutrition and improved household food security. For many poor people, the nutritional benefits derived from waste-fed aquaculture may be substantial. Additionally, if households can sell the products they raise, then indirect health benefits may also arise.

The FAO estimates that approximately 1 billion people rely on fish as their main source of animal protein. One fifth of the world's population gets at least 20% of their animal protein from fish. In 34 countries, many of them less industrialized, fish provides more than 50% of the animal protein (FAO, 2000). People who practise small-scale, household-level aquaculture are more likely to rely on wastewater and excreta as sources of fertilizer for their ponds.

Fish are highly nutritious (Randall, Bolis & Agradi, 1990; MAFF, 1995). They are a valuable source of protein of similar quality to that of meat and milk, containing essential amino acids in relatively high concentrations. Fish production through aquaculture provides significant contributions to animal protein supplies in many rural areas. In some regions, freshwater fish represent an essential, often irreplaceable, source of high-quality and cheap animal protein crucial to the balance of diets in marginally food-secure communities. Fish produced with wastewater and excreta are often small and eaten whole, thus providing important sources of both protein and minerals for poor and subsistence communities.

While protein is important for body growth, polyunsaturated fatty acids are important for maintaining healthy cardiovascular and immune systems and are essential for brain development (Randall, Bolis & Agradi, 1990; Crawford, 2002). Essential fatty acids cannot be synthesized by animals, including fish and humans, and therefore must be included in the diet. They originate in phytoplankton and are transmitted with high efficiency through the food-chain, either directly or through zooplankton to fish. Fish are the richest source of omega-3 polyunsaturated fatty acids in nature. The fat content of fish varies with species and diet, but fish are low in cholesterol and saturated fats and are high in essential polyunsaturated fatty acids. Carp (Steffens & Wirth, 1997) and tilapia (Karapanagiotidis et al., 2002) that feed in plankton-based food webs predominating in waste-fed fish ponds have considerable contents of polyunsaturated fatty acids.

Fish are also rich in fat-soluble vitamins A and D and the water-soluble vitamin B_{12} and are a good source of minerals, such as calcium, iodine, iron, phosphorus and potassium. Trace elements abundant in fish are cobalt, copper, manganese, molybdenum, selenium and zinc. Small fish eaten whole are a particularly good source of calcium and vitamin A (Thilsted, Roos & Hassan, 1997). Calcium is particularly important for pregnant and lactating women and for infants, and calcium absorption from small fish is as good as from milk. Vitamin A is important in preventing severe eye lesions (xerophthalmia) and complete blindness (keratomalacia).

In addition to fish, a number of aquatic plants are grown in wastewater. The culture of such plants, such as water spinach, provides significant incomes and makes up an important part of the diet for consumers in several South-east Asian countries. Aquatic plants are eaten raw or cooked as green vegetables. Besides being high in protein, with fresh plants of water spinach containing protein at levels varying from 1.5% to 1.6%, they are a good source of minerals, especially iron, and vitamins A, C and E (NAS, 1976).

The ability of waste-fed aquaculture to improve nutrition, especially for children, is very important for maintaining the overall health of individuals and communities. Malnutrition is estimated to play a significant role in the deaths of 50% of all children in developing countries (10.4 million children under the age of five die per year) (Rice et al., 2000; WHO, 2000a). Malnutrition affects approximately 800 million people (20% of all people) in the developing world (WHO, 2000a). Protein–energy malnutrition is the most lethal form of malnutrition. Infants and young children are most susceptible to protein–energy malnutrition-related growth impairment because of their high energy and protein needs and their vulnerability to infection. Poorly nourished children suffer up to 160 days of illness each year. Protein–energy malnutrition affects 25% of children worldwide: 150 million are underweight, and 182 million are stunted (WHO, 2000a). Malnutrition may also have long-term effects on the health and social development of a community. Malnutrition leads to both stunted physical growth and retarded cognitive development. For example, Berkman et al. (2002) found that children aged nine who had suffered severe stunting in the second year of life scored 10 points less on a standardized intelligence test than children who did not exhibit severe stunting at the age of two.

4 HEALTH-BASED TARGETS

The development of health-based targets is based on the benchmark of tolerable risk. Setting a nationally appropriate tolerable risk is discussed in chapter 2. Because the risks associated with waste-fed aquaculture are not well characterized or quantified, it is more difficult to set a meaningful tolerable risk for waste-fed aquaculture. However, different health-based targets can be developed based on the prevention of a particular disease outcome (e.g. clonorchiasis transmission) from waste-fed aquaculture. A health-based target would then be achieved through combinations of different health protection measures that would lead to this outcome — for example, wastewater/excreta treatment, produce restriction, post-harvest fish processing (drying, salting, pickling) and/or cooking fish before consumption.

For each exposure route (e.g. consumption, contact and vector transmission), a different health-based target is developed based on a relevant health outcome. This is important, because health outcomes differ by exposure route, as do health protection measures. For example, wastewater and excreta treatment may be effective in reducing diseases related to food consumption or contact with contaminated water, but will do nothing to prevent vector-borne disease transmission. Similarly, hygienic fish processing may reduce cross-contamination with bacteria and viruses but will not reduce the risk associated with the presence of encysted trematode metacercariae.

Health-based targets to protect product consumers, farmers and local communities are derived and presented in this chapter. More information on health protection measures is presented in chapter 5.

4.1 Protection of product consumers

The primary risks to product consumers are associated with trematode parasites where they are endemic; other excreta-related pathogens in the gut contents or on the surfaces of fish or plants; and toxic chemicals in the fish flesh or edible plant parts. The consumption of raw or inadequately cooked fish or plants will always be associated with a higher risk of infectious disease transmission but will not impact the risks from chemical contaminants. A balance of evidence approach was used to develop health-based targets for the use of wastewater and excreta in fish and plant aquaculture. Health-based targets for each hazard associated with product consumption are described below. Verification monitoring parameters are described for each category.

4.1.1 Trematodes

As discussed in chapters 2 and 3, a variety of foodborne trematode parasites can be transmitted through the consumption of raw or inadequately cooked fish or plants. Infection with these parasites can cause significant morbidity and, more rarely, death — especially in vulnerable groups such as children. Trematodes can survive in the host for several years or longer (WHO, 1995). Therefore, a suitable health-based target is the prevention of all foodborne trematode infections due to the consumption of fish or plants produced in waste-fed aquaculture. This can be achieved by a combination of different health protection measures, as presented in Figure 2.2, including wastewater and excreta treatment, controlling intermediate host populations, food inspection, certain food processing techniques and, most importantly, cooking food thoroughly prior to consumption.

Wastewater treatment and excreta treatment to inactivate trematode eggs are important interventions but may not protect against trematode egg contamination originating from infected animals in the watershed. Even the presence of one undetected viable egg can lead to high percentages of fish or plants containing infective metacercariae because of the large asexual multiplication of parasites that occurs in the snail intermediate hosts. Moreover, it is difficult to confirm the absence or presence of viable trematode eggs in the wastewater, excreta or pond water, for several reasons:

- Standardized procedures for conducting laboratory analysis of trematode eggs have not been developed; once they have been, their recovery efficiencies will have to be determined.
- Trematode eggs of species pathogenic to humans are difficult to distinguish from those of species that are not.
- Trematode eggs develop rapidly into miracidia in warm aerobic waters, and thus eggs may not be detectable.

In general, because of the issues noted above, testing for viable trematode eggs in wastewater, excreta or pond water should be done at the system validation stage. If the plant and fish species raised in the local area are *always* eaten after thorough cooking, testing for viable trematode eggs will not be necessary.[1] Also, foodborne trematodes are present only in certain geographic areas and thus present a hazard only where they are endemic. Table 4.1 presents microbial quality targets that can be used to facilitate compliance with the health-based target for foodborne trematodes.

Verification monitoring for foodborne trematodes includes analysis of fish and plant specimens for infective metacercariae at the point of harvest. Monitoring should be conducted by local health or food safety authorities at intervals of three to six months, depending on how common foodborne trematode infections are in the local area.

4.1.2 Other pathogens

As described in chapter 2, the reference level of risk that WHO has adopted in the third edition of the *Guidelines for drinking-water quality* is 10^{-6} DALY per person per year. This level of health protection is also appropriate as a health-based target for protecting consumers of waste-fed aquacultural products. Excreta-related diseases are often approximated by using gastrointestinal illness or diarrhoea as an indicator. A reference level of risk of 10^{-6} DALY is approximately equal to a 1 in 1000 annual risk of contracting a mild, self-limiting diarrhoea with a low case fatality rate (e.g. caused by rotavirus) (WHO, 2004a).

To achieve this level of health protection, a combination of health protection measures should be used. Wastewater treatment and excreta treatment are important health protection measures to reduce the level of contamination on the surfaces of the fish and the plants and should reduce the concentrations of pathogens in the gut. However, even fish grown in relatively clean water environments will have high microbial concentrations in their guts, of which some percentage may be pathogenic to humans. Therefore, it is important to reduce cross-contamination between the gut contents and the edible flesh during fish cleaning and processing.

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[1] Schistosomiasis is also caused by trematode species and may still present a health risk to people in contact with the pond water or other contaminated water sources in the geographic range where this disease is present.

Table 4.1 Microbial quality targets for waste-fed aquaculture

Media	Viable trematode eggs (including schistosome eggs where relevant) (number per 100 ml or per g total solids[a])	*E. coli* (arithmetic mean number per 100 ml or per g total solids[a,b])	Helminth eggs[c] (arithmetic mean number per litre or per g total solids[a,d])
Product consumers			
Pond water	Not detectable	$\leq 10^4$	≤ 1
Wastewater	Not detectable	$\leq 10^5$	≤ 1
Treated excreta	Not detectable	$\leq 10^6$	≤ 1
Edible fish flesh or plant parts	Infective metacercariae (presence or absence per fish or plant) not detectable or non-infective	Codex Alimentarius Commission specifications[e]	Not detectable
Aquacultural workers and local communities			
Pond water	Not detectable[f]	$\leq 10^3$	≤ 1
Wastewater	Not detectable[f]	$\leq 10^4$	≤ 1
Treated excreta	Not detectable[f]	$\leq 10^5$	≤ 1

[a] Excreta is measured in grams of total solids (i.e. dry weight); 100 ml of wastewater/excreta contains approximately 1–4 g of total solids.

[b] An arithmetic mean should be determined throughout the irrigation season. For pond water and product consumers, for example, the mean value of $\leq 10^4$ *E. coli* per 100 ml should be obtained for at least 90% of samples in order to allow for the occasional high-value sample (i.e. with10^5 or 10^6 *E. coli* per 100 ml).

[c] Applicable when emergent aquatic plants are grown and when there is high contact with wastewater, excreta, contaminated water or contaminated soils.

[d] An arithmetic mean should be determined throughout the irrigation season. The mean value of ≤ 1 egg per litre should be obtained for at least 90% of samples in order to allow for the occasional high-value sample (i.e. with >10 eggs per litre).

[e] The Codex Alimentarius Commission does not specify microbial qualities for fish flesh or aquatic plants; rather, it recommends the adoption of hazard analysis and critical control point (HACCP) principles as applied from production to consumption.

[f] Viable schistosome eggs where relevant.

As indicated in section 3.1.2, Lan et al. (in press) found exponential increases in the concentrations of presumptive thermotolerant coliforms in the edible fish flesh between the sampling point at harvest and the sampling point at the market. The levels of contamination for waste-fed and non-waste-fed fish were not significantly different. The use of produce restriction (i.e. raising only fish or plants that are eaten after thorough cooking) will also reduce the risk from excreta-related diseases (see chapter 5).

Setting microbial performance targets to facilitate compliance with the health-based target is difficult. The limited information from the epidemiological study (section 3.2) suggests an increased risk of diarrhoea for children less than five years old who consume fish from waste-fed ponds (geometric mean water quality of 3.9×10^4 thermotolerant coliforms per 100 ml). The risks were higher for children who did not otherwise have exposure to waste-fed aquaculture (i.e. they had lower immunity to locally endemic excreta-related diseases) (Blumenthal et al., 2000). Data from section 3.1.2 suggest that in most cases a microbial water quality of 10^4 thermotolerant coliforms per 100 ml will not lead to significant levels of contamination in the edible fish flesh at the point of harvest.

thermotolerant coliforms per 100 ml will not lead to significant levels of contamination in the edible fish flesh at the point of harvest.

There are no data concerning the level of plant contamination at this microbial water quality. QMRA used to estimate the risks from wastewater-irrigated lettuce (assuming 100 g of lettuce consumed every two days; lettuce retained between 10 and 15 ml of wastewater; with provisions for pathogen die-off between harvest and consumption) showed a median annual rotavirus risk of 1×10^{-3} (approximately 10^{-6} DALY) at a microbial water quality level of 10^3–10^4 *E. coli* per 100 ml (WHO, 2005b). These data can be extrapolated to aquatic plants that are consumed raw. Further research is needed on the health risks associated with the consumption of waste-fed aquatic plants and the relationship to microbial water quality.

The use of safe drinking-water to freshen and/or wash plants at the market or prior to consumption should reduce microbial contamination and the risk of excreta-related diseases. Likewise, the use of unsafe water could recontaminate plants and thus increase the health risks of eating them.

Based on the discussion above, a microbial quality target of $\leq 10^4$ *E. coli* (geometric mean) per 100 ml of pond water has been established to protect product consumers (see Table 4.1). This microbial water quality should also be appropriate for contaminated surface waters used for aquaculture. Microbial quality targets for wastewater and treated excreta have been set at higher levels — $\leq 10^5$ and $\leq 10^6$ *E. coli* (geometric mean) per 100 ml, respectively — to account for dilution after entering the aquacultural facility.

Although the transmission of intestinal helminths is more often associated with the use of wastewater and excreta in agriculture, consumption of some waste-fed aquacultural products — especially emergent aquatic plants — may lead to transmission of these illnesses. In these cases, authorities may wish to establish microbial water quality standards of ≤ 1 helminth egg per litre (arithmetic mean) to adequately protect product consumers from intestinal helminth infections (WHO, 2005b). Washing plants in a detergent solution will also remove a significant percentage (90–99%) of helminth eggs from the plant surfaces (B. Jiménez-Cisneros, personal communication, 2005).

Verification monitoring of *E. coli* and helminth eggs (where necessary) in pond water should be conducted at monthly intervals if fish or plants are grown that are routinely eaten raw. If the waste-fed aquacultural products are always eaten cooked, then verification monitoring can take place at three- to six-month intervals.

4.1.3 Chemicals

Information on chemicals in relation to waste-fed aquaculture is presented in section 3.3. The Codex Alimentarius Commission establishes tolerances for specific chemicals in food products. Table 4.2 presents some information on specifications for different chemicals in fish and related products. Table 4.2 also contains information on standards for aquatic plants. The health-based targets for chemical contaminants can usually be met by wastewater and excreta treatment (most heavy metals will settle out in an anaerobic pond) or by maintaining alkaline conditions in fish ponds, which cause metals to form insoluble precipitates that settle out of the water column (WHO, 1999). Where industries discharge into municipal sewerage systems, effluent pretreatment or diversion programmes should be encouraged.

Verification monitoring of chemical concentrations in waste-fed aquacultural products should be conducted at six-month intervals by local food safety authorities. It should be conducted at the point of sale. Comparisons between waste-fed fish or plants and non-waste-fed products sold in the market may provide insight into what specific contaminants are related to the use of wastewater or excreta. Contaminants that are at elevated concentrations (in relation to the standards in Table 4.2) can then be singled out for more routine monitoring as necessary.

Table 4.2 Standards for chemical concentrations in fish and vegetables

Chemical	Standard for fish and fish products (mg/kg)	Source of standard	Standard for vegetables (mg/kg)[a]	Source of standard
Heavy metals				
Arsenic	NS		0.2	Codex (2003)
Cadmium	0.05–1.0	EC (2001)	0.2	Codex (2003)
Lead	0.2	Codex (2003)	0.2	Codex (2003)
Methyl mercury	0.5–1.0	Codex (2003)	NS	
Organics				
Dioxins[b]	0.000 004	EC (2001)	NS	
DDT, TDE	5.0	USFDA (1998)	NS	
PCBs	2.0	USFDA (1998)	NS	

NS, no standard

[a] General standard for leafy vegetables except for arsenic, which is fruit based.

[b] Includes dioxins and other polychlorinated, co-planar aromatic compounds with similar properties.

4.2 Protection of aquacultural workers and local communities

Aquacultural workers (and often their families in small-scale or subsistence-level aquaculture) and local communities may also encounter hazards associated with waste-fed aquaculture. Three hazards identified in section 2.3 are relevant to deriving health-based targets to protect aquacultural workers (and their families) and local communities. These hazards relate to the risk of excreta-related diseases (including schistosomiasis, where relevant), skin irritants and vector-borne diseases. Hazards are encountered through contact with the excreta, wastewater or contaminated pond/surface waters or through exposure to disease vectors. Schistosomes can penetrate the skin of people in contact with contaminated water. Each of these categories is discussed below.

4.2.1 Pathogens

As discussed in section 4.1.2, an appropriate level of health protection for excreta-related diseases is 10^{-6} DALY per person per year, or approximately a 1 in 1000 annual risk of diarrhoeal disease from the exposure. An additional health-based target, where relevant, would be the absence of schistosomiasis transmission due to waste-fed aquacultural activities. The excreta-related disease health-based target can be achieved by:

- treating wastewater and excreta;
- using protective equipment, such as gloves and boots;
- limiting access to waste-fed aquacultural facilities;
- providing access to safe drinking-water and adequate sanitation facilities for both workers and local communities;
- practising good personal hygiene, especially thorough hand-washing with soap and water prior to food preparation and eating, after defecating and after cleaning a baby's faeces.

In addition to the health protection measures described above, the health-based target for schistosomiasis can be achieved by the following measures:

- controlling intermediate host populations by physical, chemical or biological means;
- washing body parts thoroughly with soap and safe water after exposure to wastewater, excreta or contaminated water;
- chemotherapy of infected populations and individuals.

Performance targets for wastewater and excreta treatment (as reflected in the pond water quality), including microbial water quality targets, can be derived based on the epidemiological study presented in section 3.2, which indicated that children under five years of age with heavy exposure to waste-fed aquaculture had a significant risk of diarrhoea at a microbial water quality of 3.9×10^4 thermotolerant coliforms per 100 ml (geometric mean). Additionally, QMRA modelling of heavy exposure scenarios (ingestion of 10–100 ml of wastewater/excreta per day for 300 days a year) indicates that a level of health protection of 10^{-6} DALY per person per year is roughly approximated by wastewater treated in a waste stabilization pond system to an *E. coli* concentration in the range of 10^3–10^4 per 100 ml (WHO, 2005b). Therefore, to protect the health of aquacultural workers and local communities with access to waste-fed aquacultural facilities, a microbial water quality for pond water of $\leq 10^3$ *E. coli* per 100 ml (arithmetic mean) has been selected (see Table 4.1).

The health-based target for schistosomiasis can be monitored by analysing wastewater and excreta for viable *Schistosoma* spp. eggs (they should be not detectable), by establishing the presence or absence of appropriate snail intermediate hosts in the pond environment and by testing snail intermediate hosts in the laboratory for the shedding of infectious schistosome cercariae. Any cercariae found will need genetic checking to distinguish schistosome species infectious to humans from those specific to, for example, aquatic birds.

Although the transmission of intestinal helminths is more often associated with the use of wastewater and excreta in agriculture, certain aquacultural practices (cultivation of some emergent plants, unsafe handling of excreta or wastewater, construction of ponds in contaminated soils, removal of sludge from pond bottoms, etc.) may also be associated with higher risks of the transmission of these parasites. In these cases, authorities may wish to establish microbial water quality standards of ≤ 1 helminth egg per litre (arithmetic mean) to adequately protect workers and local communities from transmission of intestinal helminth eggs due to waste-fed aquacultural activities (see Table 4.1) (WHO, 2005b).

Where relevant, verification monitoring of *E. coli* and helminth eggs (both intestinal helminths and *Schistosoma* spp. eggs) should be conducted at intervals of three to six months. Sampling should take place at the point(s) of exposure. Where schistosomiasis is a hazard, workers and local communities should be examined for signs of infection. Monitoring should take place once a year, once every two years or once every five years in areas where schistosomiasis occurs at high, moderate or low prevalences, respectively (WHO, 2002).

4.2.2 Skin irritants

In section 3.2.1, information is presented on skin diseases associated with high-contact waste-fed aquacultural activities. In the study described, untreated wastewater was used to cultivate aquatic plants (water spinach). The aquacultural activities resulted in heavy exposures of hands, arms, legs and feet to wastewater, which were associated with the development of skin diseases — mostly contact dermatitis (eczema). Specific hazards that led to the development of skin diseases were not identified, nor was the quality of the lake water specified. Although skin diseases of this type are non-life-threatening and relatively short-lived, they may cause a high level of discomfort. For skin diseases, a suitable health-based target would be their absence in the context of waste-fed aquacultural activities.

The health-based target could be achieved by limiting exposure to wastewater with substantial toxic chemical inputs, wastewater and excreta treatment — especially to remove chemical contaminants (e.g. anaerobic sedimentation, coagulation and flocculation) — wearing protective clothing (high boots, gloves) and rinsing the skin thoroughly with clean water immediately after contact with wastewater, excreta or contaminated water.

Verification monitoring would serve to confirm that the health protection measures were working and that the health-based target was being achieved, by the absence of skin diseases on aquacultural workers and other people with heavy exposure to the water. Verification monitoring should be conducted at six-month or yearly intervals.

4.2.3 Vector-borne diseases

As described in section 2.7.3, a few vector-borne diseases can be of relevance to waste-fed aquacultural activities in specific settings. Most of them can cause significant morbidity and even mortality in some cases. Therefore, an appropriate health-based target would be the prevention of vector-borne diseases due to waste-fed aquacultural activities. This health-based target can be achieved by controlling vector populations through physical, biological or chemical means (as described in chapter 5), by preventing exposure to vectors through the use of mosquito nets, repellents and/or by the use of chemoprophylactics (against malaria).

Performance targets to achieve the health-based target might include monitoring the destruction of vector breeding habitats favoured by the locally relevant vector species (e.g. surveying the pond/facility for emergent vegetation or monitoring pond waters for the relevant insect larvae). Performance targets for monitoring attainment of the health-based targets need to be based on locally available information concerning vector-borne disease transmission and its relationship to waste-fed aquacultural activities.

Verification monitoring of the pond water for the presence of insect vectors should take place every two to three months. Public health surveillance of the prevalence of vector-borne diseases can be used to ensure that the health protection measures are achieving the health-based target. Epidemiological investigations to assess the association between waste-fed aquacultural exposures and the transmission of vector-borne diseases may also be needed.

4.3 International guidelines and national standards

WHO guidelines are intended to be adopted to account for a consistent level of health protection in different settings. As described in section 1.1, countries may wish to develop their own standards based on their national environmental, sociocultural and economic conditions. In some cases, countries may choose to develop different standards for products consumed locally than for exports.

4.3.1 Food exports

The rules that govern international trade in food were agreed during the Uruguay Round of Multilateral Trade Negotiations and apply to all members of the World Trade Organization (WTO). With regard to food safety, rules are set out in the Agreement on the Application of Sanitary and Phytosanitary Measures. According to this agreement, WTO members have the right to take legitimate measures to protect the life and health of their populations from hazards in food, provided that the measures are not unjustifiably restrictive of trade (WHO, 1999). In the past, the importation of contaminated food products has led to disease outbreaks in recipient countries. Moreover, pathogens can be (re)introduced into communities that have no natural immunity to them, resulting in disease outbreaks (Frost et al., 1995; Kapperud et al., 1995). Countries should be assured that the products that they are importing are safe to consume.

WHO Guidelines for the safe use of wastewater and excreta in aquaculture are based on a risk analysis approach and a defined level of health protection. Such an approach is recognized as the fundamental methodology underlying the development of food safety standards that both provide adequate health protection and facilitate trade in food. Thus, waste-fed aquacultural products for export should be produced within the framework of the recommended WHO Guidelines to ensure the international trade of safe food products.

4.3.2 National standards

In waste-fed aquaculture, much of the production is consumed at the local or household subsistence level. Requirements for food safety should consider different contexts and the contribution of waste-fed aquaculture to household nutritional status and food security in addition to any health risks associated with the practice. In some situations, immunity to locally endemic diseases may reduce the health risks from consuming waste-fed aquacultural products or other exposures to wastewater/excreta. However, if products are to be sold and consumed in areas where immunity to these diseases is not well developed or where foodborne trematodes are endemic and products are routinely eaten raw, then stricter food safety standards may need to be applied. National standards should be aimed at protecting the different exposed groups and may be most effective when they are accompanied by other health promotion/outreach activities, such as increasing access to safe water, improved sanitation and better hygiene in the household and at the markets.

National standards should be established so as to provide incremental improvement in health, but they should be achievable within the local sociocultural, environmental and economic situation. This may mean initially setting standards that do not achieve a level of health protection of 10^{-6} DALY or meet the other health-based targets. Over time and as more resources become available, standards can be progressively tightened until they meet all of the health-based targets.

5
HEALTH PROTECTION MEASURES

As discussed in section 2.2, a number of environmental health hazards may be encountered during waste-fed aquacultural activities. Chapter 4 described health-based targets that could be achieved by combinations of different health protection measures. This chapter presents information on the health protection measures that are available to reduce exposures to the different hazards and achieve the health-based targets.

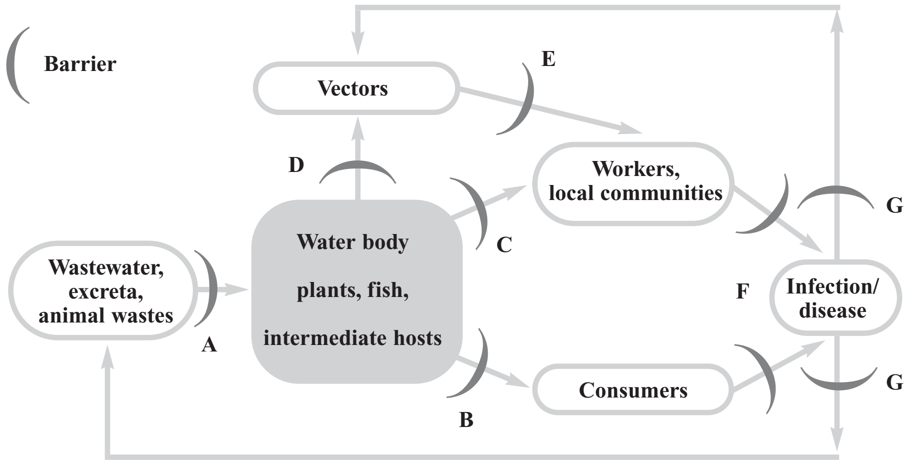
The health protection measures to reduce exposure of product consumers, workers (and their families) and local communities to hazards are described in section 5.1. Information concerning the effectiveness of different health protection measures in reducing the risks from hazards is described in section 5.2. Section 5.3 presents special considerations for managing trematodes (including schistosomiasis).

5.1 Health protection measures for different exposed groups

As Table 5.1 and Figure 5.1 indicate, a variety of health protection measures can be used to reduce health risks to product consumers, workers and their families and local communities. Sections 5.1.1–5.1.3 present information on specific health protection measures that can be targeted at these groups.

Table 5.1 Exposed groups and health protection measures

Exposed group	Risk	Health protection measure
Consumers, workers and local communities	Excreta-related diseases	Wastewater treatment
		Excreta treatment
		Health and hygiene promotion
		Chemotherapy and immunization
Consumers	Excreta-related diseases	Produce restriction
	Foodborne trematodes	Waste application/timing
	Chemicals	Depuration
		Food handling and preparation
		Produce washing/disinfection
		Cooking foods
Workers and local communities	Excreta-related diseases	Access control
	Skin irritants	Use of personal protective equipment
	Schistosomiasis	Disease vector control
	Vector-borne diseases	Intermediate host control
		Access to safe drinking-water and sanitation at aquacultural facilities and in local communities
		Reducing vector contact (mosquito nets, repellents), chemoprophylaxis



A = Wastewater/excreta treatment
B = Crop restriction, waste application/timing, depuration, food handling/preparation, produce washing/disinfection, food processing, cooking
C = Personal protective equipment, access control, access to safe drinking-water and adequate sanitation, personal hygiene
D = Vector control (physical, biological and chemical methods)
E = Prevent vector contact (mosquito nets, window screens, chemical repellents)
F = Immunization (typhoid, hepatitis A virus, Japanese encephalitis)
G = Chemoprophylaxis (malaria)

Figure 5.1
Hazards and control measures in waste-fed aquaculture

5.1.1 Product consumers

Hazards associated with the consumption of waste-fed aquacultural products include excreta-related diseases, foodborne trematodes and some toxic chemicals. The risk from infectious diseases is significantly reduced if foods are eaten after thorough cooking. Cooking has little or no impact, however, on the concentrations of toxic chemicals that might be present. Special considerations for managing trematode parasites (including schistosomiasis) are presented in section 5.3. The following health protection measures impact product consumers:

- wastewater and excreta treatment (see sections 5.2.1 and 5.2.2);
- produce restriction (see section 5.2.3);
- waste application withholding periods (see section 5.2.4);
- control of trematode intermediate hosts (see sections 5.3.2 and 5.3.5);
- depuration (see section 5.2.5);
- food handling and preparation (see section 5.2.6);
- post-harvest processing (see section 5.3.3);
- health and hygiene promotion (see section 5.2.8);
- produce washing, disinfection and cooking (see section 5.2.7);
- chemoprophylaxis and immunization (see sections 5.2.9 and 5.3.4).

5.1.2 Workers (and their families)

As Table 5.1 indicates, workers (including product handlers, processors and vendors) and their families may be exposed to excreta-related diseases, skin irritants, schistosomiasis (see section 5.3.5) and vector-borne diseases through waste-fed aquacultural activities or direct contact with the hazards. Wastewater treatment and excreta treatment (see sections 5.2.1 and 5.2.2) are control measures for excreta-related diseases, skin irritants and schistosomiasis, but they may not have much impact on vector-borne diseases (see section 5.2.11). Other health protection measures include:

- use of personal protective equipment (see section 5.2.10);
- restricted access to aquacultural facilities (see section 5.2.10);
- health and hygiene promotion (see section 5.2.8);
- chemoprophylaxis and immunization (see section 5.2.9);
- disease vector and intermediate host control (see sections 5.2.11, 5.3.2 and 5.3.5);
- reducing vector contact (see section 5.2.10).

5.1.3 Local communities

Local communities are at risk from the same hazards as workers, especially if they have access to waste-fed ponds. If they do not have access to safe drinking-water, they may use the contaminated water for drinking or for domestic purposes, such as washing clothes, dishes and themselves. Children may also play or swim in the contaminated water. Similarly, if waste-fed aquacultural activities result in increased vector breeding, then local communities can be affected by vector-borne diseases even if they do not have access to the aquacultural facilities. To reduce health hazards, the following health protection measures may be used:

- wastewater and excreta treatment (see sections 5.2.1 and 5.2.2);
- control access to facilities (see section 5.2.10);
- access to safe drinking-water and sanitation facilities at aquacultural facilities (see section 5.2.10);
- health and hygiene promotion (see section 5.2.8);
- chemoprophylaxis and immunization (see section 5.2.9);
- disease vector and intermediate host control (see sections 5.2.11, 5.3.2 and 5.3.5);
- reducing vector contact (see section 5.2.10).

5.2 Effectiveness of health protection measures

This section presents more detailed information on the health protection measures listed in section 5.1. The order of this section follows that presented in Figure 5.1 — that is, preventing contaminants from entering the water; measures to protect product consumers; measures to protect workers and local communities; vector control and prevention of vector contact; and, preventing and treating infection.

5.2.1 Excreta treatment

The direct use of untreated excreta in aquaculture is not recommended because of the high pathogen concentrations they contain. Furthermore, some fish species directly consume excreta and can therefore be expected to contain high pathogen numbers in the gut, with increased risks for subsequent cross-contamination. Also, direct human exposure to ponds fertilized with fresh excreta will represent high health risks. However, current practices (e.g. overhanging fish pond latrines) should not be abandoned without an appropriate alternative sanitation system to avoid indiscriminate defecation and negative impacts on public health.

In regions where trematode infections are present, the main priority for excreta treatment will be to inactivate trematode eggs prior to adding the excreta to the pond. As Box 5.1 suggests, storing excreta for four weeks (temperature range 10–30 °C) renders trematode eggs of most species non-viable. Storage times are counted only after the last addition of fresh faeces (i.e. as a batch operation). Storage times can be reduced to one week if, for example, *Clonorchis* or *Opistorchis* are the only locally endemic trematode infections of concern. However, storage times need to be increased to 10 weeks if *Fasciola hepatica* is a health threat in the area and aquatic plants are frequently eaten raw. Lower temperatures (e.g. 4–8 °C) will prolong egg survival; *F. hepatica* can survive for 101 days in this temperature range (Feachem et al., 1983). As Table 5.2 indicates, storage times that inactivate trematode eggs may not be long enough to inactivate some of the other pathogens, especially other helminths, which could therefore still pose a risk to plant consumers or workers.

Box 5.1 - Excreta storage times needed to render trematode eggs non-viable

Storage at 10–30 °C renders trematode eggs non-viable (colder temperatures may result in longer survival periods), and minimum storage periods to ensure that *all* eggs are completely inactivated are as follows:

Clonorchis sinensis	1 week
Fasciolopsis buski	3 weeks
Schistosoma spp.	4 weeks
Fasciola hepatica	10 weeks

Source: Feachem et al. (1983).

The period of storage refers to the time between excretion and pond application and so includes any time stored in a latrine or in a treatment process such as an anaerobic digester or a composting plant. Viable pathogens may still be present, however, if the latrine/toilet stays in operation until it is unloaded. The storage period may be reduced by treatment at a higher temperature — for instance, in aerobic composting. For the inactivation of most pathogens, a storage time of four weeks is recommended, but 12 months may be needed to inactivate intestinal helminth eggs, which are usually not the primary health hazard in waste-fed aquaculture. However, they could still pose a health risk during the handling and application stages of the excreta or to consumers of aquatic plants. The die-off rates of all types of pathogens can also be increased by adding ash or lime to the excreta. More information on the effectiveness of other excreta treatment techniques is presented in Volume 4 of the Guidelines: *Excreta and greywater use in agriculture*.

The contents of alternating twin-pit latrines (both ventilated improved pit latrines and pour-flush toilets) require no further treatment after removal from the pit before application to the pond, provided adequate time has elapsed since the pits were emptied. All the contents of single-pit latrines, septic tanks and single-vault compost toilets as well as wastewater sludges should be stored after removal for at least four weeks, since there is no way of differentiating between freshly added excreta and excreta that have been stored sufficiently to inactivate pathogens.

Table 5.2 Organism survival periods in faeces, sludge and soil

Microorganism	Survival at 20–30 °C (days)[a]		Time needed for 90% inactivation of pathogen (T_{90}) at ~20 °C (days)[a]		Absolute max[d]/ normal max survival in soil[e]
	Faeces and sludge[b]	Soil[b]	Faeces[c]	Soil[c]	
Bacteria					1 year / 2 months
Thermotolerant coliforms	<90, usually <50	<70, usually <20	*E. coli*: 15–35	*E. coli*: 15–70	
Salmonella	<60, usually <30	<70, usually <20	10–50	15–35	
Viruses	<100, usually <20	<100, usually <20	rotavirus: 20–100 hepatitis A: 20–50	rotavirus: 5–30 hepatitis A: 10–50	1 year / 3 months
Protozoa (*Entamoeba*)	<30, usually <15[f]	<20, usually <10[e]	*Giardia*: 5–50 *Crypto-sporidium*: 20–120	*Giardia*: 5–20 *Crypto-sporidium*: 30–400	? / 2 months
Helminths (egg)	Several months	Several months	*Ascaris*: 50–200	*Ascaris*: 15–100	7 years / 2 years

?, unknown; max, maximum; T_{90}, time needed for 90% inactivation of pathogen

[a] Estimated survival times and decimal reduction values of pathogens during storage of faeces and in soil; presented in days if not stated otherwise.

[b] Feachem et al. (1983).

[c] Arnbjerg-Nielsen et al. (2005).

[d] Absolute maximum for survival is possible under unusual circumstances, such as at constantly low temperatures or under well protected conditions (Feachem et al., 1983).

[e] Kowal (1985).

[f] Data are missing for *Giardia* and *Cryptosporidium*; their cysts and oocysts might survive longer than presented here for protozoa (Feachem et al., 1983).

Alternative treatment options include biogas fermenters, which have the additional advantage of energy production in the form of methane gas, and they produce sludge, which can be used as a fertilizer. Influent faecal sludge (sometimes mixed with livestock manure) needs to be mixed with straw or other crop wastes to increase the carbon to nitrogen ratio to an optimal 30 for bacterial action. Pathogen removal is not completely effective, because digestion is mesophilic (30–35 °C), retention times are relatively short (5–30 days) and operation is continuous rather than batchwise, so use of biogas sludge in aquaculture would need to be combined with other methods to safeguard health. A biogas unit can be operated as a central facility at the municipal or district level or even at the household level.

Faecal sludge (i.e. the materials collected from on-site sanitation systems such as latrines, non-sewered public toilets, septic tanks and aqua privies) may also be treated and used in aquaculture. Faecal sludge can be treated in a wastewater stabilization pond system and can be linked with aquaculture in the final ponds of the series.

considerations compared with treatment of wastewater, because faecal sludge is more concentrated. Faecal sludge contains as much as 3.5 times the concentration of solids and higher concentrations of other contaminants, such as ammonia, helminth eggs, etc. (Montangero & Strauss, 2002). More information on the treatment of faecal sludge is presented in Volume 4 of the Guidelines: *Excreta and greywater use in agriculture*.

A major technical constraint to the use of treated faecal sludge in aquaculture is its high organic matter content. Use of partially decomposed organic matter with a high carbon to nitrogen ratio in aquaculture would lead to a relatively high organic matter loading rate in the fish pond. This makes it difficult to achieve a satisfactory nitrogen loading rate and may result in poor fish growth, because the dissolved oxygen level decreases to a level harmful to the fish.

5.2.2 Wastewater treatment

This section provides a brief description of wastewater treatment options that are most compatible and most frequently used with aquaculture. A wide range of other wastewater, excreta and greywater treatment technologies are also available and are described in *Volume 2: Wastewater use in agriculture* and *Volume 4: Excreta and greywater use in agriculture* of the WHO *Guidelines for the safe use of wastewater, excreta and greywater*. Additional information on different wastewater treatment technologies can also be found in UNEP (2002), Asano (1998) and Mara (1998).

In the context of the use of wastewater and excreta in aquaculture, the removal or inactivation of excreted pathogens is the principal objective of treatment, because they pose the greatest risk to public health. Table 5.3 presents some pathogen removal ranges for different wastewater treatment options. The definitions of some wastewater treatment terms are presented in Annex 4.

As Table 5.3 illustrates, there is a great deal of variation in the pathogen removal potential between different treatments and within the same classes of treatment facility (e.g. secondary treatment). Although some variation in the treatment process is normal, a large part of the differences may in fact be linked to the overall management of the facility. The performance of treatment chains should be validated to ensure that they are capable of meeting the specified performance targets. Operational monitoring is used to ensure that components of the treatment system are working and provides information that can be used to make rapid management decisions when part of the system stops working properly — for example, if a treatment facility becomes overloaded due to a storm event or if a filtration device needs to be backwashed. Verification monitoring is done less frequently and is used to show that the system as a whole is functioning properly. Different types of monitoring and procedures for system assessment are described in chapter 6.

High concentrations of chemicals in the wastewater can reduce the effectiveness of biological wastewater treatment processes. In most treatment processes, a large percentage of the toxic chemicals (both inorganic and organic) will end up in the sludge. Sludge may require special handling, treatment and disposal if many toxic chemicals are present. The handling and treatment of faecal sludges are discussed in Volume 4 of the *Guidelines for the safe use of wastewater, excreta and greywater*.

Table 5.3 Log unit reduction or inactivation of excreted pathogens achieved by selected wastewater treatment processes

Treatment process	Log unit pathogen removals[a]			
	Viruses	**Bacteria**	**Protozoan (oo)cysts**	**Helminth eggs**
Low-rate biological processes				
Waste stabilization ponds	1–4	1–6	1–4	1–3[b]
Wastewater storage and treatment reservoirs	1–4	1–6	1–4	1–3[b]
Constructed wetlands	1–2	0.5–3	0.5–2	1–3[b]
Primary treatment				
Primary sedimentation	0–1	0–1	0–1	0–<1[b]
Chemically enhanced primary treatment	1–2	1–2	1–2	1–3[b]
Anaerobic upflow sludge blanket reactors	0–1	1–2	0–1	0.5–1[b]
Secondary treatment				
Activated sludge + secondary sedimentation	0–2	1–2	0–1	1–<2[b]
Trickling filters + secondary sedimentation	0–2	1–2	0–1	1–2[c]
Aerated lagoon or oxidation ditch + settling pond	1–2	1–2	0–1	1–3[c]
Tertiary treatment				
Coagulation/flocculation	1–3	0–1	1–3	2[b]
High-rate granular or slow-rate sand filtration	1–3	0–3	0–3	1–2[b,d]
Dual-media filtration	1–3	0–1	1–3	2–3[b,d]
Membrane bioreactors	2.5–>6	3.5–>6	>6	>3[b,d]
Disinfection				
Chlorination (free chlorine)	1–3	2–6	0–1.5	0–<1[b]
Ozonation	3–6	2–6	1–2	0–2[e]
Ultraviolet irradiation	1–>3	2–>4	>3	0[e]

Sources: Feachem et al. (1983); Schwartzbrod et al. (1989); Sobsey (1989); El-Gohary et al. (1993); Rivera et al. (1995); Rose et al. (1996, 1997); Strauss (1996); Landa, Capella & Jiménez (1997); Clancy et al. (1998); National Research Council (1998); Yates & Gerba (1998); Karimi, Vickers & Harasick (1999); Lazarova et al. (2000); Jiménez et al. (2001); Jiménez & Chávez (2002); Jiménez (2003, 2005); von Sperling et al. (2003); Mara (2004); Rojas-Valencia et al. (2004); von Sperling, Bastos & Kato (2004); WHO (2004a); NRMMC & EPHCA (2005).

[a] The log unit reductions are $\log_{10}$ unit reductions defined as $\log_{10}$(initial pathogen concentration/final pathogen concentration). Thus, a 1-log unit reduction = 90% reduction; a 2-log unit reduction = 99% reduction; a 3-log unit reduction = 99.9% reduction; and so on.

[b] Data from full-scale plants.

[c] Theoretical efficiency based on removal mechanisms.

[d] Data from tests with up to 2 log units initial content; removal may be greater than that reported.

[e] Data from laboratory tests.

In general, a wide range of treatment options are available for wastewater, a number of which are capable of meeting the WHO microbial water quality performance targets. For example, to achieve the 3- to 4-log removal of *E. coli* from raw sewage necessary to meet the recommended microbial water quality performance target of $\leq 10^4$ *E. coli* per 100 ml, the following treatments would work:

- a well designed series of waste stabilization ponds;
- sequential batch-fed wastewater storage and treatment reservoirs;
- optimized activated sludge plant plus filtration and disinfection;
- optimized activated sludge plus polishing ponds.

Evidence for the efficiency of wastewater treatment for removing trematode eggs is very limited. However, because trematode egg sizes and characteristics are similar to those of other helminth eggs (e.g. *Taenia*, *Ascaris*), it is thought that they will be removed in similar fashion (e.g. by sedimentation). Secondary treatment plus rapid sand filtration have been found to remove schistosome eggs (WHO, 1995). A retention time of about 15 days in a waste stabilization pond system (warm climate, 20–30 °C) consisting of an anaerobic pond, facultative pond and one maturation pond should be adequate to remove *Ascaris* eggs, but whether this is also sufficient to remove trematode eggs is a question for further research.

In some cases, trematode eggs will hatch into miracidia in the wastewater treatment system, especially in well aerated components such as activated sludge reactors and maturation ponds. The miracidia must infect a snail host quickly, or they will die within a few hours. Therefore, treatment systems can effectively increase miracidium inactivation by incorporating a final step with a retention time of one to two days (e.g. a storage reservoir after an activated sludge plant, provided it is kept free of snail intermediate hosts). Rapid sand filtration of the final effluent also should remove miracidia.

Secondary treatment (e.g. trickling filter or activated sludge) of wastewater containing *Schistosoma mansoni* eggs was found to have very high egg removal rates. Analysis for miracidia was not conducted. Snails exposed to the treatment plant effluents for 3–6 h did not become infected. However, earlier experiments at the same facility with higher egg concentrations in the influents did lead to snail infection after exposure to the treatment plant effluents (Rowan, 1964; Feachem et al., 1983).

In waste stabilization pond systems, schistosome eggs can hatch in any of the ponds, although hatching is reduced in anaerobic ponds. Most eggs that have not hatched will be removed by sedimentation in the anaerobic and facultative ponds. Snails can survive in anaerobic ponds and can live and reproduce normally in facultative and maturation ponds. Miracidia can survive for up to 6 h in anaerobic ponds and up to 10 h in maturation ponds. If the appropriate snail species are found in the ponds, then further life cycle development can occur. Infective cercariae released from the snails must infect a human or other definitive host within about a day. If the pond system has an adequate retention time (15 or more days), the cercariae will die in the ponds before they can infect a human host (Feachem et al., 1983). However, treatment facility workers may be at risk if they come into contact with pond water that contains infective cercariae. Therefore, protective clothing should be worn where contact with the partially treated effluents is likely (Feachem et al., 1983). Adequate sanitation facilities close to the treatment facility are also important to prevent infected workers from reintroducing schistosome eggs into later stages of the treatment process, where they could survive long enough to infect humans upon final effluent discharge. Information on the survival of other trematodes in waste stabilization pond systems is not available.

In practice, the wastewater treatment facilities used most commonly with waste-fed aquaculture are low-rate biological treatment processes such as waste stabilization ponds. Waste stabilization ponds are usually the lowest-cost wastewater treatment system where adequate land is available. The ponds used in these types of treatment systems are a natural fit for raising fish or aquatic plants and can often be used in the existing form for this purpose without the need for expensive modifications. Facultative and maturation ponds provide a highly enriched environment that supports the growth of phytoplankton, which serve as fish food. A waste stabilization pond designed to facilitate waste-fed aquaculture has been proposed by Mara et al. (1993) and Mara (1997). This system is described in Annex 1.

5.2.3 Produce restriction

To protect consumers, wastewater and excreta can be used to raise aquatic plants and fish to be used as high-protein animal feed. As wastewater/excreta use in these systems is indirect, through the incorporation of an extra step in the food-chain, such lengthening of the food-chain may lead to excreta and wastewater use becoming feasible in societies in which direct use is socially unacceptable (Edwards, 1990). It is important, however, to prevent trematode infection of fish or plants used for fish feed, as trematodes can remain infective for as long as the host is alive. The production of fish and aquatic plants for fish feed increases the risk for accumulation of toxic chemicals in the final fish product.

Another type of produce restriction is to grow only plants and fish that are always eaten after thorough cooking. As described in section 5.2.7, thorough cooking of fish or plants is a very effective method to eliminate or reduce risks.

Fingerlings

Excreta, faecal sludge or wastewater can be used to produce fingerlings in aquacultural nursery operations, which are subsequently grown on to full-size table fish in separate systems without the use of wastewater. This would normally be expected to result in less contaminated adult fish. However, precautions against trematode infections would still be required for the same reasons as discussed above.

Duckweed as high-protein animal feed

The cultivation of duckweed in ponds fed with manure (human or livestock) is a traditional practice in China (Edwards, 1990). The objective is to produce green fodder of small enough size for herbivorous grass carp fingerlings to feed on until they grow larger and can consume grass.

There has been research over the last three decades in many parts of the world on duckweed-based wastewater treatment and use systems (see reviews by Skillicorn, Journey & Spira, 1993; Iqbal, 1999). Much of this research has been inspired by the positive attributes of duckweed as high-protein animal feed for fish or livestock, with protein production up to 10 times greater than that of soybean; high crude protein content of 25–45% on a dry matter basis; high growth rate of 10–40 t dry matter per hectare per year; ability to grow in shallow water and shade; and ready harvesting by net and pole. On the downside, growth is adversely affected by low and high temperatures and by high light intensity; duckweed is occasionally infested with insects; it is difficult to dry economically, so it needs to be fed fresh; and it decomposes rapidly (UNEP, 2002). Another disadvantage of waste-fed duckweed cropping is the greater requirement for land than for fish cultivation. In a study of direct and indirect use of excreta to culture tilapia, the area required for waste-fed duckweed cultivation was about three times that required for direct excreta use for fish cultivation. Duckweed cultivation on excreta for feeding fish in a separate pond system required almost twice the area for fish culture, with ponds for fish culture required only in direct use (Edwards, Pacharaprakiti & Yomjinda, 1990).

As duckweed consists of small floating plants without an extensive root system, most of the biological activity in a duckweed-covered wastewater-fed pond is due to microorganisms suspended in the water column. Duckweed cover helps to minimize water loss through surface evaporation and reduces the salinity of the effluent by uptake of dissolved nutrients (Gijzen & Veenstra, 2000).

There are limited scientific data on the possible transmission of pathogens through the use of duckweed as animal feed in waste-fed systems. An experiment carried out in Thailand revealed that duckweed concentrates bacteria on its surface. The mean concentration of thermotolerant coliforms on the surface of the plants was 5.7×10^5 MPN/100 g, compared with 8.0×10^3 MPN/100 g in the water of excreta-fed ponds (Edwards, Polprasert & Wee, 1987). However, tilapia raised in separate pond systems had comparable bacterial profiles irrespective of being fed duckweed or pelleted feed or being raised in control ponds without nutritional inputs. Thermotolerant coliforms were detected in muscle tissue of fish from all ponds at very low concentrations of $\leq$30 MPN/100 g; fish fed with duckweed had lower levels of contamination in their muscle tissue than fish fed pellets or grown in control ponds (Edwards et al., 1984). These data indicate that tilapia fed with excreta-raised duckweed do not have higher levels of contamination with faecal bacterial indicators than tilapia cultivated under traditional conditions.

Fish as high-protein animal feed

Research was carried out in Thailand on the use of tilapia cultured in septage-fed ponds as a source of high-protein animal feed (Edwards, Polprasert & Wee, 1987; Edwards, 1990). Three experimental diets were used to feed walking catfish, two containing septage-raised tilapia (minced sun-dried meal and minced fresh) and one in which marine fish were used as feed components as a control. Mean concentrations of thermotolerant coliforms were high in all diets: tilapia meal (1.2×10^6 MPN/100 g), fresh tilapia (3.8×10^7 MPN/100 g) and marine fish (8.1×10^5 MPN/100 g). High concentrations were to be expected in tilapia-based diets because they comprised minced whole fish, including the digestive tract contents, which have high concentrations of microorganisms.

Although catfish were fed with diets containing relatively high microbial contamination, the concentrations of microorganisms in the fish, with the exception of the digestive tract contents, were very low. Thermotolerant coliforms and bacteriophages were not detectable in muscle tissue, blood and bile. Heterotrophic plate count revealed the presence of aerobic bacteria in catfish muscle tissue in very low concentrations, with a maximum count of 40/g. These data indicate that carnivorous fish fed with processed excreta-raised tilapia do not have high levels of contamination.

5.2.4 Waste application withholding period

The timing of application of the wastewater and excreta can be an important risk management tool. Evidence suggests that the longer the period between last application of wastewater and excreta and fish or plant harvest, the more pathogen die-off there is in the pond. Pathogen die-off in fish ponds in theory should be similar to that for facultative or maturation ponds in waste stabilization pond systems. For optimum pathogen die-off prior to fish or plant harvest, a batch-fed process (i.e. all of the wastewater enters the treatment system at one time, and no new wastewater is added until the crop is harvested) could be used. It should be noted, though, that in urban areas, larger aquatic ponds will often be receiving untreated wastewater and latrine wastes from surrounding households on a continuous basis.

There is good evidence for a rapid die-off of thermotolerant coliforms in waste-fed fish ponds. Thermotolerant coliform concentrations in experimental fish ponds in Lima, Peru, declined from geometric means of $1.3 \times 10^4 - 3.2 \times 10^4$ MPN/100 ml in tertiary pond effluent to $1.0 \times 10^2 - 3.3 \times 10^3$ MPN/100 ml in fish pond water, declines of 1–2 orders of magnitude (Cavallini, 1996). According to Pal & Das Gupta (1992), thermotolerant coliform concentrations in raw sewage of 10^8–10^9/100 ml decrease in pond water within 15 days to about 10^4–10^6/100 ml and do not change thereafter. Bhowmik, Chakrabarti & Chattopadhyay (2000) reported concentrations of thermotolerant coliforms in raw sewage and fish pond water ranging from 6.2×10^6/100 ml to 5.9×10^7/100 ml and from 1.3×10^4/100 ml to 1.0×10^5/100 ml, respectively. Roy (2000) indicated that sewage entering Kolkata fish ponds contains up to 1.0×10^7 thermotolerant coliforms per 100 ml, compared with water that flows out of the ponds, with only 10^3–10^4/100 ml.

Excreta may be added in small batches to fertilize the pond at different intervals, and sometimes excreta or faeces are added to the pond directly from overhanging latrines. The volumes of the excreta are much smaller than the volumes of wastewater that would be added. A small volume of excreta with high concentrations of indicator organisms would rapidly be diluted when added to a fair-sized pond, although fish may directly consume faeces. Research in Thailand on fish ponds fed with excreta with a mean thermotolerant coliform concentration of 3.0×10^6 MPN/100 ml showed means for 25 ponds ranging from 7.4×10^1 to 4.0×10^3 MPN/100 ml, with 60% of pond means less than 10^3 MPN/100 ml (Edwards et al., 1984). An experiment in which microorganisms were sampled before loading excreta followed by 3-h intervals showed an initial reduction of 99% due to dilution of the excreta by fish pond water, followed by a further 99% reduction from 10^4 MPN/100 ml to 10^2 MPN/100 ml within only 30 h (Edwards et al., 1984).

5.2.5 Depuration

Before marketing, fish may be held in clean water to reduce contamination, a process known as depuration. Depuration is often recommended in waste-fed aquacultural systems and can be carried out either by stopping application of the waste or by moving the fish to clean ponds. Keeping fish in clean water for at least two to three weeks before harvest is likely to remove residual objectionable odours (an aesthetic issue that affects the taste of the fish but has no impact on health) and to reduce the degree of contamination with faecal microorganisms. However, such depuration does not completely remove all pathogens from fish tissues and digestive tracts, especially when the water in which the fish was grown was very contaminated (Buras, 1990). Depuration will not have any effect on trematode metacercariae already present in the fish.

Although there have been few studies on the safety of depurated fish, common sense would suggest that depuration would lower health risks by reducing opportunities for cross-contamination from the skin surface and gut contents to the edible flesh.

5.2.6 Food handling and preparation

The gut contents of fish contain elevated concentrations of microbial flora that are present in the water. If the water is wastewater derived, excreta-related bacteria, viruses and potentially other pathogens such as *Giardia* or *Cryptosporidium* will be present at higher levels than they are in the water. Similarly, if opportunistic pathogens such as *Aeromonas* occur in the water, then they will occur at higher concentrations in the fish gut contents.

Studies of fish produced in waste-fed aquaculture indicate that cross-contamination during fish cleaning/processing is much more important in determining fish flesh quality than the quality of the water in which the fish is grown. For example, a study in Viet Nam evaluated the quality of fish produced in waste-fed ponds and fish grown with surface water. The fish flesh for both groups was analysed at the point of harvest and the point of sale in the market. Bacterial quality of the fish muscle at the point of harvest was nearly identical for both groups; most samples did not contain any thermotolerant coliforms, with a few samples containing 2–3 thermotolerant coliforms per gram. Fish muscle samples at the point of sale (i.e. after cleaning and processing) showed, however, thermotolerant coliform concentrations ranging from 800 to 19 000 per gram; there was no significant difference between the fish raised in the waste-fed pond and the fish raised with river water. The fish were cleaned at the point of sale on contaminated cutting boards, with contaminated knives and without removing the gut contents first (Lan et al., in press).

It is very important that steps are taken to prevent cross-contamination of the fish flesh with the gut contents during cleaning of the fish. This can be achieved by removing the intact guts of the fish prior to removing the fish muscle and by rinsing the gut cavity with safe drinking-water (WHO, 2004a). After removing the gut contents, it is important to use a different clean knife for cutting the fish flesh. Also, knives used to process raw fish should be cleaned thoroughly before they are used for other purposes (e.g. to cut cooked fish or other products such as vegetables).

5.2.7 Produce washing/disinfection and cooking of food

Vigorous washing in tap water of aquatic plants that are eaten uncooked reduces bacteria by 1–2 log units (Brackett, 1987; Beuchat, 1998; Lang, Harris & Beuchat, 2004). Washing in a disinfectant solution (commonly a hypochlorite solution) and rinsing in tap water can reduce microbial contamination by 1–2 log units. Washing in a detergent (e.g. washing-up liquid) solution and rinsing in tap water can reduce helminth egg numbers by 1–2 log units (B. Jiménez-Cisneros, personal communication, 2005).

Peeling fruits and root vegetables reduces pathogens by at least 2 log units. Cooking vegetables achieves an essentially complete reduction (5–6 log units) of all pathogenic microorganisms.

These reductions are extremely reliable and should always be taken into account when selecting the combination of wastewater treatment and other health-based control measures. Effective hygiene education and promotion programmes will be required to inform local food handlers (in markets, in the home and in restaurants and food kiosks) how and why they should wash produce grown with wastewater inputs effectively with water or disinfectant and/or detergent solutions.

5.2.8 Health and hygiene promotion

In many cases, it will be difficult to improve public health without promoting better domestic and personal hygiene. In waste-fed aquaculture, the people most at risk are the pond workers, their families, produce handlers, consumers of produce and people with access to the ponds. There is a range of behaviours that can be targeted to better protect public health. Health promotion should target the different exposed groups with relevant messages.

In many cases, it may be possible to tie educational and hygiene promotion initiatives to current aquacultural extension and health outreach activities (Blumenthal et al., 2000). However, health interventions should focus on a few key specific behaviours and may work better if social and cultural reasons for changing hygiene practices are emphasized rather than exclusively focusing on health benefits (Box 5.2) (Curtis & Kanki, 1998; Blumenthal et al., 2000).

Box 5.2 - Reducing trematode infections: changing food-related behaviours

Efforts to induce people to give up eating raw or insufficiently cooked food by health promotion (sometimes backed by legislation) have been largely unsuccessful. However, experience in some countries where opisthorchiasis or paragonimiasis is endemic indicates that control can be more successful when health promotion has been introduced into the project. A field study in paragonimiasis-endemic villages in the Jiangxi and Anhui provinces of China indicated that after three years, a programme of health promotion had reduced the percentage of villagers who ate raw crabs from 48.3% to 0% in Jiangxi Province and from 50.3% to 0.3% in Anhui Province. Control of opisthorchiasis in Thailand (Cross, 1991) through single-dose drug treatment and health education aimed at altering food habits was reported to have been successful, although this approach had limited success in several other countries (WHO, 1995).

In spite of the possibility of failure, health promotion with the aim of changing hazardous food habits is the priority approach to the control of foodborne trematodes under subsistence conditions. Simply providing information about the dangers of eating raw food is not enough to change risky habits. A WHO Consultation on Health Education in Food Safety (WHO, 1988b) recommended that, before educational activities are initiated, a systematic awareness campaign should be undertaken. First, government authorities should be made aware and convinced of the importance of the problem and of the necessity for health education. Then, health staff should be trained and equipped to carry out their part.

Nongovernmental organizations and local groups, including women's groups, should be formally invited to participate in the educational and intervention programmes. The educational messages should be based on sound epidemiological information and on the results of sociocultural and anthropological studies; the food preparation and food processing techniques recommended should be effective and should have been well reviewed and tested.

Communication of such messages to all levels of society in an endemic country will support long-term success in control of aquaculture-related trematode infections. The mass media should be integrated into the plan of action where appropriate, but sensationalism and exaggeration of the problem rather than emphasizing the solution can be counterproductive. Periodic evaluations should be carried out and the programme modified as and when necessary.

Two basic requirements for eventual success in achieving change have been identified (WHO, 1984, 1995):

- perception of the advantage of change by the community;
- acceptability of both the economic and the social costs of the change (WHO, 1995).

5.2.9 Immunization and chemotherapy

Immunization against helminthic infections and most diarrhoeal diseases is currently not feasible. However, for highly exposed groups, immunization against typhoid may be worth considering.

Additional protection may be provided by the availability of adequate medical facilities to treat diarrhoeal disease and by regular chemotherapy. This might include chemotherapeutic control of intense helminth infections in children and control of anaemia in both children and adults, especially women and post-menarche girls. Chemotherapy must be reapplied at regular intervals to be effective. The frequency required to keep worm burdens at a low level (e.g. as low as in the rest of the population) depends on the intensity of the transmission, but it may be required 2–3 times a year for children living in endemic areas (Montresor et al., 2002). Albonico et al. (1995) found that infection with helminths could return to pretreatment levels within six months of a mass chemotherapy campaign if the prevailing conditions did not change.

For schistosomiasis, a chemotherapy programme targeted at the highest-risk populations is recommended. In high-prevalence situations, WHO suggests that school-age children be treated once a year. Community-directed treatment for other high-risk groups (aquacultural workers, farmers, irrigation workers) should be made available. Where the prevalence of schistosomiasis is moderate, school-age children should be treated once every two years. In communities where schistosomiasis prevalence is low, school-age children should be treated twice during primary schooling (once at the beginning and again on leaving) (WHO, 2002).

Specific issues related to chemotherapy campaigns to treat foodborne trematode infections are discussed in section 5.3.4.

5.2.10 Exposure control measures for workers, product handlers and local communities

Control measures that can be used to protect the health of pond workers, those who process or handle aquacultural products and local communities are presented below.

Pond workers can be protected from exposures to pathogens in the following ways:

- wearing personal protective equipment (gloves, boots);
- managing ponds to reduce vector breeding activity;
- avoiding skin contact with wastewater, excreta or contaminated products;
- provision of safe water and adequate sanitation facilities near the pond;
- good personal hygiene (e.g. washing hands and other exposed body parts with soap after contact with wastewater or contaminated products).

As most pathogens entering fish ponds in traditional use practices settle in pond sediments, there may be an occupational risk for workers who wade in the ponds to harvest fish from pathogens in sediments (Strauss, 1996) as well as in water. There may also be a risk of helminth infections if sediments are removed from ponds and applied to fields as fertilizers (see *Volume 2: Wastewater use in agriculture* for more information concerning risks from intestinal helminths in agriculture). However, there does not seem to be any evidence that pond workers will be at increased risk of helminth infection.

In an informal survey of fish farm workers in the wastewater-fed ponds in Hanoi, few men or women reported any problems with urogenital diseases or skin problems associated with physical contact with water (A. Dalsgaard, personal communication, 1996). Skin problems such as itching and discoloration were occasionally reported. The main problem was secondary infections of skin lesions on the feet caused by mollusc shells and broken glass bottles.

Exposure of workers to pond water and sediments could be minimized by the wearing of protective clothing, but use of gloves, boots or waders is rare, as they hinder activities and are uncomfortable to wear in hot climates. It is particularly difficult to wear boots in ponds with thick deposits of soft sediments. Exposure to schistosomiasis can also be controlled by the wearing of Wellington boots or high-body waders (depending on the depth of the pond), but their use is rare and would interfere, for example, with the practice of harvesting lotus by loosening their roots with the toes, as well as being uncomfortable in hot climates.

A study from Viet Nam indicates that workers at waste-fed aquacultural facilities are becoming increasingly willing to wear long rubber gloves and boots while working in the ponds. This behavioural change is due to the new local availability of affordable soft rubber gloves and boots that are comfortable and easy to use (van der Hoek et al., 2005).

The provision and use of adequate sanitation facilities at the pond may help to prevent contamination of the pond with schistosomes by infected workers. Fish and aquatic plant handlers should take the following precautions to reduce their exposures to pathogens and chemicals:

- wearing personal protective equipment (e.g. gloves, boots);
- avoiding skin contact with contaminated products;
- use of safe water and adequate sanitation facilities at food processing plants and markets where products are sold;
- hygienic storage of aquatic plants at retail markets and use of safe water for moistening the plants;
- adoption of processing techniques that do not lead to cross-contamination between the gut contents and edible portions of the fish;
- ensuring good personal hygiene (e.g. washing hands with soap after contact with contaminated products).

Fattal et al. (1993) suggested that a major public health concern could be the risk of *Aeromonas* wound infections among workers who handle as well as process fish. However, a number of other pathogens may also cause wound infections, in particular as secondary infections of skin abrasions and cuts.

The most effective exposure prevention steps for local communities will be to:

- limit access to the waste-fed rivers, canals and ponds, through closed sewers and fences or in some cases by placing warning signs; children are particularly at risk;
- managing ponds to reduce vector breeding activity to reduce the spread of vector-borne diseases to local communities;
- ensuring access to safe drinking-water (i.e. to prevent the use of contaminated surface waters for drinking-water and water for domestic purposes) and adequate sanitation facilities (this will help to prevent the continuing transmission of trematodes, including schistosomes).

Local residents should be informed which ponds are fertilized with excreta or wastewater, so that they may prevent their children from playing or swimming in them. Warning notices should be posted by ponds adjacent to roads, especially if they are unfenced, although not everyone is likely to be able to read, especially children. Where there is no access to safe drinking-water or basic sanitation, however, local residents are likely to continue using the pond water for bathing, defecation and other purposes. Providing access to safe drinking-water and basic sanitation is therefore an important measure for human exposure control.

5.2.11 Control of vector-borne diseases

There is concern that construction of ponds for waste-fed aquaculture may provide an environment for the breeding of mosquitoes that are vectors of malaria, yellow fever, dengue/dengue haemorrhagic fever, Japanese encephalitis and Bancroftian filariasis. Three groups of species are of particular importance (Feachem et al., 1983):

- *Anopheles* species, vectors of malaria, breed in fairly clean stretches of water such as flood or irrigation water and in forested areas or forest fringes and are, therefore, unlikely to breed in waste-fed fish ponds.
- *Aedes aegypti*, the vector of yellow fever and dengue/dengue haemorrhagic fever, breeds especially in clean water stored in pots and cisterns and would also be unlikely to breed in waste-fed ponds.
- *Culex quinquefasciatus*, the vector of the nematode worm *Wuchereria bancrofti*, which causes Bancroftian filariasis, prefers to breed in organically polluted water, such as in open drains and poorly maintained waste stabilization ponds. It is thus potentially associated with waste-fed aquaculture. Vectors of the *Culex gelidus* group (which transmit Japanese encephalitis), on the other hand, breed by preference in irrigated rice fields.

In a review of the literature on wastewater stabilization ponds as breeding sites for mosquitoes, the conclusions of which also apply to waste-fed fish ponds, Feachem et al. (1983) concluded that mosquito breeding in ponds can be controlled by appropriate design and management to avoid vegetation emerging through, or hanging into, the surface of the pond. Aquatic macrophyte growth is prevented by constructing ponds at least 1 m deep, which is also required for productive fish culture, although aquatic plants may be farmed on occasion in shallow ponds and thus provide a hazard. Farmers or workers should manage vegetation on pond dikes, which is often terrestrial vegetables or fruit for human consumption.

Macrophagous fish such as grass carp eat vegetation, thereby eliminating the breeding habitat of mosquitoes, and most fish directly consume mosquito larvae and pupae (Edwards, 1992).

A more or less complete plant cover on the surface of a duckweed aquacultural system can prevent mosquitoes from breeding, as the deposition of egg-rafts would be prevented and the larval stages would be unable to surface for breathing. The common name of *Azolla*, an aquatic fern with the same form as duckweed, is "mosquito fern," possibly from its former use in Europe and North America to prevent mosquitoes from breeding in shallow water by covering the water surface. Research in China and India with applications of *Azolla* in rice fields has shown that mosquito production is often already past its peak by the time full coverage by such weeds has been achieved.

5.3 Trematodes: Special considerations

As discussed in chapter 2, trematodes (including schistosomes) are found only in limited geographical regions. However, because their transmission is associated with the consumption of fish and plants and may cause severe health outcomes, a separate section on their control has been added to the Guidelines. Figure 5.2 illustrates potential trematode inputs to waste-fed aquacultural systems and indicates some possible control measures; the possible health protection measures at different stages of waste-fed aquaculture are elaborated in the explanatory text underneath. Table 5.4 describes in more detail possible health protection measures at different stages of the waste-fed aquacultural process.

5.3.1 Reducing trematode contamination of ponds and interrupting trematode life cycles

Wastewater and excreta entering a pond may be sources of trematode parasites. However, even if the wastewater and excreta are treated to inactivate or remove trematodes, other sources of the pathogens may also contaminate the ponds (see Figure 5.2). Experiments in Viet Nam, Thailand and the Lao People's Democratic Republic to prevent contamination of fish flesh by *Clonorchis sinensis* and *Opisthorchis viverrini* metacercariae in fish ponds identified the water supply, fish fry, fish feed and pond conditions as potential hazards. By initiating preventive actions at these points, researchers were able to eliminate metacercarial infections of fish in the experimental ponds. However, in the control ponds without interventions, 45% of the fish were infected with *C. sinensis* metacercariae (Son et al., 1995). Similar results were obtained for *O. viverrini* (Son et al., 1995).

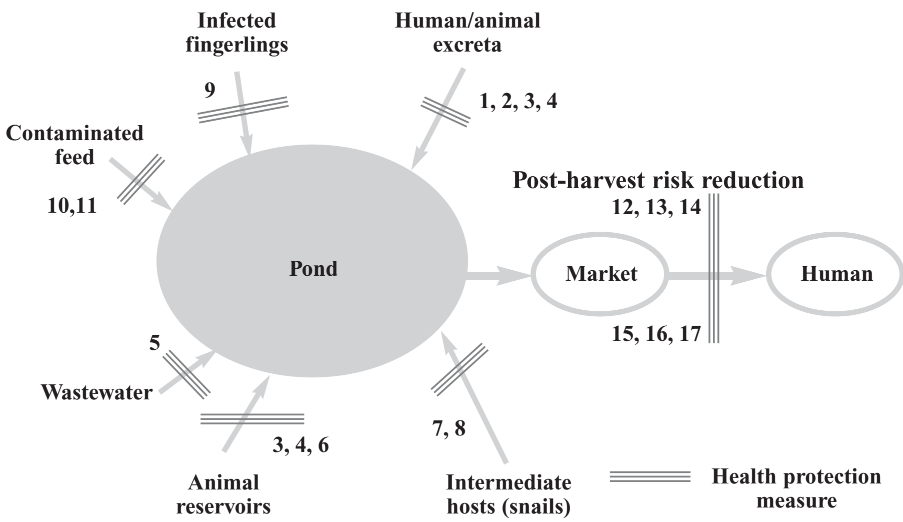


Figure 5.2
Health protection measures against trematodes in waste-fed aquaculture (see Table 5.4 for details on numbered health protection measures)

Table 5.4 Health protection measures against trematodes

	Health protection measures
Sources of hazards	
Human/animal excreta	1. Treat wastes by storage for >30 days prior to addition to the pond.
	2. Prevent deliberate and accidental faecal contamination through surface runoff and household latrines connected to ponds. Replace overhanging fish pond latrines with safer sanitation facilities.
	3. Keep animals away from ponds.
	4. Treat infected humans and other animals with appropriate medication.
Wastewater	5. Treat wastewater by adequate methods to remove or inactivate trematode eggs. See also Annex 1 on waste-fed aquacultural fish pond design.
Animal reservoirs	3. Keep animals (e.g. cats, dogs) away from ponds.
	4. Treat infected domestic animals with appropriate medication.
	6. Dispose of raw fish remains after cleaning so that animals cannot access them.
Intermediate hosts (snails)	7. Remove vegetation from ponds and pond surroundings.
	8. Use other snail control techniques as appropriate.
Infected fingerlings	9. Prevent faecal contamination of fingerling production ponds.
Contaminated fish feed	10. Process fish feed to inactivate trematode metacercariae.
	11. Use non-infected fish to produce fish feed.
Post-harvest controls	
Cooking	12. Cook fish or plants thoroughly prior to consumption.
	13. Clean knives and other utensils carefully to remove any eggs, which tend to adhere to such surfaces.
Hygiene	14. Wash hands thoroughly after handling and cleaning fish.
Health promotion	15. Educate children and communities at risk about parasite life cycles and how to prevent infection.
Food processing	16. Fish or plants may be processed at home or commercially with heat, acid, salt, irradiation, freezing, drying or combinations of these processes to inactivate infective trematode metacercariae.
Fish and plant inspection	17. Fish and plants in the market should be periodically inspected to indicate contamination problems and trigger implementation of health protection measures by local health authorities.

In trematode-endemic areas, a variety of domestic and wild animals may act as reservoirs. The definitive animal hosts of *Clonorchis sinensis* include cats, dogs, rats and possibly also pigs. Cats and dogs have been linked to the ongoing transmission of *Opisthorchis viverrini* in Thailand and the Lao People's Democratic Republic. *Fasciola hepatica* infects a variety of domestic and wild animals, including cattle, sheep, goats, buffaloes, camels, llamas, deer, pigs, horses and rabbits (WHO, 1995). Therefore, it is important to take measures to reduce trematode infections in domestic animals by preventing their access to ponds (e.g. by constructing fences or other barriers) by domestic and wild animals that might be infected. Fish remains (e.g. from households and food processing plants) should be disposed of in such a way as to prevent animals from consuming them raw or otherwise inadequately treated (Lun et al., 2005). In practice, it may be difficult to reduce the introduction of trematode eggs into ponds from wild and domestic animals.

Trematodes that have infected fish may remain as infective metacercariae for the life of the fish. Thus, fish that are infected with trematodes as fingerlings can carry infective metacercariae in their tissues until they are harvested. Therefore, it is also

Trematodes that have infected fish may remain as infective metacercariae for the life of the fish. Thus, fish that are infected with trematodes as fingerlings can carry infective metacercariae in their tissues until they are harvested. Therefore, it is also important to manage fingerling production ponds in the same manner as grow-out ponds to prevent trematode contamination.

Fish feed used in aquaculture should be processed in such a way as to render any infective metacercariae present in the fish flesh or on the plant surface non-infective. This can be done through a series of processing techniques, including heating or drying fish or plants prior to addition to feeds (WHO, 1995).

5.3.2 Control of intermediate hosts

Snail control is one way of interrupting the life cycle of the parasite and thus preventing human infection. Appropriate snail control approaches should be based on an adequate understanding of snail ecology and the environment. Most of the intermediate hosts of *Fasciola hepatica* live in marshy ground, and water is essential for snail reproduction and for transmission of the parasite. It is therefore possible to reduce snail populations by physical means, such as the installation of drainage channels or the removal of vegetation from ponds and the surrounding dikes (WHO, 1995).

Control of foodborne trematode infections by use of molluscicides or other snail control methods has not been attempted except in the case of animal fascioliasis. Before introducing chemical snail control measures, the impact on the cultured fish, on the quality of the fish or plants and on the environment should be considered (WHO, 1995).

5.3.3 Post-harvest health protection measures

With the exception of schistosomiasis, trematode infections are transmitted through the consumption of contaminated fish or plants and not via direct contact.[1] Once fish flesh or plants contain infective metacercariae, disease transmission can be stopped by processes that render the metacercariae non-infective. Cooking food products thoroughly prior to consumption is the most effective method of preventing trematode transmission from contaminated products. However, the practice of consuming raw fish or aquatic plants is often firmly anchored in cultural traditions, and it may be difficult to change these behaviours (WHO, 1995).

There is also evidence to suggest that people who have been handling or cleaning infected fish can become infected via the accidental ingestion of infective metacercariae on their hands (Lun et al., 2005). Thus, washing hands thoroughly with soap and water after handling or cleaning freshwater fish or plants is an important health protection measure.

Post-harvest processing of fish and plants to inactivate infective larvae is possible either by the consumer or by commercial food processors. For further information on food processing techniques to inactivate trematode metacercariae, see WHO (1995). Apart from extensive washing (which may damage plants), few specific preparation procedures can reduce the risk from trematode-contaminated plants, especially because they are usually eaten fresh and not after processing (e.g. watercress). Metacercariae of *Fasciolopsis buski* can be inactivated by drying the plants or dipping them in boiling water prior to consumption (Feachem et al., 1983).

[1] In human endemic areas, fascioliasis is thought to be transmitted via the consumption of contaminated drinking-water in addition to the consumption of contaminated plants (see Mas-Coma [2004] for more discussion of human fascioliasis).

Food inspectors may periodically inspect fish and plants for the presence of infective trematode metacercariae and prevent their sale in the market, but this is likely to prevent only a small fraction of contaminated products from reaching consumers. Techniques for fish and plant inspection are described in WHO (1995). Food inspection can be used to identify contamination problems and trigger health protection measures by local authorities.

5.3.4 Chemotherapy of humans and animals

Humans who have been diagnosed with trematode infections can be effectively treated. Chemotherapy reduces the prevalence and intensity of infection in the target population, as measured by faecal egg counts. Treatment also reduces morbidity, although the effects are greater in the initial stages of disease than once it is advanced. After chemotherapy, reinfection occurs in endemic areas, but faecal egg counts in infected individuals are much lower than before treatment (WHO, 1995).

The use of chemotherapy in the control of foodborne trematode infections should be based on sound epidemiological data for the target population. It may be feasible to examine a high-risk group, such as school-age children, as an indicator of the prevalence in an entire population. Community-based treatment without epidemiological data for monitoring its effect is not recommended. In most control programmes, annual treatment is provided for the target population for up to three years. After this initial phase, reduced prevalence can be maintained by treatment through local health services (WHO, 1995).

Several approaches to community-based treatment can be used (WHO, 1995). They include:

- *Mass treatment:* Treatment of entire populations without regard for individual infection status.
- *Selective population treatment:* Treatment of infected people identified by a diagnostic survey of the whole population.
- *Selective group treatment:* Treatment of all members or of infected members of a high-risk age or occupational group.
- *Phased treatment:* Use of the above strategies in a sequence of progressively greater selectivity.

Epidemiological data indicating a high prevalence of infection at the beginning of a control programme may justify the treatment of entire populations without further individual diagnosis. If the response is satisfactory, according to predefined goals for coverage of the population and reduction of infection levels, selective approaches are then recommended. Unnecessary treatment is unacceptable; after mass treatment, various minor, transitory side-effects are likely to be seen in the treated population (WHO, 1995).

Longitudinal studies on the retreatment of opisthorchiasis have been completed in endemic areas in the Mekong Basin. In Thailand, 90% of the people treated (all of whom had initial egg counts of less than 10 000 eggs per gram of faeces) remained egg-negative two years after a single treatment. Among the 10% who remained egg-positive, the infections were light, and no unusual clinical symptoms were noted. In general, retreatment for opisthorchiasis should be carried out at yearly intervals for up to three years, after which the need for it should be determined by epidemiological surveillance (WHO, 1995).

In 1981, a small pilot programme to reduce opisthorchiasis infections in Khon Kaen province, Thailand, was initiated. The programme used a combination of annual single-dose chemotherapy (40 mg of praziquantel per kilogram of body weight), intensive health education directed at improving food habits and promotion of latrine construction and use (Sornmani, 1988). After two years, opisthorchiasis was reduced from an initial prevalence of 56% to less than 10%, and the incidence of new infections and mean faecal egg output were also reduced. Similar results were obtained when the project was extended to seven north-eastern provinces of Thailand in 1988 (WHO, 1995). Mass chemotherapy programmes have also been successful in reducing trematode infections in Japan and the Republic of Korea (WHO, 1995).

Few, if any, studies have been obtained on treatment of animals (e.g. cats, dogs, pigs) as a mean of preventing/reducing the introduction of trematode eggs into aquacultural ponds. It seems unlikely that such an approach will be feasible in most places where waste-fed aquaculture is practised.

5.3.5 Schistosomiasis

Schistosomiasis or bilharziasis is a waterborne disease caused by the infection of the intestinal and urinary venous system by trematodes of the genus *Schistosoma*. Schistosomiasis infects 200 million people globally, mostly in sub-Saharan Africa, of whom 20 million suffer severe consequences (WHO, 2001). As disease incidence has increased with the construction of reservoirs and irrigation schemes, there is a need to consider the possible role of waste-fed aquaculture in its transmission. The relationship between schistosomiasis and aquaculture has been reviewed previously by McCullough (1990) and Edwards (1992). Although most schistosomiasis occurs in sub-Saharan Africa, where there is very little waste-fed aquaculture, there are still pockets of schistosomiasis in parts of Asia where waste-fed aquaculture is practised, and thus precautions should be taken so that waste-fed aquaculture does not increase schistosomiasis transmission in these areas.

Humans are the definitive hosts of schistosomiasis infection. Infected humans discharge parasite eggs into the environment in faeces or urine. The eggs hatch into miracidia, which infect freshwater snails. The miracidia mature and asexually reproduce in the snails to become cercariae, which are released from the snails and infect humans who have entered the water for domestic, occupational or recreational purposes by penetrating their skin. Eggs cause damage to various organs, particularly the bladder and liver.

Schistosomiasis management strategies may involve controlling the snail intermediate hosts, for which a knowledge of their taxonomy, distribution and ecology is required (see Box 5.3). Not all areas, particularly in Asia, which has a much more localized distribution of schistosomiasis than Africa and the Americas, may have the snail intermediate hosts. Several snail species that act as schistosomiasis intermediate hosts thrive in static or slow-moving water containing some faecal pollution and may grow in waste-fed ponds, especially where there is vegetation, as they prefer to browse on plant surfaces. Habitat modification has played a major role in national schistosomiasis control programmes in Japan, where *S. japonicum* has been eradicated, and in China, where schistosome morbidity was reduced to very low levels (McCullough, 1990).

Box 5.3 Reduction of schistosomiasis in China

China reduced the number of schistosomiasis cases from 10 million in 1955 to fewer than 1 million in 1996. During this same period, aquacultural production dramatically increased. The Chinese strategy to reduce schistosomiasis focused on large-scale chemotherapy and snail control with molluscicides and environmental modification. Concerted efforts were made to reduce snail habitat in endemic areas by draining rivers and swamps. The Chinese experience shows that it is possible to reduce schistosomiasis incidence in endemic areas while simultaneously expanding aquacultural production.

Source: Hotez et al. (1997).

Besides environmental control of snail hosts, outlined above, chemical and biological means are also available. Molluscicides have been used to reduce the transmission of schistosomiasis in small water bodies, including ponds, but most are toxic to fish, which prevents their use where aquaculture is practised. Biological control of snail intermediate hosts by snail-eating fish has been researched, but it has rarely completely eliminated the snails. In Africa, the use of crayfish to eat snails has been investigated. Experiments in Kenya have shown that crayfish quickly eliminated snails that acted as intermediate hosts for schistosomiasis when added to ponds where the snails were present (Mkoji et al., 1992). Crayfish or other species that are non-indigenous to a region should be introduced only into areas in which they are already present to prevent possible ecosystem disruption.

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 in support of hands-on management; and verification, which usually takes place at the end of the process to ensure that the system is achieving its specified targets.

The most effective means of consistently ensuring safety in waste-fed aquaculture is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in waste-fed aquaculture, from the generation and use of wastewater and excreta to the product consumer. This approach is captured in the Stockholm Framework (see chapter 2). System assessment and its components are discussed in section 6.3.

6.1 Monitoring

The combination of health protection measures adopted in a particular waste-fed aquacultural use scheme is a system that requires regular monitoring to ensure that it continues to function effectively. Monitoring, in the sense of observing, inspecting and collecting samples for analysis, however, is not sufficient on its own. Institutional arrangements must be made for the information collected to provide feedback to those who implement the health protection measures. In other words, answers must be provided in advance to the following questions:

1) What monitoring information will be collected?
2) How often will monitoring information be collected, and by whom?
3) To whom will this monitoring information be given?
4) What decisions will be taken on the basis of the monitoring information?
5) What instruments will exist to ensure that those decisions are implemented?

Answering question 4 requires a set of guidelines or standards with which the monitoring results can be compared. There are two types of answer to question 5. First, in the case of monitoring by an operating agency, those who interpret the monitoring information can simply give orders to their subordinates to take any corrective action needed. Second, in the case of surveillance by an enforcement agency (e.g. a Ministry of Health), the agency must have legal powers to enforce compliance with quality standards and other legislation. A complete monitoring and control system therefore needs:

- guidelines or standards;
- monitoring or surveillance to assess compliance;
- institutional arrangements for feedback and/or enforcement.

The responsibility for the monitoring of health protection measures should be clearly defined.

6.2 Monitoring functions

The three functions of monitoring are each used for different purposes at different times (see Table 6.1). Operational monitoring is used on a routine basis to indicate

Table 6.1 Definitions of monitoring functions

Function	Definition
Validation	Obtaining evidence that the measures employed to control the hazards are adequate to meet the targets (e.g. that the type of excreta treatment selected is capable of inactivating trematode eggs)
Operational monitoring	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)
Verification	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. non-detection of viable trematode eggs, lack of infective metacercariae in fish flesh)

Source: Adapted from NRMMC/EPHCA (2005).

that processes are working as expected. Monitoring of this type relies on simple measurements that can often be read in real time so that decisions can be made quickly to remedy a problem. 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. Verification is used to show that the end product (e.g. treated wastewater and excreta; plant or fish) meets treatment targets (e.g. microbial quality specifications; no infective metacercariae in fish flesh) and ultimately the health-based targets (e.g. absence of trematode infections in the population exposed to waste-fed aquacultural activities). Information from verification monitoring may arrive too late to allow a manager to make management 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).

6.3 System assessment

The first step in developing a risk management system is to form a multidisciplinary team of experts with a thorough understanding of waste-fed aquaculture. Typically, such a team would include aquacultural 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 some independent members, such as from universities.

Effective management of the waste-fed aquacultural system requires a comprehensive understanding of the system, the range and magnitude of hazards that may be present and the ability of existing processes and 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 waste-fed aquacultural production process. Figure 6.1 illustrates the development of a risk management plan.

The assessment and evaluation of a waste-fed aquacultural system are enhanced through the development of a flow diagram. Diagrams provide an overview description of the system, including the identification of sources of hazards and health protection measures. It is important that the representation of the waste-fed aquacultural system is 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 the diagram against features observed on the ground. Table 6.2 provides a description of potential hazards and their respective control measures at different points in the system

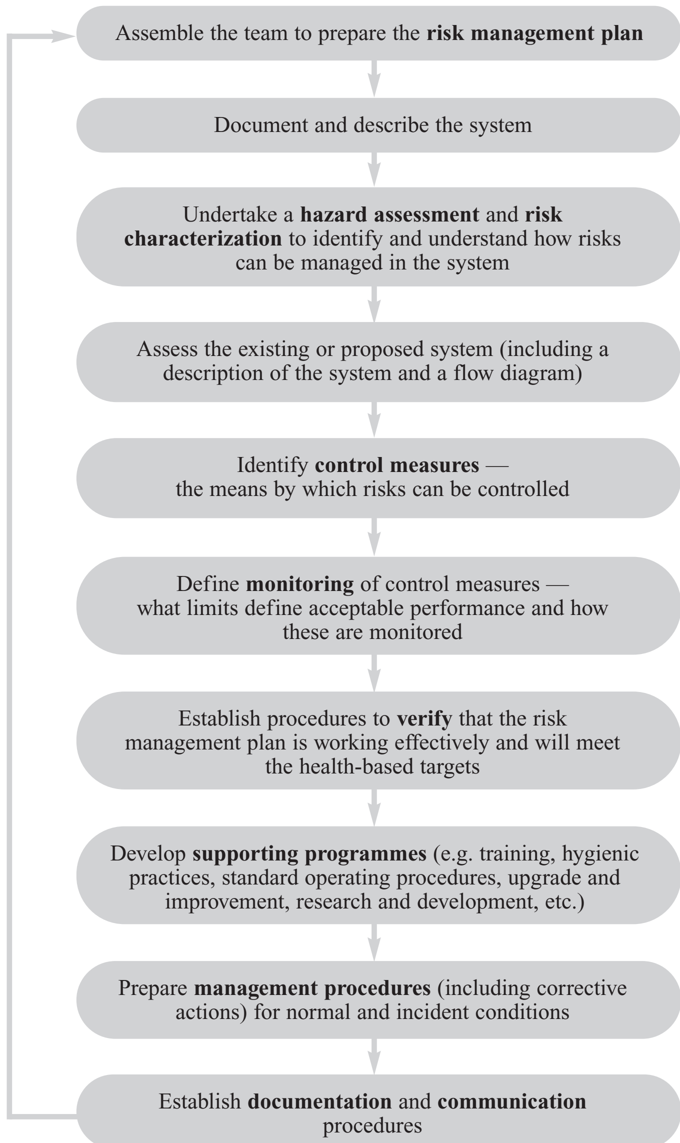


Figure 6.1
Development of a risk management plan (from WHO, 2004a)

Table 6.2 Waste-fed aquacultural system components and health protection measures

System component	Health protection measure
Waste → water body	Waste treatment
	Provision of sanitary facilities near aquacultural schemes
Water body → fish, aquatic plants	Waste application, frequency and timing
Water body → humans (including aquacultural pond)	Protective equipment (e.g. gloves, shoes)
	Limit access to children and animals (e.g. fences and signs)
	Good personal and domestic hygiene (e.g. wash hands and other exposed body parts with soap after water contact)
Water body → disease vectors/ intermediate hosts	Biological, chemical and physical control of disease vectors and intermediate hosts (e.g. remove vegetation next to ponds, control snail populations, introduce mosquito larvae predators)
Disease vectors/intermediate hosts → water, fish, aquatic plants	Biological, chemical and physical control of disease vectors and intermediate hosts (e.g. remove vegetation next to ponds, control snail populations, introduce mosquito larvae predators)
Disease vectors/intermediate hosts → humans	Prevent vector contact (e.g. mosquito nets, window screens, chemical repellents, adequate clothing)
	In case of schistosomiasis, prevent contact with contaminated water
Fish, aquatic plants → humans	Depuration (effective for certain pathogens when contamination is low)
	Produce restriction (e.g. growing fish/plants for non-human consumption)
	Improve plant harvesting techniques to reduce/prevent contact with waste-fed water
	Protective equipment
	Personal/domestic hygiene
	Food hygiene (e.g. avoiding cross-contamination from fish gut contents to muscle and from plants to other foodstuffs)
	Cook food thoroughly prior to consumption
	Fish and plant inspection for trematode metacercariae
Humans → infection/disease	Immunization
	Chemoprophylaxis
Infection/disease	Chemotherapy

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 waste-fed aquacultural system are considered concurrently and that interactions and influences between elements and their overall effect are taken into consideration.

6.4 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 health-based 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 and excreta treatment, depuration, food processing to inactivate infective metacercariae, etc.), when equipment is upgraded (e.g. new toilet design) or when new equipment or processes are added (e.g. addition of lime to excreta). 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 could confirm that the design retention time was being achieved in practice. Validation of an on-site excreta treatment/storage system could provide data on trematode egg die-off under different conditions (e.g. temperature, moisture content, after addition of lime, etc.).

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 waste 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).

6.5 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, pond systems, on-site excreta treatment/storage facilities, waste application techniques, use of protective clothing, sanitary conditions in the market and hygienic fish handling and processing. 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 and excreta 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, storage times in an on-site excreta treatment system, presence of aquatic plants in waste-fed aquacultural ponds (habitat for the snail intermediate host of trematodes) and the presence of suitable snail intermediate hosts for trematode reproduction. Operational monitoring should take place around system parameters that indicate the potential for increased risk of hazard break-through. It is facilitated by simple observations and measurements that can be taken quickly. For example, the presence of emergent vegetation in a fish pond may facilitate the breeding of disease vectors; this can be checked quickly by periodic visual inspections. Vegetation found can then be removed to reduce the associated risks. Examples of parameters that can be monitored are presented in Table 6.3.

Table 6.3 Validation, operational monitoring and verification monitoring parameters for different control measures

Control measure	Validation requirements	Operational monitoring parameters	Verification monitoring parameters
Wastewater and excreta treatment	Effectiveness of treatment processes at inactivating/removing pathogens and indicator organisms (*E. coli*, trematode eggs, other helminths, e.g. *Ascaris*) 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	*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) Total ammonia-nitrogen *High-rate processes:* BOD Turbidity pH Organic carbon Particle counts Membrane integrity (pressure testing) Chlorine residual	*E. coli* Viable trematode eggs (including *Schistosome* spp., where appropriate) Helminth eggs (*Ascaris*) Locally important toxic chemicals
Health and hygiene promotion	Testing of promotional materials with relevant stakeholder groups	Local programmes in operation Promotional materials available Promotion included in school curriculum	Increased awareness of health and hygiene issues in key stakeholder groups Improved practices
Chemotherapy and immunization[a]	Effectiveness of different vaccines/ drugs in preventing or treating locally important infections	Numbers of people immunized/treated Villages/schools targeted near waste-fed aquacultural facilities Frequency of campaigns	Reduced prevalence and intensity of infections Fewer disease outbreaks in targeted areas
Product restriction	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	Types of fish and plant species grown in waste-fed aquacultural facilities	Water quality testing of ponds to ensure that plants or fish eaten raw meet the WHO microbial requirements

Table 6.3 (continued)

Control measure	Validation requirements	Operational monitoring parameters	Verification monitoring parameters
Waste application/ timing	Test the amount of time needed under different climatic conditions and for different pathogens/ indicators between waste application and harvest of fish and plants to ensure minimal contamination	Monitor waste application timing and time to harvest	Monitor pond water quality
Depuration, food handling and preparation, produce washing, disinfection, food processing, cooking foods	Research on which methods are most effective in reducing or preventing cross-contamination, pathogen inactivation Testing of educational materials among relevant stakeholders	Inspection by food safety authorities to ensure that proper procedures are being used at markets or restaurants where products are prepared	Periodic microbial testing of the hygiene of food preparation spaces in markets and restaurants, product testing to investigate where contamination occurs
Access control, use of personal protective equipment	Testing access control measures for effectiveness in preventing public exposures to wastewater and excreta Testing 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	Visual inspection of aquacultural facility for warning signs, fences, etc. Visual inspection of workers to ensure that they are wearing the appropriate personal protective clothing	Public health surveillance of workers to document reductions in skin diseases, schistosomiasis (where relevant) and hookworm
Intermediate host and vector control	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 biological measures such as mosquito-eating fish	Visual inspection of facilities to observe vegetative growth in and near ponds Inspection of waters for relevant insect larvae or snail intermediate hosts	Public health surveillance to document vector-borne diseases or schistosomiasis in workers, foodborne trematode infections in product consumers

[a] Immunization, chemoprophylaxis and chemotherapy are considered to be supplementary health protection measures and should not be used instead of other health protection measures such as wastewater/excreta treatment.

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 waste-fed 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 specifications are not met, then there is the potential for a hazard break-through. The amount of time needed to correct an action should determine the frequency of operational monitoring. For example, with waste stabilization pond systems used in conjunction with aquaculture, operational monitoring for various parameters (see Table 6.3) 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. For the treatment of excreta, storage time and temperature can be monitored to indicate pathogen inactivation.

A variety of physicochemical parameters should be monitored at regular intervals to verify the performance of a waste treatment system. Five-day biochemical oxygen demand, 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 measure helminth eggs, which requires a trained parasitology technician and suitable laboratory facilities.

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 are being grown (e.g. fish), then it will be necessary to monitor the relevant chemicals.

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 logical sampling plan, to minimize negative public health impacts (WHO, 2004a).

6.6 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 water and excreta quality, verification is likely to include microbial testing. In most cases, it will involve the analysis of faecal indicator microorganisms, but in some circumstances it may also include assessment of specific pathogen densities (e.g. *Ascaris* ova and viable trematode eggs). Verification of the microbial quality of wastewater and excreta may be undertaken by local public health agencies.

Approaches to verification include testing of wastes after treatment or wastes 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 freedom from 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.

6.7 Small systems

Validation, operational monitoring and verification monitoring are important steps to identify and eventually mitigate public health issues that might be associated with waste-fed aquaculture. However, waste-fed aquaculture can be difficult to monitor, because it takes place mostly at the subsistence level, with small facilities spread out in many locations. Additionally, much of the waste-fed aquaculture that is practised is indirect and informal (e.g. aquacultural activities take place in faecally contaminated surface waters) and is therefore harder to plan and control. Governments and particularly local authorities will need to develop ways of supporting small systems in building their capacity to take on monitoring tasks addressing the most important local public health issues, and taking into account the local availability of professional staff and access to laboratory facilities.

When many household-level ponds are involved in waste-fed aquaculture, 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 aquacultural 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 if latrines empty directly into a fish pond or if emergent vegetation is present that will facilitate vector and intermediate host breeding. Similarly, food markets can be quickly inspected visually to detect unsafe fish cleaning and preparation activities. Local authorities will have knowledge about which fish or plant species are frequently eaten raw and can thus identify these species in facilities where control measures are not adequate to reduce the risk.

Verification monitoring may be easier to conduct at a central point (e.g. a fish market). In areas where foodborne trematode infections are common, fish flesh and plants can be periodically inspected for infective metacercariae. Inspecting fish and plants for infective metacercariae requires trained staff and a microscope but otherwise does not require expensive laboratory reagents and is relatively uncomplicated. Data from public health surveillance for foodborne trematodes, schistosomiasis, intestinal helminth infections and other locally important diseases should be used to adjust health protection measures as necessary.

6.8 Other types of monitoring

6.8.1 Food inspection

Periodically, the microbial and chemical contamination of waste-fed products should be tested. Products should be tested for *E. coli* or thermotolerant coliforms and possibly others, such as trematode metacercariae, where relevant. 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 safe limits as specified by the Codex Alimentarius Commission (see chapter 4).

It is often useful to test the products at different steps — that is, immediately after harvest, after transportation to the market, after processing at the market or at home and at the point of consumption (e.g. after cooking or raw, if it will be consumed that way). This type of monitoring can indicate points where contamination may occur. For example, experiments in Viet Nam indicated that most of the fish flesh contamination occurred post-harvest during processing, and thus health protection measures aimed at fish processing would have more impact than, for example, treating the wastewater to a higher degree (Lan et al., in press).

6.8.2 Public health surveillance

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

7
SOCIOCULTURAL, ENVIRONMENTAL AND ECONOMIC ASPECTS

This chapter presents information on the sociocultural, environmental and economic aspects associated with waste-fed aquaculture. These aspects should be taken into account when developing health protection measures. More information on these issues is presented in *Volume 2: Wastewater use in agriculture* and *Volume 4: Excreta and greywater use in agriculture*.

7.1 Sociocultural aspects

Human behavioural patterns are a key determining factor in the transmission of excreta-related diseases. The social feasibility of changing certain behavioural patterns in order to introduce safe excreta or wastewater use schemes or to reduce disease transmission in existing schemes can be assessed only with a prior understanding of the cultural values attached to practices that appear to be social preferences, yet which facilitate disease transmission. Cultural beliefs vary so widely in different parts of the world that it is not possible to assume that any of the practices that have evolved in relation to excreta and wastewater use can be readily transferred elsewhere; a thorough assessment of the local sociocultural context is always necessary (Cross, 1985). However, there does appear to be a positive correlation between the occurrence of traditional waste use in societies and their population density, which has been called the "nutritional imperative." Societies that use excreta or have used it in the recent past in agriculture or aquaculture are the most densely populated: Europe, India, China and South-east Asia (Edwards, 1992).

Closely associated with cultural beliefs is the public perception of wastewater and excreta use. There seems to be more acceptance of wastewater and excreta use when it is indirect. Psychologically, it may be easier to use faecally contaminated river water for aquaculture than to use wastewater or excreta directly. The use of wastewater and excreta is also easier to accept by the public in conditions of water scarcity or when there are obvious benefits associated with their use, such as higher fish or plant yields.

7.1.1 Public perception

The maintenance of good public relations by food producers, especially with respect to protection of consumer health, is important. The public must have confidence that the food they are consuming is in no way harmful to their health. In this respect, programmes for the routine monitoring of wastewater and excreta and of produce quality are extremely important, as is the demonstrated absence of the transmission of infectious disease.

The public perception of wastewater and excreta use in aquaculture varies much from one community to another. Communities with high incomes and without previous contact with wastewater and excreta frequently oppose it due to possible health risks, environmental issues, odour problems and possible decreases in property values. The situation is completely different in poor areas with lack of work opportunities, where the use of wastewater and excreta represents a possibility to improve the quality of life by increasing incomes and contributing to food security (Hussain et al., 2001). When a community or part of a city is developed and people's social and economic status improves, the public perception can change from a general acceptance of wastewater and excreta use to reluctance and an opposition towards such usage.

It is important to recognize that even in situations where advanced wastewater and excreta treatment processes will be used and effective health risks will be very low, negative public perception can derail even well planned projects. Bridgeman (2004) outlines several conclusions regarding public perception that arose during the development of various wastewater and excreta use projects in California, USA:

- Public perception varies by community; there is no one solution that will work in all communities. Outreach programmes must be based on a comprehensive understanding of the profile of the community that the planned project is to serve. From this, stakeholder-specific action plans should be developed.
- Community participation and stakeholder participation at the earliest stages of the project are both important.
- The strength of public opinion regarding the use of wastewater and excreta must never be underestimated.
- Consistent, clear and reliable communication with the community is important. Key messages should be presented in a manner that is understandable to community members.
- Public outreach should be proactive and not reactive.
- Successful projects require trust between the project planners and the potential recipients.
- Messages should be focused on the positive benefits of the project.
- Education of the recipient communities is essential for projects to succeed.
- Timing of implementation and careful monitoring of public opinion are important. Communities may be more receptive to wastewater and excreta use projects when they are faced with a drought.
- Regardless of the economic and scientific basis behind the proposals for schemes, there might be people who, for their own reasons, will never accept waste-fed aquaculture.
- Monitoring programmes are key elements for reassuring the public.

7.1.2 Excreta use

Human society has evolved very different sociocultural responses to the use of untreated excreta, ranging from abhorrence through disaffection and indifference to predilection. For example, in Africa, the Americas and Europe, excreta use is generally regarded with disaffection or, at best, indifference. This results from the strongly held view that human excreta, especially faeces, are repugnant substances best kept away from the senses of sight and smell. Products fertilized with raw excreta are regarded as tainted or defiled in some way. Such views are not held, or at least not so rigidly, in relation to excreta-derived compost or wastewater sludges, and these materials are commonly used in agriculture, horticulture and land reclamation schemes.

In contrast, both human and other animal wastes have been used in agriculture and aquaculture in, for example, China, Japan and parts of Indonesia for centuries. This practice is in social accord with the Chinese and Japanese traditions of frugality and reflects a deep ecological, as well as economic, appreciation of the dependent relationship between soil fertility and human wastes. In such societies, intensive cultivation practices have evolved in response to the need to feed a large number of people living in an area of limited land availability, and this has necessitated the careful use of all the resources available to the community, including excreta. Thus, excreta use is dictated by survival economics. Even so, any attempts to minimize health risks by altering the established excreta use practices are likely to meet with social acceptance and success only if the changes are minor and socially unimportant. Attempts to alter a social preference, such as the consumption of certain raw fish dishes at celebrations, are more likely to fail.

In Islamic societies, direct contact with excreta is abhorred, since by Koranic edict excreta are regarded as containing impurities (*najassa*). Their use is permitted only when the *najassa* have been removed. Thus, the agricultural use of untreated excreta would not be tolerated, and any attempt to modify this would be futile. On the other hand, excreta use after treatment would be acceptable if the treatment is such that the *najassa* are removed — for example, after thermophilic composting, which produces a humus-like substance that has no visual or odorous connection with the original material. *Najassa* may be deemed to be removed in other ways. In Indonesia, for example, it is acceptable to fertilize fish ponds with untreated excreta, because the excreta are diluted by the pond water and because the water flows from one pond to the next; this combination of dilution and flow is considered to render the water pure (*tahur*), and so the practice is religiously acceptable.

In many developing countries, the task of collecting urban nightsoil is regarded as employment of very low status; consequently, it is becoming increasingly difficult for urban authorities to recruit people for such work. As a result, sanitation facilities that produce nightsoil, such as bucket latrines, are being replaced by those that do not, such as pour-flush latrines. Indeed, in some countries (e.g. India), the government is promoting programmes to replace bucket latrines with pour-flush toilets not only for reasons of improved health but also because of "society's demand for doing away with the degrading practice of human beings carrying nightsoil loads" (Venugopalan, 1984). There is a trend for nightsoil to be replaced by latrine sludges as the raw material in excreta use schemes. From the viewpoint of excreta-related disease control, this is to be welcomed, as the pathogen load, and hence the potential risk to health, is substantially reduced.

7.1.3 Wastewater use

Untreated wastewater is currently used for aquaculture in different parts of the world, with the main practice in Asia. Although there does not appear to be any significant sociocultural revulsion at this practice because of economic necessity, treated wastewater is much less objectionable in appearance than untreated wastewater and, from a socioaesthetic viewpoint, is more suitable for agricultural and aquacultural use. Public fears may be allayed by suitably designed information programmes.

In Islamic countries, it has been judged that wastewater may be used for irrigation provided that the impurities (*najassa*) present in raw wastewater are removed. According to Farooq & Ansari (1983), there are three ways in which impure water may be transformed into pure water:

1) self-purification of the water (e.g. removal of the impurities by sedimentation);
2) addition of pure water in sufficient quantity to dilute the impurities;
3) removal of the impurities by the passage of time or physical effects (e.g. sunlight and wind).

The first and third of these transformations are essentially similar to those achieved by wastewater treatment processes, especially stabilization ponds.

In 1978, the Council of Leading Islamic Scholars of Saudi Arabia issued a fatwa (legal ruling on an issue of religious importance) concerning the use of wastewater in Islamic societies. The fatwa indicated that "impure waste water can be considered as pure water and similar to the original pure water, if its treatment using advanced technical procedures is capable of removing its impurities with regard to taste, colour and smell, as witnessed by honest, specialized and knowledgeable experts. Then it can be used to remove body impurities and for purifying, even for drinking. If there are negative impacts from its direct use on the human health, then it is better to avoid its use, not because it is impure but to avoid harming the human beings." The Council of Leading Islamic Scholars prefers to avoid using wastewater for drinking (where possible) to "protect health and not to contradict with human habits" (Faruqui, Biswas & Bino, 2001). A publication by Faruqui, Biswas & Bino (2001) goes into more detail on wastewater use in Islamic societies.

Nevertheless, untreated wastewater is in fact used in some Islamic countries, principally in areas where there is an extreme water shortage and then generally from a local wadi (ephemeral desert stream), but this is clearly a result of economic need and not of cultural preference.

In other contexts, knowledge that the waste-fed produce will be thoroughly cooked prior to consumption seems to make the use of wastewater and excreta more culturally acceptable. For example, people purchasing freshwater fish in the Kolkata market are well aware that the fish they purchase are grown in wastewater, but they eat the fish only after thorough cooking (e.g. deep-fat frying of the whole fish), and thus the practice is readily accepted.

7.1.4 Food-related determinants

Human foodborne trematode infections result from ingesting raw and inadequately processed fish, shellfish and water plants or from drinking water contaminated with metacercariae. Risks of human foodborne trematode infections are, therefore associated with dietary habits. Food habits often change with economic development. In Viet Nam, the improvement in people's socioeconomic status seems to have led to an increase in the consumption of raw and inadequately processed fish dishes. This, together with a general trend in consumption of "sushi-like" seafood, may increase risk for foodborne trematode infections. Several sociocultural, economic and behavioural factors promote the transmission of infection to humans (Box 7.1) (WHO, 1995).

Perceptions of food are related to beliefs, culture, taboos and traditions and are increasingly influenced by mass communication. Food habits are formed under particular social and economic conditions. When adapted by individuals or groups to other settings, they may be unsuitable or can even be harmful to health. For example, rural or indigenous peoples moving to urban areas or migrant workers, tourists or refugees living in foreign communities often maintain their food habits, although they may be inappropriate or inadequate to local conditions for food production, preparation or processing (WHO, 1995).

The sensory properties of a food, the anticipated consequences of ingestion and knowledge of the nature or origin of the food all interact to influence food choice, but the hedonistic response — like or dislike — is the major determinant (WHO, 1995).

Understanding the food-related determinants of foodborne trematode infections is the crux of any control strategy and is important for assessing the suitability of any alternative food sources or preparation methods proposed. Ultimately, these

Box 7.1 Examples of sociocultural practices that lead to disease transmission

Consumption of raw or undercooked fish and shellfish is widely prevalent around the world, particularly in areas near lakes, streams and ponds where fresh fish is readily available. In the Republic of Korea, raw fish is usually served at male social gatherings as an accompaniment to rice wine; this can result in infection with *Clonorchis* spp. and many species of intestinal fluke. In southern China, slices of raw fish are dipped in boiling soup for a moment and eaten with or without spices or sauce; another popular dish in China is raw fish in hot rice congee.

Crab soaked in soy sauce (*ke-jang*) is the main source of *Paragonimus* infection in the Republic of Korea, and pickled or wine-soaked ("drunken") crabs are considered a delicacy by the Chinese living in endemic areas of paragonimiasis. *Kinilow* (raw crab or fish) and *sinigang* (which includes crab) are favourite dishes in endemic areas of paragonimiasis in the Philippines, as is *pla poo* (raw crab) in Thailand.

Opisthorchis infection is acquired by eating raw or inadequately cooked, frozen, salted or smoked fish — for example, in the form of *koi pla* (raw fish) in Thailand. Similar local dishes are available in many other endemic countries.

In northern Luzon, in the Philippines, a 69% prevalence of *Echinostoma malayanum* infection in one area was associated with the long-standing tradition of eating raw *Lymnaea* snails.

Among plant carriers of trematode infections, some species of watercress are most commonly, although not always, responsible for human fascioliasis when eaten raw in green salads. Watercress is frequently consumed in southern Europe and outside Europe in countries to which southern Europeans have migrated. In Algeria, during the French occupation, outbreaks of fascioliasis occurred among Europeans living there, whereas no cases were recorded among native Algerians who did not eat watercress. A favourite snack, especially for rural children, is water caltrop, the most important vegetable source for fasciolopsiasis in East Asia. Changes in dietary habits towards "organically" grown or wild leaf vegetables are increasingly associated with human fascioliasis in Europe and the Americas among members of the upper social classes.

Crayfish are usually not eaten raw in the Republic of Korea. However, the traditional practice of using the raw juice of crushed crayfish as home treatment for measles has been a significant source of infection and may cause devastating neurological sequelae from cerebral paragonimiasis in children. In certain Cameroonian (Bakosi) and Nigerian (Calabar) tribes, raw crabs are believed to increase a woman's fertility. In Ecuador, parents grind up crabs (*Hypolobocera* spp.) and give the supernatant to their sick children as a medication.

Source: WHO (1995).

determinants will affect the extent to which changes in methods of food preparation and processing will be accepted and implemented (WHO, 1995).

7.2 Environmental concerns

Excreta and wastewater use schemes, if properly planned and managed, can have a positive environmental impact as well as producing fish and plants. Environmental improvement occurs as a result of several factors, the most important of which are:

- avoidance of surface water pollution, which would occur if the wastewater were not used but discharged into rivers or lakes; major environmental pollution problems, such as depletion of dissolved oxygen, eutrophication, foaming and fish kills, can be avoided;
- conservation or more rational use of freshwater resources, especially in arid and semi-arid areas: fresh water for urban demand, wastewater for aquacultural use;

- reduction in risks for flooding in urban areas, as wastewater-fed canals, ponds and lakes act as a "buffer" during heavy rains, thus preventing floods;
- reduced requirements for artificial fertilizers, with a concomitant reduction in energy expenditure and industrial pollution elsewhere.

In fact, waste-fed fish ponds function in a similar way to maturation ponds, the terminal ponds in a series of waste stabilization ponds, the primary purpose of which is to destroy pathogens and which are always aerobic. It is essential that farmers maintain a healthy environment in the pond for fish, to ensure good growth and production. Farmers have developed bioassays to manage waste-fed ponds through experience. These involve maintaining an optimal level of natural food production for fish in the pond, as indicated by the colour of water and the degree of light penetration into the water column. The farmers also test that there is adequate dissolved oxygen for the fish by observing the degree of surfacing behaviour of the fish at dawn when the pond oxygen concentration is at a minimum (Anon, 1980).

Excreta use in aquaculture would appear to have many of the advantages of wastewater use and fewer potential environmental disadvantages. Most on-site sanitation systems could be designed or adapted for use, and the resulting latrine sludges could be safely used.

A general overview of the two-way interaction between the environment and aquaculture is outlined in Box 7.2. Noteworthy is the positive impact of wastewater-fed aquaculture in the treatment of wastes to use nutrients and reduce eutrophication, as recognized in the United Nations Conference on Environment and Development's "Agenda 21," the United Nations action plan for sustainable development (United Nations, 1993).

The FAO Code of Responsible Fisheries, in Article 9, Aquaculture Development, encourages States to promote responsible development and management of aquaculture in relation to ecosystem integrity towards which waste-fed aquaculture contributes. States are advised to promote efforts to use appropriate fertilizers, including manures. Faecal sludge and wastewater are not specifically mentioned in the Code but fall under "manures." Sections of the FAO Code of Responsible Fisheries related to aquacultural development are presented in Annex 2.

7.3 Economic and financial feasibility

Economic factors are especially important when the viability of a new scheme for the use of wastewater and excreta is being appraised, but even an economically worthwhile project can fail without careful financial planning. Economic appraisal considers whether a project is worthwhile, whereas financial planning looks at how projects are to be paid for. Improvements to existing practices must be paid for in some way and therefore also require some financial planning.

7.3.1 Economic appraisal

The economic appraisal of a wastewater/excreta use project is undertaken to determine the cost-effectiveness of the project and whether it is worthwhile to proceed with it (Squire & Van Der Tak, 1975; Gittinger, 1982). This requires a calculation of the marginal costs and benefits of the project — that is, the differences between the costs and benefits of the project and the costs and benefits of the alternative. For a scheme to be viable, its marginal benefits must exceed its marginal costs.

Box 7.2 Overview of potential environmental interactions of waste-fed aquaculture

Impacts of the external environment on aquaculture may be positive or negative. Nutrient enrichment of water bodies may provide nutrients beneficial to aquacultural production in some extensive culture systems (e.g. culture-based fisheries in lakes and reservoirs, seaweeds). However, excessive loadings with wastewater and excreta can have severe consequences for aquacultural operations when exposed to contamination with toxic pollutants, pathogens and phytotoxins. With increasing aquatic pollution and physical degradation of aquatic habitats by other developments, aquaculturists can face risks of mass mortalities of farmed stock, disease outbreaks, product contamination and reduced availability of wild seed or broodstock. Unlike capture fisheries, aquaculture at least offers opportunities to adapt farming systems and management practices to optimize aquatic food production under sometimes suboptimal environmental conditions.

Many types of aquaculture can contribute positively to environmental improvement. Recycling of nutrients and organic matter through integrated farming systems is long recognized as being environmentally sound. Recent developments in integrated pest management have shown how rice–fish culture can help farmers reduce use of environmentally damaging pesticides. Wastewater-fed freshwater aquaculture and seaweed farming can be used to recover excess nutrients, thereby reducing risks of eutrophication, etc. Negative impacts have been associated mainly with high-input, high-output intensive systems and not waste-fed aquaculture. Misapplication of chemicals, collection of seed from the wild, introduction of exotic species and overuse of fishery resources as feed inputs have also raised concern in some locations.

Source: Adapted from Barg et al. (1997); Phillips & Macintosh (1997).

It may be necessary to consider important cost transfer implications where wastewater treatment and excreta treatment are concerned. For example, households that are wealthier may benefit from sewerage, but if the sewage is not treated, this may transfer costs to the poor in terms of adverse health impacts and on to society in general in terms of environmental impacts. There have been many cases where the costs of sewage treatment have not been accounted for during planning. Important "downstream" costs of sewage discharges that need to be considered include drinking-water treatment, degradation of the coastal environment, damage to fishing industries, recreational water pollution and lost tourism revenues.

Economic analysis should also be applied to the components of a system. For example, planners should conduct an analysis of various options for each component of the wastewater and excreta treatment and use system — including conveyance.

Some economic considerations include the following:

- Sewerage systems are expensive to build, operate and maintain; less expensive alternatives, such as settled sewage, condominial sewers and other technologies, may be available.
- The cost of pumping sewage can be substantial; wastewater and excreta treatment facilities should be planned in the same areas where the wastewater and excreta can be cost-effectively used with minimal pumping (e.g. ponds could be located downhill of treatment facilities).
- Low-cost, effective wastewater and excreta treatment technologies are available.
- Combinations of different treatment technologies (e.g. primary sedimentation plus polishing ponds) can increase pathogen removal efficiencies at low cost and provide flexibility for upgrading treatment facilities.

- Users of wastewater and excreta are often willing to pay for access to the wastewater and excreta.
- Wastewater and excreta tariffs may help to foster cost recovery.
- Differential prices for treated wastewater and excreta and fresh water may entice farmers to use wastewater and excreta instead of high-quality freshwater sources.
- Wastewater and excreta treatment facilities may be able to recover some treatment costs by growing and selling produce at the facility (see Box 7.3).

Box 7.3 Cost offsets from sale of aquacultural products raised in waste stabilization pond treatment systems in tropical and subtropical countries

In some cases, the sale of aquacultural products raised in treated wastewater can partially or completely offset treatment costs. Based on data generated from waste stabilization ponds in Lima, Peru, a model was developed that would calculate the revenues for different-sized waste stabilization pond treatment systems in tropical and subtropical areas. In tropical areas, the size of a system required to give an adequate financial return is lower, because warmer temperatures allow up to three fish harvests per year. For example, to produce 60 t per year, a waste stabilization pond system of 19 ha is required in subtropical climates, while for the same yield in tropical climates, a waste stabilization pond of just 9 ha is needed.

In a typical example for a tropical farm, the model calculates that initial investments of US$76 000 and US$16 000 for operational costs per year are required to produce 60 t of fish per year. The cost of raising fish is estimated at US$0.31/kg compared with a market price of US$1.00–3.00/kg. This low cost competes with commercial fishing and generates a 45% internal rate of return. Of course, it is necessary to determine in advance that products raised in the treatment system will be acceptable to consumers and that they can be sold for a reasonable price in the market. This example does not consider land cost and assumes that the project is located in uncultivated areas; however, the model can analyse profit variation according to different costs of land and water treatment. In some cases, the cost of treatment will be necessary to comply with local regulations in any case, and thus profits from the sale of fish will reduce these costs.

Sources: Cavallini (1996); UNEP (2002).

7.3.2 Financial feasibility

Where wastes are distributed by an agency separate from that which collects and treats them, a charge of some sort is normally payable. Charges are also levied when the wastes are distributed to individuals.

The level of these charges must be decided at the planning stage. The government must decide whether the charges should be set to cover only the operation and maintenance costs or set higher to recover the capital costs of the scheme as well. While it is, of course, desirable to ensure the maximum recovery of costs, an important consideration is to avoid discouraging the permitted use of the wastes. Some prior investigation of the willingness and ability to pay is therefore essential, not only in determining the level of charges but also in determining the frequency, timing and means of payment. For instance, an annual charge payable after the harvest season may be the easiest to collect.

On the other hand, sometimes aquacultural producers may be willing to share in the investment in treatment works that are a prerequisite to obtaining use permits. Their contribution may be in cash or in the form of land for treatment and storage facilities. Experiences in Peru have indicated that farmers may be willing to perform operational and maintenance tasks associated with treatment, storage and conveyance of wastewater, as in-kind contributions to the running costs of the scheme (Bartone & Arlosoroff, 1987).

A producer will pay for wastewater for aquaculture only if its cost is less than that of the cheapest alternative water and the value of the nutrients it contains. How, then, is the cost of the wastewater determined by the agency that sells it? There are three basic approaches to establishing the price of wastewater. It can be related to:

1) its production costs (additional treatment and conveyance);
2) the benefits derived from its use; or
3) some value judgement based on the user's ability or willingness to pay.

In the case of aquaculture, the price for the excreta or wastewater is usually based either on the marginal cost of treatment and conveyance or on the value of the nutrient (usually nitrogen) content, whichever is lower. There are several possible ways of charging for the waste, such as:

- per cubic metre;
- per hour of discharge from a standard sluice;
- per hectare of pond area.

It can also be paid in various ways:

- as a specific water rate or purchase price;
- as a renewal fee for an abstraction permit;
- as a surcharge on the land rent;
- as a deduction from the price of centrally marketed produce.

8
POLICY ASPECTS

The safe management of waste-fed aquacultural practices is facilitated by appropriate policies, legislation, institutional frameworks and regulations at the international, national and local levels. In many countries where waste-fed aquaculture takes place, these frameworks are lacking. This chapter looks at different country-level strategies for developing appropriate frameworks at each level that will help to encourage the safe use of wastewater and excreta in aquaculture. It is important that countries create appropriate waste-fed aquacultural policies based upon the specific conditions that occur nationally.

As Figure 8.1 shows, policy is the overall framework that sets national development priorities. It can be influenced by international policy decisions (e.g. Millennium Development Goals, Commission on Sustainable Development), international treaties or commitments (e.g. the United Nations Environment Programme's Global Programme of Action for the Protection of the Marine Environment from Land-based Activities) or multilateral development institutions. Policy may lead to the creation of relevant legislation. Legislation establishes the responsibilities and rights of different stakeholders — that is, the institutional framework. The institutional framework determines which agency is responsible for creating regulations and who has the authority to implement and enforce the regulations.

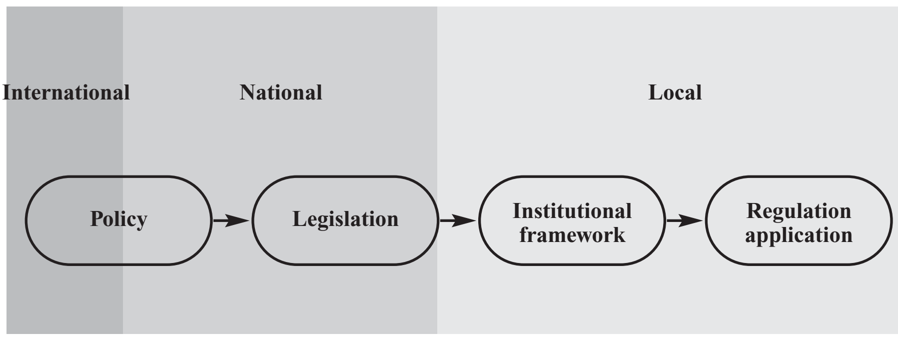


Figure 8.1
Policy framework

8.1 Policy

According to Elledge (2003), policy is the set of procedures, rules and allocation mechanisms that provide the basis for programmes and services. Policies set priorities, and associated strategies allocate resources for their implementation. Policies are implemented through four types of policy instruments:

1) *Laws and regulations:* Laws generally provide the overall framework. Regulations provide the more detailed guidance. Regulations are rules or governmental orders designed to control or govern behaviour and often have the force of law. Regulations for wastewater and excreta use can cover a wide range of topics, including the practices of service providers, design standards, tariffs, treatment requirements, water and excreta quality requirements, monitoring requirements, crop restrictions, environmental protection and

contracts. These regulations, especially treatment and water and excreta quality standards, have to be adapted to local conditions.

2) *Economic measures:* Examples of economic measures are user charges, subsidies, incentives and fines. User charges, or tariffs, are charges that households and enterprises pay in exchange for the removal of wastewater and excreta. Subsidies are allocations in cash or kind to communities and households for establishing recommended types of sanitation facilities or services. Fines are monetary charges imposed on enterprises and people for unsafe disposal, emissions and/or risky hygienic behaviours and practices, which are a danger to people and the environment.
3) *Information and education programmes:* These programmes include public awareness campaigns and educational programmes designed to generate demand and public support for efforts to expand sanitation and hygiene services.
4) *Assignment of rights and responsibilities for providing services:* National governments are responsible for determining the roles of national agencies and the appropriate roles of the public, private and non-profit sectors in programme development, implementation and service delivery.

8.1.1 International policy

International policy may affect the creation of national wastewater and excreta use policies. Countries agree to treaties, conventions, international development targets, etc. that may commit them to carry out certain actions. For example, countries may have commitments with respect to the Millennium Development Goals (as described in chapter 1) or the Commission on Sustainable Development or in relation to reducing the use and/or contamination of water resources that cross international boundaries (e.g. by requiring less freshwater abstraction or by requiring wastewater and excreta discharges to be treated to higher qualities to reduce basin-wide contamination). Another major issue is the worldwide export of food. As described in chapter 4, the WTO recognizes the rights of countries to establish standards for the safety of foods imported into their countries. Food products raised in compliance with the WHO *Guidelines for the safe use of wastewater, excreta and greywater* are internationally recognized as being developed within an appropriate risk management framework. This can help to facilitate international trade in safe food products produced with wastewater and excreta.

8.1.2 National wastewater and excreta use policies

Policy priorities for each country are necessarily different to reflect local conditions. National policy on the use of wastewater and excreta in aquaculture needs to consider various issues, including:

- the health implications of wastewater and excreta use in aquaculture (requirement for a health impact assessment prior to large-scale project implementation; see Annex 3) and setting of appropriate standards and regulations;
- water scarcity;
- the amount of wastewater and excreta generated now and in the future;
- locations where wastewater and excreta are generated;
- the acceptability of wastewater and excreta use in aquaculture;
- the extent and types of wastewater and excreta use currently practised;

- the ability to effectively treat wastewater and excreta and implement other health protection measures;
- downstream impacts if wastewater and excreta are not used for aquaculture;
- numbers of people dependent upon wastewater and excreta use in aquaculture for their livelihoods;
- trade implications of exporting fish or plants produced with wastewater and excreta.

8.1.3 Wastewater and excreta in integrated water resources management

Wastewater is increasingly being viewed in the greater context of integrated water resources management, especially in arid and semi-arid areas. Wastewater is often a reliable water resource, with constant flows even in the dry season. The use of wastewater and excreta in aquaculture should figure more prominently in water resources management, because it enables communities to reserve higher-quality water resources (e.g. groundwater or uncontaminated surface water) for uses such as drinking-water supply. The use of wastewater and excreta as a supplementary water resource is important in many communities in arid or semi-arid regions.

8.2 Legislation

If projects for the use of wastewater and excreta for aquaculture are to be introduced or promoted, legislative action may be needed. Legislation may both *facilitate* the safe use of wastewater and excreta by, for example, creating economic incentives for wastewater and excreta treatment and use facilities and *regulate* it by developing water quality or other standards. In many cases, it may be sufficient to amend existing regulations, but sometimes new legislation is required. The following areas deserve attention:

- creation of new institutions or allocation of new powers to existing bodies;
- roles of and relationships between national and local government in the sector;
- rights of access to and ownership of wastewater and excreta, including public regulation of its use (see Box 8.1);
- land tenure;
- public health and aquacultural legislation: wastewater and excreta quality standards, produce restrictions, application methods, occupational health, food hygiene, etc.

8.2.1 Institutional roles and responsibilities

Enabling legislation may be required to establish a national coordinating body for wastewater and excreta use and to set up local bodies to manage individual schemes. These will require authority either to charge for the wastewater and excreta they distribute or to sell any produce. Working within an existing institutional framework may be preferable to creating new institutions.

At the national level, waste-fed aquaculture is an activity that touches the responsibilities of several ministries or agencies. Examples of ministries or agencies that may have jurisdiction over the use of wastewater and excreta in aquaculture might include:

Box 8.1 Water access rights improve health

Giving people access and rights to water is an important step for improving health at the household and community levels through better nutrition and food supply. Many countries lack legal frameworks that ensure access to water rights, especially for the poor. To improve access to water, FAO (2002) suggests that legal reforms that cover the following issues are needed in many countries:

- allocation of water resources between different users, particularly those in rural and urban areas;
- minimizing conflict between those who use the resource for water supply and those who use it for waste disposal;
- promotion of efficient water use;
- regulation of use of wastewater and excreta so that they can be safely used;
- reduction of the role of government in rural water projects, increasing the importance of local user groups and removal of impediments to charging for water and recovering costs;
- evolution of systems of land tenure towards written and individual or group titles;
- ensuring legal access to land and water for female heads of household and women generally;
- creation or improvement of an effective water rights administration to manage the water sector in general and the rural water sector in particular.

Sources: IPTRID (1999); FAO (2002).

- *Ministry of Agriculture and Fisheries:* overall project planning; management of state-owned land; installation and operation of irrigation infrastructure; agricultural and aquacultural research and extension, including training; control of marketing.
- *Ministry of Environment:* sets wastewater and excreta treatment and effluent quality standards based on environmental concerns; establishes practices for protecting water resources (both surface waters and groundwaters) and the environment; establishes monitoring and analytical testing protocols.
- *Ministry of Health:* health protection, particularly establishment of quality standards and standards for "good practice" (for both treated wastewater and excreta; products; health protection measures), monitoring methods and schedules for treated wastewater and excreta; monitoring implementation of health protection measures; validation of health protection measures for small-scale waste-fed aquacultural producers; health education; disease surveillance and treatment.
- *Ministry of Water Resources:* integration of wastewater and excreta use into water resources planning, development and management.
- *Ministry of Education:* develop school curricula concerning sanitation and personal and domestic hygiene and safe practices related to the use of wastewater and excreta in aquaculture.
- *Ministry of Public Works/Local Government:* excreta and wastewater collection, treatment and use.
- *Ministry of Finance and Economic Planning:* economic and financial appraisal of projects; import control (equipment, fish feed); development of financing mechanisms for wastewater conveyance and treatment and use infrastructure.

Other ministries and government agencies — for example, those concerned with land tenure, rural development, cooperatives and women's affairs — may also be involved.

Cooperation between the relevant agencies is required, particularly between the technical staff involved. Some countries, especially those in which there are limited natural water resources, may find it advantageous to establish an executive body, such as an interagency technical standing committee, under the aegis of a leading ministry (Agriculture or Water Resources), or possibly a separate organization (with both government and private funding sources), such as an Office for Wastewater Recycling, to be responsible for planning, development and management.

In many countries, a simple *ad hoc* committee may be sufficient. Alternatively, existing organizations may be given responsibility for waste-fed aquaculture, or parts of it: for example, a National Water Board might be made responsible for waste use in aquaculture. Such an organization should then convene a committee of representatives from the different agencies having sectoral responsibilities. Setting up an interagency or interministerial committee will help to inform others of the challenges/ opportunities facing the sector.

In countries with a regional or federal administration, such arrangements for interagency collaboration will be important at the regional or state level. Whereas the general framework of wastewater and excreta use policy and standards may be defined at the national level, the regional body will have to interpret and add to these in the light of local conditions.

With regard to health protection measures, the Ministry of Health should coordinate with the interministerial body to:

- develop a coherent national or regional policy and monitor its implementation;
- define the division of responsibilities between the respective ministries and other bodies involved in the sector, and the form of liaison between them;
- appraise new and existing schemes from the point of view of public health and environmental protection;
- oversee the promotion and enforcement of national legislation and codes of practice;
- develop a coherent human resources development policy.

The local body managing a scheme, or at least the agency collecting the wastewater and excreta, will often be under municipal control. If wastewater and excreta use is to be promoted in the context of a national policy, this implies careful coordination and definition of the relationship between local and national governments. On the one hand, it may be necessary for the national government to offer incentives to local authorities to promote safe wastewater and excreta use; on the other hand, sanctions of some sort may have to be applied to ensure that schemes are implemented without undue risk to public health.

Local governments should be given the authority to develop their own regulations. For example, they should have the ability to collect fees for wastewater and excreta treatment or other services, issue permits, conduct inspections, develop produce restrictions, inspect markets, develop decentralized wastewater and excreta treatment and use facilities, etc.

Local authorities should have the ability to issue permits for the use of wastewater and excreta in aquaculture from a public conveyance network. Permits may be issued by the local agricultural or water resources administration or by the body controlling the wastewater and excreta distribution system. Provision of such permits for wastewater and excreta use could be made conditional to the effective observation of sanitary practices regarding application methods, produce restriction and exposure control.

It is also common for the body administering the distribution of wastewater and excreta to deal with the landowners through users' associations, which may develop from traditional institutions. Permits to use the wastewater and excreta can then be issued to the associations, which simplifies the administrative task of dealing separately with a large number of small users and also delegates to the associations the task of enforcing the regulations that must be complied with for a permit to be renewed.

A joint committee or management board, which may include representatives of these associations, as well as any particularly large users, the authorities that collect and distribute the wastewater and excreta and also the local health authorities, is required. Even in small-scale organizations, some arrangement such as a committee with community representatives is important for the users to participate in the management of the project.

In some cases, farmers will be able to directly negotiate contracts for a specified supply of treated wastewater and excreta with the utility that treats the wastewater and excreta.

8.2.2 Rights of access

Aquacultural producers will be reluctant to install infrastructure or treatment facilities unless they have some confidence that they will continue to have access to the wastewater and excreta. This access may be regulated by permits and dependent on efficient or sanitary practice by the fish farmer. Legislation may therefore be required to define the users' rights of access to the wastewater and excreta and the powers of those entitled to allocate or regulate those rights.

8.2.3 Land tenure

Security of access to wastewater and excreta is worth little without security of land or water tenure. Existing tenure legislation is likely to be adequate for most eventualities, although it may be necessary to define the ownership of virgin land newly brought under cultivation. If it is decided to amalgamate individual aquacultural farms under a single management, powers of compulsory purchase may be needed.

8.2.4 Public health

The area of public health, with ministries of health as the national authorities, includes rules governing produce restrictions and methods of application, as well as quality standards for treated wastewater and excreta used in aquaculture, product quality standards and other health protection measures discussed in chapter 5, which may require an addition to existing regulations. It also covers other aspects of health protection, such as occupational health and food hygiene, which are unlikely to need any new measures but may need to be changed to better reflect specific risks associated with waste-fed aquaculture. The factors affecting the feasibility of enforcing produce restrictions, discussed in chapter 4, are relevant to both new and existing aquacultural schemes. Consumers also have the right to expect safe aquacultural food products.

Where new waste-fed aquacultural schemes are proposed or existing activities will be expanded, health impact assessment provides an effective tool to quantify health impacts on local populations. Health impact assessment with regard to waste-fed aquaculture is discussed in more detail in Annex 3.

8.3 Regulations

Regulations governing waste-fed aquaculture should be practical and focus on protecting public health (other issues will also be relevant, such as environmental protection). Regulations should also spell out the rights and responsibilities of different stakeholders, establish permit requirements, specify the risk management approaches for different settings, describe water quality/produce monitoring requirements, establish enforcement mechanisms and create disease surveillance systems. Most importantly, regulations should be feasible to implement, given the local circumstances.

A framework of regulations could be set up around the different health protection measures (i.e. wastewater and excreta treatment, produce restriction, wastewater and excreta application, exposure control, immunization/chemotherapy). Regulations may already exist for some of the protective measures. Without some complementary measures, such as regulations that control market hygiene (e.g. availability of adequate sanitation and safe water supplies, market inspectors, periodic laboratory analysis of produce from waste-fed aquaculture), safe food products raised in compliance with the wastewater and excreta use regulations could easily become recontaminated in the market, mitigating any impact of previous public health protective measures that have been implemented (see Table 8.1 for examples of activities that might require regulations).

Table 8.1 Examples of activities that might be covered in regulations

Points of control	Regulatory considerations
Wastewater and excreta	Access rights; tariffs; management (e.g. municipalities, communities, user groups, etc.)
Conveyance	Agency responsible for building infrastructure and operations and maintenance, pumping costs, delivery trucks
Treatment	Treatment requirements depending on final use; process requirements
Monitoring	Types of monitoring (e.g. process monitoring, analytical, parameters), frequency, location, financial responsibilities
Wastewater and excreta application	Fencing, need for buffer zones
Produce restrictions	Types of produce permitted, not permitted, enforcement, education of aquaculturists/public
Exposure control	Access control for use areas (e.g. sign posting, fences), protective clothing requirements, provision of water and sanitation facilities for workers, hygiene education responsibilities
Market hygiene	Market inspection, provision of safe water and adequate sanitation facilities at markets
Food safety	Fish and plant inspection for trematode metacercariae, produce analysis for other pathogens and toxic metals, consumer education
Financial authority	Financial authority for charging tariffs, collecting fines
Enforcement	Authority responsible for ensuring regulatory compliance

8.4 Developing a national policy framework

In developing a national policy framework to facilitate safe waste-fed aquaculture, it is important to define the objectives of the policy, assess the current policy environment and develop a national approach.

8.4.1 Defining objectives

The use of wastewater and excreta in aquaculture can have one or more of several objectives. Defining these objectives is important for developing a national policy framework (Mills & Asano, 1998). The main objectives will be:

- to increase national or local economic development;
- to increase aquatic crop production;
- to augment supplies of fresh water and otherwise take full advantage of the resource value of wastewater and excreta;
- to dispose of wastewater and excreta in a cost-effective, environmentally friendly manner;
- to improve household income, food security and/or nutrition.

Where wastewater and excreta are already used, sub-objectives may include the incorporation of health and environmental safeguards into management strategies or the improvement of produce or fish yields through better practice.

8.4.2 Assessment of the policy environment

As discussed in section 8.2.5, the right policies can facilitate the safe use of wastewater and excreta in aquaculture. Policies often already exist that impact waste-fed aquaculture, both negatively and positively. Conducting an assessment of current policies is often helpful for developing a new national policy or for revising existing policies. The assessment should take place at two levels: from the perspective of a policy-maker and a project manager. Policy-makers will want to assess the national policies, legislation, institutional framework and regulations to ensure that they meet the national wastewater and excreta use objectives (e.g. maximize economic returns without endangering public health or the environment). Project coordinators will want to ensure that current and future waste-fed aquacultural schemes will be able to comply with all relevant national and local laws and regulations.

The main considerations are:

- *Policy:* Are there clear policies on the use of wastewater and excreta in aquaculture? Is waste-fed aquaculture encouraged or discouraged?
- *Legislation:* Is waste-fed aquaculture governed in legislation? What are the rights and responsibilities of different stakeholders?
- *Institutional framework:* Which ministry/agency, mass organizations, etc. have the authority to control the use of wastewater and excreta in aquaculture, at the national level and at the district/community level? Are the responsibilities of different ministries/agencies clear? Is there one lead ministry, or are there multiple ministries/agencies with overlapping jurisdictions? Which ministry/agency is responsible for developing regulations? Which ministry/agency monitors compliance with regulations? Which ministry/agency enforces the regulations?
- *Regulations:* Do regulations exist? Are the current regulations adequate to meet wastewater and excreta use objectives (protect public health, prevent environmental damage, meet produce quality standards for domestic and international trade, preserve livelihoods, conserve water and nutrients, etc.)? Are the current regulations being implemented? Is regulatory compliance being enforced?

It is easier to make regulations than to enforce them. In drafting new regulations (or in choosing which existing ones to enforce), it is important to plan for the institutions, staff and resources necessary to ensure that the regulations are followed. It is important to ensure that the regulations are realistic and achievable in the context in which they are to be applied. It will often be advantageous to adopt a gradual approach or to test a new set of regulations by persuading a local administration to pass them as by-laws before they are extended to the rest of the country.

8.4.3 Developing national approaches based on the WHO Guidelines

Developing national approaches for safe waste-fed aquacultural practices based upon the WHO Guidelines will protect public health the most when they are integrated into comprehensive public health programmes that include other sanitary measures, such as health and hygiene promotion, improving access to safe drinking-water and adequate sanitation. For example, if the Guidelines are followed during fish and plant production but there is recontamination of the fish and plants at the market, then some of the potential health gains are likely to be erased. The use of overhanging fish pond latrines, where excreta are not treated, may continue to facilitate the transmission of foodborne trematodes in endemic areas. Other complementary programmes, such as chemotherapy campaigns, should be accompanied by health promotion/education to change behaviours that lead to reinfection with foodborne trematodes and/or intestinal helminths.

National approaches need to be adapted to the local sociocultural, environmental and economic circumstances and should aim at progressive improvement of public health. Interventions that address the greatest local health threats first should be given the highest priority. As resources and new data become available, additional health protection measures can be introduced. Box 8.2 illustrates some steps that might be used to develop a progressive national approach for increasing the safety of waste-fed aquaculture.

8.4.4 Research

Research on minimizing health impacts associated with waste-fed aquaculture should be conducted at national institutions, universities or other research centres. It is important to conduct research at the national level, because data concerning local conditions are the most important for developing effective health protection measures and may well vary considerably between countries. Pilot schemes can be developed to investigate feasible health protection measures and answer production-related questions. In situations where waste-fed aquaculture is practised in small-scale diffuse facilities, often at the household level, national research may be used to validate health protection measures and then develop guidelines and standards to be used by small-scale producers. Research results should be disseminated to various groups of stakeholders in a form that is useful to them.

A pilot project is particularly useful in countries with little or no experience with waste-fed aquaculture or when the introduction of new techniques is envisaged. Health protection is an important consideration, but there are other questions that are difficult to answer without local experience of the kind a pilot project can give. These questions are likely to include important technical, social and economic aspects. A pilot scheme can help to identify any potential health risks and develop ways to control them.

Box 8.2 Developing a national approach to safe waste-fed aquaculture

An approach to safe waste-fed aquaculture should be based on knowledge of local practices, the health implications of these practices and the need to comply with existing legislation/regulation. The first step is often to assess the situation.

Assess the situation
Types of information that might be helpful in developing an approach include:

- the availability and types of wastewater and excreta treatment available;
- the types of aquacultural products grown in the area (e.g. eaten cooked or raw);
- techniques for wastewater and excreta conveyance/application in aquaculture (e.g. pipes, lined channels, unlined channels, pumping requirements, carts and trucks, proximity to local communities, presence of fences, signs, etc.);
- human exposure to wastewater and excreta during aquacultural practices (e.g. do they wear protective clothing? do they practise good hygiene? are hygiene and sanitation facilities available at the field level?);
- hygienic conditions of current harvesting techniques and during storage and transport of produce to markets;
- practices in markets where crops are sold (e.g. is there access to safe water and adequate sanitation facilities in markets? do vendors practise good hygiene? is safe water used to wash/freshen produce?).

Public health risks vary from place to place. It is important to understand what health problems may arise in relation to waste-fed aquaculture. Foodborne trematodes and schistosomiasis occur only in limited geographic areas but may be important diseases locally. Also, the incidence of vector-borne diseases will vary and should be considered in relevant situations. Information on local public health priorities can be obtained through scientific studies of disease, review of clinical data, outbreak information and prevalence data and interviews with health staff (doctors, nurses, pharmacists) and farmers. There should also be an effort to quantify positive health impacts — for example, on household nutrition and food security.

Involve stakeholders
When possible, relevant stakeholders should be involved in the development of public health approaches. Without their involvement, health protection measures are less likely to succeed. Stakeholders can be involved in the development of policies through participation in national or district-level workshops or through aquacultural extension outreach activities.

Strengthen national/local capacity
The implementation of health protection measures will require both national and local institutional oversight. In some cases, institutional capacities may need to be defined or strengthened. Local health authorities should understand their responsibilities for implementing, monitoring, enforcing and promoting health protection measures.

Phased implementation of health protection measures
Health protection measures can be progressively phased in over time. The first measures to be implemented should try to address the greatest public health priorities. For example, in trematode-endemic areas, initial steps might be to encourage aquaculturists to store excreta for 30 days prior to their addition to the pond or to encourage farmers to grow only fish or plants that are eaten cooked. Development of educational materials and initiation of local workshops to educate aquaculture practitioners about how to reduce trematode infections could be initiated quickly. Similar programmes could be implemented at markets to improve food hygiene and reduce cross-contamination during fish cleaning. Wastewater treatment might be initiated over time with progressive upgrades of the system until it is capable of achieving the WHO microbial water quality targets discussed in chapter 4.

Pilot projects should be planned — that is, a variety of fish (both old and new) and plants should be investigated, with different application rates of wastewater and excreta. Information is required not only on yields but also on microbial contamination levels; uptake of toxic metals in produce; accumulation of toxic metals and parasite eggs in pond sediment; and effects on drinking-water sources.

A pilot project should operate for at least one growing season, or at least one year if production through the seasons is to be investigated. It must be carefully planned so that the work involved is not underestimated and can be carried out correctly; otherwise, repetition in the following year is required. After the experimental period, a successful pilot project may be translated into a demonstration project with training facilities for local operators and farmers.

9
PLANNING AND IMPLEMENTATION

Planning and implementation of waste-fed aquacultural programmes require a comprehensive progressive approach that responds to the greatest health priorities first. Strategies for developing national programmes should include elements on communication to stakeholders; interaction with stakeholders; and the collection and use of data. This chapter describes key considerations for planning and implementation of waste-fed aquacultural programmes at the national level.

At a local level, the sustainability of waste-fed aquaculture relies on the assessment and understanding of eight important factors. These eight factors — health, economic feasibility, social impact and public perception, financial feasibility, environmental impact, market feasibility, institutional feasibility and technical feasibility — have been described in previous chapters. A brief description of how these factors relate to planning and implementation of waste-fed aquacultural projects is included in this chapter.

The protection of public health in waste-fed aquaculture requires the development and use of mechanisms for promoting improvement. This is an important planning aspect. The focus on waste-fed aquacultural improvement (whether as investment priority at the regional or national level, development of hygiene education programmes or enforcement of compliance) will depend on the nature of the waste-fed aquacultural practices and the types of problems identified (WHO, 2004a). A checklist of mechanisms for waste-fed aquacultural improvement is given below:

- √ *Establishing national priorities:* When the most common problems and shortcomings in waste-fed aquaculture have been identified, national strategies can be formulated for improvements and remedial measures; these might include changes in training (of managers, administrators, extension workers or field staff), rolling programmes for improvement or changes in funding strategies to target specific needs.
- √ *Establishing regional priorities:* Regional or local health agencies can determine the communities in which to work and which improvement activities are priorities; public health criteria should be considered when priorities are set.
- √ *Establishing hygiene education programmes:* Many of the health-related issues associated with waste-fed aquaculture are related to personal hygiene and food hygiene and cannot be solved by technology alone. The solutions to many of these problems are likely to require participatory educational and promotional activities.
- √ *Auditing of systems and upgrading:* Waste-fed aquacultural systems should be audited or inspected. The results of these audits can be used to encourage producers to improve their practices. Enforcement of local regulations to improve health protection measures may be difficult with small-scale producers. It may be more productive to work with producers through extension workers to improve practices by educating them about health protection measures and risk reduction strategies.
- √ *Ensuring community operation and maintenance:* Support should be provided by a designated authority to enable community members to be trained so that they are able to assume responsibility for the operation and maintenance of household and community waste-fed aquacultural ponds or facilities.

√ *Establishing public awareness and information channels:* Publication of information on public health aspects of waste-fed aquaculture can encourage producers to follow good practices, mobilize public opinion and response and reduce the need for regulatory enforcement, which should be an option of last resort.

In order to make best use of limited resources, it is advisable to start with a basic programme that develops in a planned manner. An example of a step-by-step approach, with actions to be taken at initial, intermediate and advanced phases, is described below:

- **Initial phase**
  - — Establish requirements for institutional development.
  - — Provide training for staff involved in the programme.
  - — Define the role of participants (e.g. aquacultural extension staff, local health authorities, food safety inspectors, etc.).
  - — Develop health protection measures suitable for the area.
  - — Implement health protection measures in priority areas.
  - — Monitor performance, but limit verification monitoring to a few essential parameters and known hazards of the greatest importance.
  - — Establish reporting, filing and communication systems.
  - — Advocate improvements according to identified priorities.
  - — Establish reporting to local communities, media and regional authorities.
  - — Establish liaison with communities; identify community roles in developing health protection measures and means for promoting community participation.

- **Intermediate phase**
  - — Train staff involved in the programme.
  - — Establish and expand systematic implementation of health protection measures.
  - — Expand access to analytical capability for monitoring (often by means of regional laboratories, national laboratories being largely responsible for analytical quality control and training of regional laboratory staff).
  - — Develop capacity for statistical analysis of data.
  - — Establish a national database.
  - — Identify common problems, and promote activities to address them at regional and national levels.
  - — Expand reporting to include interpretation at the national level.
  - — Draft or revise health-based targets for waste-fed aquaculture.
  - — Use legal enforcement where necessary.
  - — Involve communities routinely in the development and implementation of health protection measures.

- **Advanced phase**
  - — Instititutionalize a staff training programme.
  - — Establish routine testing for all health-related parameters at defined frequencies.
  - — Use a national risk management framework for waste-fed aquaculture.

— Improve waste-fed aquacultural practices on the basis of national and local priorities, hygiene education and enforcement of standards.
— Establish regional databases compatible with the national database.
— Disseminate data and other information at all levels (local, regional and national).
— Involve communities routinely in the development and implementation of health protection measures.

9.1 Reporting and communication

An important element of a successful waste-fed aquacultural programme is the sharing of information with stakeholders. It is useful to establish appropriate systems of communication with all relevant stakeholders. Proper communication involves both the provision of information and the solicitation of feedback from interested parties. The ability to improve waste-fed aquacultural practices is highly dependent on the ability to analyse and present information in a meaningful way to different target audiences (see Box 9.1). The target audiences may include:

- public health officials at local, regional and national levels;
- organizations or utilities that manage the collective treatment of wastewater or excreta;
- local administrations;
- communities and aquacultural producers;
- local, regional and national authorities responsible for development planning and investment.

9.2 Interaction with community and consumers

Community participation is a desirable component of the planning and implementation of waste-fed aquacultural programmes. Communities often share both the benefits of waste-fed aquaculture and exposure to the hazards. The community represents a resource that can be drawn upon for local knowledge and experience. They are the people who are likely to first notice health problems associated with waste-fed aquacultural practices and thus can help to change them. Communication strategies should include provision of summary information to product consumers and producers and establishment and involvement of consumer associations at the local, regional and national levels.

It may not always be feasible to provide information directly to an entire community. Thus, it may be appropriate to use community organizations, where they exist, to provide an effective channel for providing feedback and other information to users. By using local organizations to relay information, it is often easier to initiate a process of discussion and decision-making within the community. The most important elements in working with local organizations are to ensure that the organization selected can access the whole community and can initiate discussion on the health protection measures selected and used in waste-fed aquacultural programmes.

9.3 Use of data and information

Strategies for regional prioritization are typically of a medium-term nature and have information requirements. While the management of information at a national level is aimed at highlighting common or recurrent health issues, the objective at a regional level is to assign a degree of priority to individual interventions. It is therefore

Box 9.1 Communicating health issues

A key issue in the planning process is the communication of important health issues to different stakeholders. Communicating health-related issues to the public and policy-makers should be based on scientific evidence, transformation of the evidence into meaningful information, the development of feasible solutions, impact assessment and engagement and communication with key stakeholders. These are discussed below.

- ***Evidence*** of a particular environmental or health problem or issue develops. This may be via formal scientific research or analysis or via the monitoring of various environmental and health indicators. Alternatively, evidence may surface anecdotally, in the media or as a result of a catastrophic event. Usually, the evidence, whether formal or informal, will relate directly to local conditions.

- ***Transformation*** of formal scientific evidence into evidence that is meaningful to policy-makers and/or the general public takes place. This may be via a process of epidemiological/burden of disease assessment, cost-effectiveness and cost–benefit analysis, risk assessment or the aggregation of environmental and health monitoring data into a few core indicators that are readily understandable to decision-makers.

- ***Solutions*** (i.e. policy alternatives) are considered, along with a discussion of the environmental and health problems. For politicians, the emphasis on or discussion of problems that have no apparent solution is unappealing. Conversely, problems that have solutions may be transformed into political capital.

- ***Impact assessment*** must occur, to consider the evidence in light of existing and proposed policies. That process may be formalized as part of a health impact assessment (see Annex 3), a loan process, a poverty reduction strategy, a national plan or a budget debate. Alternatively, it may be a completely informal process. In all cases where government articulates policy explicitly, some sort of "impact assessment" is taking place.

- ***Engagement*** of key decision-makers and stakeholders takes place, considering new evidence and new policy options. That engagement may be facilitated by the activities of local nongovernmental organizations and academic institutions, the activities of a local or international champion or processes triggered by international and intergovernmental agencies, including new conventions or protocol agreements. Commitment by key decision-makers to consider new evidence may require attitude change on the personal, as well as the institutional, level. This change usually occurs incrementally.

- ***Communication*** of the health risks, and the potential solutions or policies that may address the problem, takes place alongside the engagement and impact assessment process. Optimally, that communication should involve actors in government, the media and all interest groups/ stakeholders. Communication is most effective when it is "hands-on," demonstrates the tangible results of the intervention and is interactive, not frontal or passive — e.g. getting key decision-makers, media and stakeholders involved in observing or participating in the improvement of waste-fed aquaculture, sampling/tracking water quality results or running through an estimate of savings to health. Communication materials should be multilayered — e.g. one-page briefs for top officials, more detailed background materials for the professional level, media materials, etc.

Source: Fletcher (2005).

important to derive a relative measure of health risk. Feasible health protection measures that address the hazards associated with the highest relative risks can then be developed and implemented.

In many situations, especially where production occurs at very small scales, waste-fed aquacultural practices may fail to adequately protect public health. In such circumstances, it is important that realistic goals for progressive improvement are agreed upon and implemented.

9.4 Project planning criteria

Eight criteria should be considered when planning waste-fed aquacultural projects: health, economic feasibility, social impact and public perception, financial feasibility, environmental impact, market feasibility, institutional feasibility and technical feasibility (see Figure 9.1) (Mills & Asano, 1998). Failure to meet any one of these criteria may cause a project to fail. Meeting all the criteria can help to ensure that the project is sustainable.

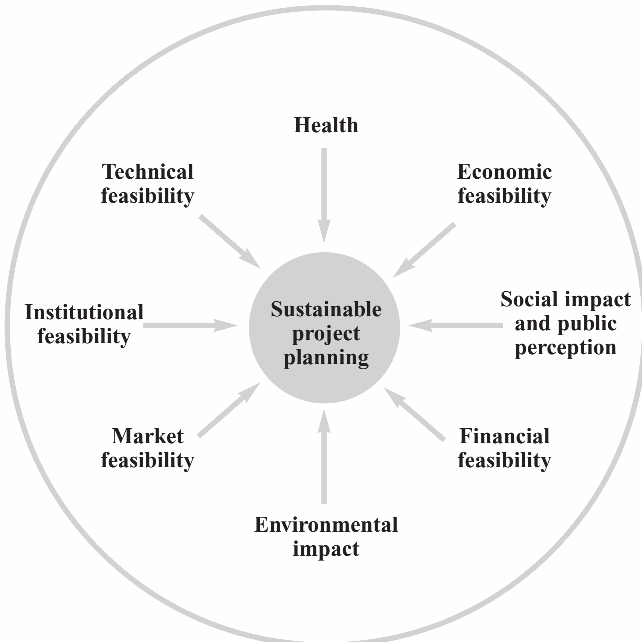


Figure 9.1
Project planning: Eight criteria that impact project success

Most of the eight criteria have been discussed in previous chapters, but a brief discussion of each follows:

1) *Health:* Health is the focus of these Guidelines. Because health issues may vary from one location to the next in the same country, it is important to understand and determine which health issues associated with waste-fed aquaculture are likely to be the most important. Studies are often necessary to identify the key issues. Conducting a health impact assessment prior to the development of new projects or as part of an assessment of ongoing projects is an important planning tool (see Annex 3). Health impact assessment helps to identify populations (e.g. local communities in close proximity to waste-fed aquacultural facilities) that might be at increased risk from different waste-fed aquaculture-related exposures (e.g. vector-borne diseases or schistosomiasis) but may not be considered in other studies. Health impacts, both positive and negative, on the most susceptible

populations (e.g. subsistence-level practitioners) need to be considered in the project planning, through effective assessment procedures.

2) *Economic feasibility:* Economic feasibility is discussed in chapter 7. Health protection measures that provide the greatest health benefit at the lowest cost should be considered first during project planning.
3) *Social impact and public perception:* These issues are discussed in chapter 7. Cultural practices with respect to wastewater and excreta use, food consumption patterns and other behaviours are very important in the development of health protection measures. It may be very difficult to change long-held beliefs or practices. Health protection measures should be planned to accommodate or even incorporate traditional beliefs and practices. Public perception can be a powerful tool for the acceptance or rejection of a waste-fed aquacultural scheme. It is important to involve the public in project planning and communicate with different stakeholders. If there is a perceived need for the activity (e.g. because of economic reasons or other factors such as water scarcity), then the public is more likely to accept it.
4) *Financial feasibility:* This is discussed in more detail in chapter 7. Financial planning looks at how a project can be funded. A viable project will be able to attract adequate funding at all of its stages (i.e. start-up to completion), including equipment, operations and maintenance activities, staff training, monitoring, etc. In some cases, project planners may want to create user's fees or sell products grown in the waste-fed aquacultural system to recover costs.
5) *Environmental impact:* This is discussed in greater detail in chapter 7. Waste-fed aquaculture often has positive environmental benefits by recycling important nutrient resources and offering a form of wastewater/excreta treatment. However, it can lead to contamination of surface waters and groundwaters, especially if the aquifers are near the surface. Project management to reduce environmental consequences should also assess whether waste-fed aquacultural activities could lead to increased habitats for vector or snail breeding. Environmental impact assessment can be efficiently linked to health impact assessment.
6) *Market feasibility:* The demand for products produced in waste-fed aquaculture should be assessed before they are produced. For example, if one of the health protection measures chosen to meet the health-based target is produce restriction, there has to be sufficient market demand to ensure that that product can be profitably sold in the market (this does not apply to products for household consumption). This also applies to an agency that treats wastewater and wants to create a user fee to recover costs. Treated wastewater can only be sold at a price that aquacultural producers are willing and able to pay.
7) *Institutional feasibility:* Project planners should understand the legal and regulatory requirements concerning waste-fed aquaculture. They should be aware of what national and local institutions control waste-fed aquacultural activities and involve them in the planning process. Institutional feasibility is further discussed in chapter 8.
8) *Technical feasibility:* A waste-fed aquacultural project must be technically feasible for it to succeed. Technologies include aspects such as hardware used in the treatment, storage, distribution and use of wastewater and excreta; and other aspects, such as technical support services and technical training. The most sustainable technologies will be cost-effective, upgradable and easy to operate and maintain with local resources. The main technical aspects that should be considered during planning are listed in Box 9.2.

Box 9.2 Technical information to be included in a project plan

- Current and projected generation rates of the wastewater and excreta, proportion of industrial effluents, dilution by surface water
- Existing and required waste treatment facilities, pathogen removal efficiencies, physicochemical quality
- Existing and required pond areas: size, location, soil types, proximity to nearby villages
- Evaporation, especially in waste stabilization ponds (impacts salinity and need for dilution water)
- Conveyance of treated wastewater and excreta to ponds (collection of treated wastewater and excreta by fish and aquatic plant farmers or delivery by treatment authority)
- Storage requirements for the wastewater and excreta
- Wastewater and excreta application rates and methods
- Types of fish and plants to be cultured, and their requirements for wastewater and excreta quality and supplementary feed
- Estimated yields of fish/plants per hectare of pond per year
- Strategies for health protection

9.4.1 Support services

Various support services to aquaculturists are particularly relevant to the implementation of health protection measures, and detailed consideration should be given to them at the planning stage. They include the following:

- machinery (sales and servicing, or hire);
- supplementary feed, pumps, fences, protective clothing, etc.;
- facilities for processing produce;
- extension and training;
- marketing services, especially where new products are to be introduced or new land is to be brought into productive use;
- primary health care, possibly including regular health checks for workers and their families.

9.4.2 Training

Training requirements must be carefully evaluated at the planning stage, and it may often be necessary to start training programmes, especially for pond workers and operators, before the project begins, in order to ensure that adequately trained staff is available. Sewage treatment plant operators require on-the-job training in all aspects of the operation of the treatment plant, delivery systems and pumping stations; producers will need training in aquacultural methods most suitable for wastewater and excreta use; and technicians will require training in sample collection and analysis.

Similarly, the likely need for aquacultural extension services must be estimated and provision made for them to be available to producers after implementation of the project. Extension officers will themselves need training in the methods appropriate to health protection, as will the staff responsible for enforcing sanitary regulations regarding produce restriction, occupational health, food hygiene, etc.

REFERENCES

Albonico M et al. (1995). Rate of reinfection with intestinal nematodes after treatment of children with mebendazole or albendazole in a highly endemic area. *Transactions of the Royal Society for Tropical Medicine and Hygiene*, 89:538–541.

Anon (1980). *Pond fish culture in China. Lecture notes for FAO training course.* Guangzhou, Pearl River Fisheries Research Institute.

APHA et al. (1981). *Glossary: Water and wastewater control engineering*, 3rd ed. Washington, DC, American Public Health Association, American Society of Civil Engineers, American Water Works Association and Water Pollution Control Federation.

Arnbjerg-Nielsen K et al. (2005). [*Risk assessment of partly composted faeces for use in private gardens.*] Copenhagen, Danish Environmental Protection Agency (in Danish with English summary; http://www.mst.dk/udgiv/Publikationer/2005/87-7614-693-6/pdf/87-7614-694-4.PDF).

Asano T, ed. (1998). *Wastewater reclamation and reuse*. Lancaster, PA, Technomic Publishing Company.

Asano T, Levine AD (1998). Wastewater reclamation, recycling, and reuse: an introduction. In: Asano T, ed. *Wastewater reclamation and reuse.* Lancaster, PA, Technomic Publishing Company, pp. 1–56.

Barg UC et al. (1997). Aquaculture and its environment: a case for collaboration. In: Hancock DA et al., eds. *Developing and sustaining world fisheries resources. The state of science and management. Proceedings of the 2nd world fisheries congress, Brisbane, Australia, 28 July – 2 August 1996*. Collingwood, CSIRO Publishing, pp. 462–470.

Barlow CH (1925). The life cycle of the human intestinal fluke *Fasciolopsis buski* (Lankester). *American Journal of Hygiene Monograph Series*, 4:1–98.

Bartone CR, Arlosoroff S (1987). Reuse of pond effluents in developing countries. *Water Science and Technology*, 19(12):289–297.

Bartram J, Fewtrell L, Stenström T-A (2001). Harmonised assessment of risk and risk management for water-related infectious disease: an overview. In: Fewtrell L, Bartram J, eds. *Water quality: Guidelines, standards and health — Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing on behalf of the World Health Organization.

Berkman DS et al. (2002). Effects of stunting, diarrhoeal disease, and parasitic infection during infancy on cognition in late childhood: a follow-up study. *Lancet*, 359(9306):542–571.

Beuchat LR (1998). *Surface decontamination of fruits and vegetables eaten raw: a review.* Geneva, World Health Organization (Report No. WHO/FSF/FOS/98.2).

Beveridge MCM et al. (1993). Grazing rates on toxic and non-toxic cyanobacteria by *Hypophthalmichthys molitrix* and *Oreochromis niloticus*. *Journal of Fish Biology*, 43:901–907.

Bhowmik ML, Chakrabarti PP, Chattopadhyay A (2000). Microflora present in sewage-fed systems and possibilities of their transmission. In: Jana BB et al., eds. *Waste recycling and resource management in the developing world: ecological engineering approach.* Kalyani, University of Kalyani, and Wolhusen, International Ecological Engineering Society, pp. 71–77.

Biswas JK, Santra SC (2000). Heavy metal levels in marketable vegetables and fishes in Calcutta metropolitan area, India. In: Jana BB et al., eds. *Waste recycling and* *resource management in the developing world: ecological engineering approach.* Kalyani, University of Kalyani, and Wolhusen, International Ecological Engineering Society, pp. 371–376.

Blum D, Feachem R (1985). *Health aspects of nightsoil and sludge use in agriculture and aquaculture. Part III. An epidemiological perspective.* Duebendorf, International Reference Centre for Waste Disposal (Report No. 05/85).

Blumenthal UJ et al. (1991–1992). Recent epidemiological studies to test microbiological quality guidelines for wastewater use in agriculture and aquaculture. *Public Health Reviews*, 19:237–242.

Blumenthal UJ et al. (2000). *Guidelines for wastewater reuse in agriculture and aquaculture: recommended revisions based on new research evidence (WELL Study, Task No.: 68 Part 1).* London, Water and Environmental Health at London and Loughborough.

Bose PC (1944). Calcutta sewage and fish culture. *Proceedings of the National Institute of Sciences of India*, 10(4):443–454.

Brackett RE (1987). Antimicrobial effect of chlorine on *Listeria monocytogenes*. *Journal of Food Protection*, 50:999−1003.

Bridgeman J (2004). Public perception towards water recycling in California. *The Water and Environment Journal*, 18(3):150–154.

Buras N (1990). Bacteriological guidelines for sewage-fed fish culture. In: Edwards P, Pullin RSV, eds. *Wastewater-fed aquaculture, proceedings of the international seminar on wastewater reclamation and reuse for aquaculture, Calcutta*. Bangkok, Asian Institute of Technology, Environmental Sanitation Information Center, pp. 223–226.

Buras N (1993). Microbial safety of produce from wastewater-fed aquaculture. In: Pullin RVC, Rosenthal H, MacLean JL, eds. *Environment and aquaculture in developing countries. Proceedings of the 31st ICLARM conference.* Manila, International Centre for Living and Aquatic Resources, pp. 285–295.

Buras N, Duek L, Niv S (1985). Reactions of fish to microorganisms in wastewater. *Applied Environmental Microbiology*, 50:989–995.

Buras N et al. (1987). Microbiological aspects of fish grown in treated wastewater. *Water Research*, 21(1):1–10.

Carr R, Bartram J (2004). The Stockholm Framework for guidelines for microbial contaminants in drinking-water. In: Cotruvo J et al., eds. *Waterborne zoonoses: Identification, causes, and control*. London, IWA Publishing on behalf of the World Health Organization.

Cavallini JM (1996). *Aquaculture using treated effluents from the San Juan stabilization ponds, Lima, Peru*. Lima, Pan American Center for Sanitary Engineering and Environmental Sciences.

Chen MG et al. (1994). Progress in assessment of morbidity due to *Clonorchis sinensis* infection: a review of recent literature. *Tropical Diseases Bulletin*, 91:R7–R65.

Chorus I, Bartram J, eds. (1999). *Toxic cyanobacteria in water.* Geneva, World Health Organization.

CIFA (undated). *Sewage treatment through aquaculture*. Orissa, Central Institute of Freshwater Aquaculture.

Clancy JL et al. (1998). UV light inactivation of *Cryptosporidium* oocysts. *Journal of the American Water Works Association*, 90(9):92–102.

Codd GA, Bell SG (1995). *Occurrence, fate and behaviour of cyanobacterial hepatotoxins.* Bristol, National Rivers Authority (Research and Development Project Record 271/7/A).

Codex (2003). *Consideration of the Codex general standard for contaminants and toxins in food (GSCT).* Rome, Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission, Codex Committee on Food Additives and Contaminants.

Crawford MA (2002). Cerebral evolution. *Nutrition and Health*, 16:29–34.

Cross JH, ed. (1991). Emerging problems in food-borne parasitic zoonoses: impact on agriculture and public health. Proceedings of the 33rd SEAMO-TROPMED Regional Seminar. *Southeast Asian Journal of Tropical Medicine and Public Health*, 22(Suppl.).

Cross P (1985). *Health aspects of nightsoil and sludge use in agriculture and aquaculture. Part I: Existing practices and beliefs in the utilization of human excreta*. Duebendorf, International Reference Centre for Waste Disposal (Report No. 04/85).

Curtis V, Kanki B (1998). *Happy, healthy and hygienic. Vol. 3. Motivating behaviour change*. New York, UNICEF, Water, Environment and Sanitation (WES Technical Guidelines Series No. 5).

De NV et al. (2003). The food-borne trematode zoonoses of Vietnam. *Southeast Asian Journal of Tropical Medicine and Public Health*, 34(Suppl. 1):12–35.

Demanou J, Brummett RE (2003). Heavy metal and faecal bacterial contamination of urban lakes in Yaoundé, Cameroon. *African Journal of Aquatic Science*, 28(1):49–56.

Djajadiredja R et al. (1979). *The role of nightsoil and household wastes in freshwater fish culture: a case study in West Java, Indonesia*. Paper presented at International Development Research Centre Nightsoil Survey Leaders' Meeting, 4–6 June 1979, Singapore.

Easa M El-S et al. (1995). Public health implications of waste water reuse for fish production. *Water Science and Technology*, 32(11):145–152.

EC (2001). Commission Regulation (EC) No. 466/2001 setting maximum levels of certain contaminants of foodstuffs. *Official Journal of the European Communities*, L77:1–14.

Edwards P (1984). *Aquaculture: A component of low cost sanitation technology*. Washington, DC, United Nations Development Programme/World Bank Integrated Resource Recovery Project, 45 pp. (World Bank Technical Paper No. 36).

Edwards P (1990). An alternative excreta-reuse strategy for aquaculture: the production of high-protein animal feed. In: Edwards P, Pullin RSV, eds. *Wastewater-fed aquaculture, proceedings of the international seminar on wastewater reclamation and reuse for aquaculture, Calcutta.* Bangkok, Asian Institute of Technology, Environmental Sanitation Information Center, pp. 209–221.

Edwards P (1992). *Reuse of human wastes in aquaculture: a technical review*. Washington, DC, United Nations Development Programme and The World Bank, Water and Sanitation Program.

Edwards P (2000). Wastewater-fed aquaculture: state-of-the-art. In: Jana BB et al., eds. *Waste recycling and resource management in the developing world: ecological engineering approach.* Kalyani, University of Kalyani, and Wolhusen, International Ecological Engineering Society, pp. 37–49.

Edwards P, Pullin RSV, eds. (1990). *Wastewater-fed aquaculture, proceedings of the international seminar on wastewater reclamation and reuse for aquaculture, Calcutta.* Bangkok, Asian Institute of Technology, Environmental Sanitation Information Center.

Edwards P, Pacharaprakiti C, Yomjinda M (1990). Direct and indirect reuse of septage for culture of Nile tilapia *Oreochromis niloticus*. In: Hirano R, Hanju I, eds. *The second Asian fisheries forum*. Manila, Asian Fisheries Society, pp. 165–168.

Edwards P, Polprasert C, Wee KL (1987). *Resource recovery and health aspects of sanitation*. Bangkok, Asian Institute of Technology, Environmental Sanitation Information Center (AIT Research Report No. 205).

Edwards P et al. (1984). *Re-use of cesspool slurry and cellulose agricultural residues for fish culture*. Bangkok, Asian Institute of Technology (AIT Research Report No. 166).

El-Gohary F et al. (1993). Assessment of the performance of oxidation pond system for wastewater reuse. *Water Science and Technology*, 27(9):115−123.

Elledge MF (2003). *Thematic overview paper: Sanitation policies.* Delft, IRC International Water and Sanitation Centre.

FAO (2000). *The state of world fisheries and aquaculture — 2000*. Rome, Food and Agriculture Organization of the United Nations (http://www.fao.org/docrep/003/x8002e/x8002e00.htm).

FAO (2002). *Crops and drops: making the best use of water for agriculture*. Rome, Food and Agriculture Organization of the United Nations.

Farooq S, Ansari ZI (1983). Water reuse in Muslim countries — an Islamic perspective. *Environmental Management*, 7(2):119–123.

Faruqui NI, Biswas AK, Bino MJ, eds. (2001). *Water management in Islam*. Ottawa, International Development Research Centre and United Nations University Press.

Fattal B, Doan A, Tchorsh Y (1992). Rates of experimental microbiological contamination of fish exposed to polluted water. *Water Research*, 26:1621–1627.

Fattal B et al. (1981). Study of enteric disease transmission associated with wastewater utilization in agricultural communities in Israel. In: *Proceedings of the water reuse symposium II, Vol. 3.* Denver, CO, American Water Works Association, pp. 2200–2215.

Fattal B et al. (1993). Microbiological purification of fish grown in fecally contaminated commercial fish pond. *Water Science and Technology*, 27(7–8):303–311.

Feachem RG et al. (1983). *Sanitation and disease: health aspects of excreta and wastewater management.* Chichester, John Wiley & Sons (World Bank Studies in Water Supply and Sanitation 3).

Fewtrell L, Bartram J, eds. (2001). *Water quality: Guidelines, standards and health — Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing on behalf of the World Health Organization.

Fletcher E (2005). *Environment and health decision-making in a developing country context*. Geneva, World Health Organization/United Nations Environment Programme.

Frost JA et al. (1995). An outbreak of *Shigella sonnei* infection associated with consumption of iceberg lettuce. *Emerging Infectious Diseases*, 1:26–29.

Garrett ES, Lima dos Santos C, Jahncke ML (1997). Public, animal, and environmental health implications of aquaculture. *Emerging Infectious Diseases*, 3(4):1–6.

Ghosh D (1997). Ecosystems approach to low-cost sanitation in India: where the people know better. In: Etnier C, Guterstam B, eds. *Ecological engineering for wastewater treatment*, 2nd ed. *Proceedings of the international conference at Stensund Folk College, Sweden*. Boca Raton, FL, CRC Press, pp. 51–65.

Gijzen HJ, Ikramullah M (1999). *Pre-feasibility of duckweed-based wastewater treatment and resource recovery in Bangladesh*. Delft, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE), and Bangladesh, Project in Agriculture, Rural Industry Science and Medicine (PRISM) Bangladesh

Gijzen HJ, Veenstra S (2000). Duckweed based wastewater treatment for rational resource recovery and re-use. In: Olguin EJ, Sanchez G, Hernandez EJ, eds. *Environmental biotechnology and cleaner bioprocesses*. London, Taylor and Francis, pp. 83–100.

Gilroy DJ et al. (2000). Assessing potential health risks from microcystin toxins in blue-green algae dietary supplements. *Environmental Health Perspectives*, 108(5):435–439.

Gittinger JP (1982). *Economic analysis of agricultural projects*. Baltimore, MD, Johns Hopkins University Press.

Haq AHMR, Ghosal TK (2000). Wastewater reclamation using duckweed. In: Jana BB et al., eds. *Waste recycling and resource management in the developing world: ecological engineering approach.* Kalyani, University of Kalyani, and Wolhusen, International Ecological Engineering Society, pp. 495–499.

Hendy SMH, Youssef RG (2002). *Wastewater management and reuse, Egypt country profile*. Cairo, Government of Egypt, Ministry of Health and Population, and WHO Regional Office for the Eastern Mediterranean.

Hotez PJ et al. (1997). Emerging and reemerging helminthiases and the public health of China. *Emerging Infectious Diseases*, 3(3):1–11 (http://www.cdc.gov/ncidod/eid/vol3no3/hotez.htm).

Hurst CJ, Benton WH, Stetler RE (1989). Detecting viruses in water. *Journal of the American Water Works Association*, 8(9):71–80.

Huss HH, Ben Embarek PK (2003). Parasites. In: Huss HH, Ababouch L, Gram L, eds. *Assessment and management of seafood quality*. Rome, Food and Agriculture Organization of the United Nations (FAO Fisheries Technical Paper 444).

Hussain I et al. (2001). *A framework for analyzing socioeconomic, health and environmental impacts of wastewater use in agriculture in developing countries.* Colombo, International Water Management Institute, 23 pp. (Working Paper 26).

IPTRID (1999). *Poverty reduction and irrigated agriculture*. Rome, Food and Agriculture Organization of the United Nations, International Programme for Technology and Research in Irrigation and Drainage (Issues Paper No. 1).

Iqbal S (1999). *Duckweed aquaculture. Potentials, possibilities and limitations for combined wastewater treatment and animal feed production in developing countries*. Duebendorf, Department of Water and Sanitation in Developing Countries (SANDEC Report No. 6/99).

Jana BB (1998). Sewage-fed aquaculture: The Calcutta model. *Ecological Engineering*, 11:73–85.

Jenkins MB et al. (2002). *Cryptosporidium parvum* oocyst inactivation in three soil types at various temperatures and water potentials. *Soil Biology and Biochemistry*, 34(8):1101−1109.

Jiménez B (2003). Health risk in aquifer recharge with recycled water. In: Aertgeerts R, Angelakis A, eds. *Health risks in aquifer recharge using reclaimed water —*

State of the art report. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/wastewater/wsh0308/en/index.html).

Jiménez B (2005). Treatment technology and standards for agricultural wastewater reuse: a case study in Mexico. *Journal of Irrigation and Drainage*, 54:1−11.

Jiménez B, Chávez A (1998). Removal of helminth eggs in an advanced primary treatment with sludge blanket. *Environmental Technology*, 19:1061–1071.

Jiménez B, Chávez A (2002). Low cost technology for reliable use of Mexico City's wastewater for agricultural irrigation. *Environmental Technology*, 9(1−2):95−108.

Jiménez B et al. (2001). The removal of a diversity of micro-organisms in different stages of wastewater treatment. *Water Science and Technology*, 43(10):155−162.

Jørgensen K (2005). *Accumulation of toxic metals in aquatic vegetables cultivated with use of urban wastewater in Hanoi and Nam Dinh, Vietnam* [MSc thesis]. Frederiksberg, Royal Veterinary and Agricultural University.

Kapperud G et al. (1995). Outbreak of *Shigella sonnei* infection traced to imported iceberg lettuce. *Journal of Clinical Microbiology*, 33(3):609–614.

Karapanagiotidis IT et al. (2002). Tilapias from different aquatic systems contain variable amounts of ω-3 and ω-6 polyunsaturated fatty acids: implications for human nutrition. In: *World aquaculture 2002, Beijing, book of abstracts*. Baton Rouge, LA, World Aquaculture Society, p. 342.

Karimi AA, Vickers JC, Harasick RF (1999). Microfiltration goes Hollywood: the Los Angeles experience. *Journal of the American Water Works Association*, 91(6):90–103.

Keiser J, Utzinger J (2005). Food-borne trematodiasis: an emerging public health problem. *Emerging Infectious Diseases*, 11(10):1503–1510.

Keshavanath P et al. (1994). The functional grazing response of a phytoplanktivorous fish *Oreochromis niloticus* to mixtures of toxic and non-toxic strains of the cyanobacterium *Microcystis aeruginosa*. *Journal of Fish Biology*, 45:123–129.

Khalil MT, Hussein HA (1997). Use of wastewater for aquaculture: an experimental field study at a sewage-treatment plant, Egypt. *Aquaculture Research*, 28:859–865.

Kosek M, Bern C, Guerrant RL (2003). The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bulletin of the World Health Organization*, 81(3):197–204.

Kowal NE (1985). *Health effects of land application of municipal sludge*. Research Triangle Park, NC, United States Environmental Protection Agency, Office of Research and Development, Health Effects Research Laboratory (EPA/600/1–85/015) [cited in USEPA, 1992].

Lan NTP et al. (in press). Microbiological quality of fish grown in wastewater-fed and non-wastewater-fed fishponds in Hanoi, Vietnam: influence of hygiene practices in local retail markets. *Journal of Water and Health.*

Landa H, Capella A, Jiménez B (1997). Particle size distribution in an effluent from an advanced primary treatment and its removal during filtration. *Water Science and Technology*, 36(4):159−165.

Lang MM, Harris LJ, Beuchat LR (2004). Survival and recovery of *Escherichia coli* O157:H7, *Salmonella*, and *Listeria monocytogenes* on lettuce and parsley as affected by method of inoculation, time between inoculation and analysis, and treatment with chlorinated water. *Journal of Food Protection*, 67:1092–1103.

Larsson B (1994). *Three overviews on environment and aquaculture in the tropics and sub-tropics*. Harare, Food and Agriculture Organization of the United Nations, Aquaculture for Local Communities Development Programme (ALCOM Field Document No. 27).

Lazarova V et al. (2000). Wastewater disinfection by UV: Evaluation of the MS2 phages as a biodosimeter for plant design. In: *Proceedings of the WateReuse Association annual symposium 2000, 12–15 September 2000, Napa, CA*. Alexandria, VA, WateReuse Association.

Li SF (1997). Aquaculture and its role in ecological wastewater treatment. In: Etnier C, Guterstam B, eds. *Ecological engineering for wastewater treatment*, 2nd ed. *Proceedings of the international conference at Stensund Folk College, Trosa, Sweden.* Boca Raton, FL, CRC Press, pp. 37–49.

Little DC, Pham AT (1995). *Overview of freshwater fish seed production and distribution in Vietnam.* Bangkok, Asian Institute of Technology (Working Paper No. NV-6).

Lun Z-R et al. (2005). Clonorchiasis: a key foodborne zoonosis in China. *The Lancet Infectious Diseases*, 5:31–41.

MAFF (1995). *Manual of nutrition*, 10th ed. London, Ministry of Agriculture, Fisheries and Food, HMSO (Reference Book 342).

Mara D (1997). *Design manual for waste stabilization ponds in India*. Leeds, Lagoon Technology International Ltd.

Mara DD (1998). Waste stabilization ponds and wastewater storage and treatment reservoirs: the low-cost production of microbiologically safe effluents for agricultural and aquacultural reuse. In: Asano T, ed. *Wastewater reclamation and reuse*. Lancaster, PA, Technomic Publishing Company, pp. 141–158.

Mara DD (2004). *Domestic wastewater treatment in developing countries.* London, Earthscan Publications.

Mara DD, Silva SA (1986). Removal of intestinal nematode eggs in tropical waste stabilization ponds. *Journal of Tropical Medicine and Hygiene*, 89(2):71–74.

Mara DD et al. (1993). A rational approach to the design of wastewater-fed fishponds. *Water Research*, 27(12):1797–1799.

Mas-Coma S (2004). Human fascioliasis. In: Cotruvo JA et al., eds. *Waterborne zoonoses: identification, causes and control*. London, IWA Publishing on behalf of the World Health Organization.

Mathers CD et al. (2002). *Global burden of disease 2000: Version 2 methods and results*. Geneva, World Health Organization.

McCullough FS (1990). Schistosomiasis and aquaculture. In: Edwards P, Pullin RSV, eds. *Wastewater-fed aquaculture, proceedings of the international seminar on wastewater reclamation and reuse for aquaculture, Calcutta.* Bangkok, Asian Institute of Technology, Environmental Sanitation Information Center, pp. 237–249.

Mead PS et al. (1999). Food-related illness and death in the United States. *Emerging Infectious Diseases*, 5(5):607–625.

Mills RA, Asano T (1998). Planning and analysis of wastewater reuse projects. In: Asano T, ed. *Wastewater reclamation and reuse*. Lancaster, PA, Technomic Publishing Company, pp. 57–111.

Mkoji GM et al. (1992). Control of natural populations of schistosome-transmitting snails by the crayfish, *Procambarus clarkii* in temporary man-made ponds in Kenya. In: Harrison BA, Shay EG, Ruskin FR, eds. *Aquaculture and schistosomiasis.* Washington, DC, National Academy Press.

Montangero A, Strauss M (2002). *Faecal sludge management.* Delft, IHE-Delft University, Swiss Federal Institute for Environmental Science and Technology (EAWAG) / Department of Water and Sanitation in Developing Countries (SANDEC) (home page on the Internet at: http://www.sandec.ch/FaecalSludge).

Montresor A et al. (2002). *Helminth control in school-age children: a guide for managers of control programmes*. Geneva, World Health Organization, 64 pp.

Morrice C, Chowdhury NI, Little DC (1998). Fish markets in Calcutta. *Aquaculture Asia*, 3(2):12–14.

Murray CJL, Lopez AD, eds. (1996). *The global burden of disease. Vol. 1*. Cambridge, MA, Harvard School of Public Health on behalf of the World Health Organization and The World Bank.

NAS (1976). *Making aquatic weeds useful; some perspectives for developing countries.* Washington, DC, National Academy of Sciences, 175 pp.

National Research Council (1998). *Issues in potable reuse: The viability of augmenting drinking water supplies with reclaimed water.* Washington, DC, National Academy Press.

NRMMC/EPHCA (2005). *National guidelines for water recycling: managing health and environmental risks.* Sydney, Natural Resource Management Ministerial Council and the Environment Protection and Heritage Council of Australia.

Olah J (1990). Wastewater-fed fish culture in Hungary. In: Edwards P, Pullin RSV, eds. *Wastewater-fed aquaculture, proceedings of the international seminar on wastewater reclamation and reuse for aquaculture, Calcutta.* Bangkok, Asian Institute of Technology, Environmental Sanitation Information Center, pp. 79–89.

Oragui JI et al. (1987). Removal of excreted bacteria and viruses in deep waste stabilization ponds in northeast Brazil. *Water Science and Technology*, 19:569−573.

Pal D, Das Gupta C (1992). Microbial pollution in water and its effect on fish. *Journal of Aquatic Animal Health*, 4:32–39.

Pettygrove GS, Asano T (1985). *Irrigation with reclaimed municipal wastewater — a guidance manual*. Chelsea, MI, Lewis Publishers.

Phillips MJ, Macintosh DJ (1997). Aquaculture and the environment: challenges and opportunities. In: Nambiar KPP, Singh T, eds. *Sustainable aquaculture. Proceedings of INFOFISH-AQUATECH '96 international conference on aquaculture, Kuala Lumpur, Malaysia, 25–27 September 1996.* Kuala Lumpur, INFOFISH, pp. 159–170.

Prein M (1996). Wastewater-fed aquaculture in Germany: a summary. In: Staudenmann J, Schönborn A, Etnier C, eds. *Recycling the resource, proceedings of the second international conference on ecological engineering for wastewater treatment, School of Engineering, Wädenswil-Zürich, 18–22 September 1995*. Zurich, Transtec Publications, pp. 155–160.

Prüss A, Havelaar A (2001). The global burden of disease study and applications in water, sanitation, and hygiene. In: Fewtrell L, Bartram J, eds. *Water quality: Guidelines, standards and health — Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing on behalf of the World Health Organization.

Randall D, Bolis L, Agradi E (1990). Fish in human nutrition research and the implications for aquaculture. *Ambio*, 19(5):272–275.

Rice AL et al. (2000). Malnutrition as an underlying cause of childhood deaths associated with infectious diseases in developing countries. *Bulletin of the World Health Organization*, 78:1207–1221.

Rivera F et al. (1995). Removal of pathogens from wastewater by the root zone method (RZM). *Water Science and Technology*, 32(3):211−218.

Robertson LJ, Campbell AT, Smith HV (1992). Survival of *Cryptosporidium parvum* oocysts under various environmental pressures. *Applied and Environmental Microbiology*, 58(11):3494–3500.

Rojas-Valencia N et al. (2004). Ozonation by-products issued from the destruction of micro-organisms present in wastewaters treated for reuse. *Water Science and Technology*, 50(2):187–193.

Rose JB et al. (1996). Removal of pathogenic and indicator microorganisms by a full-scale water reclamation facility. *Water Resources*, 30(11):2785–2797.

Rose JB et al. (1997). Evaluation of microbiological barriers at the Upper Occoquan Sewage Authority. In: *1996 water reuse conference proceedings, 25–28 February 1997, San Diego, California.* Denver, CO, American Water Works Association, pp. 291–305.

Rowan WB (1964). Sewage treatment and schistosome eggs. *American Journal of Tropical Medicine and Hygiene*, 13:572–576.

Roy S (2000). Ecology sustainability and metropolitan development — the Calcutta experience. In: Jana BB et al., eds. *Waste recycling and resource management in the developing world: ecological engineering approach.* Kalyani, University of Kalyani, and Wolhusen, International Ecological Engineering Society, pp. 293–302.

Sagik BP, Moor BE, Sorber CA (1978). Infectious disease potential of land application of wastewater. In: *State of knowledge in land treatment of wastewater. Vol. 1. Proceedings of an international symposium.* Hanover, NH, United States Army Corps of Engineers, Cold Regions Research and Engineering Laboratory.

Schwartzbrod J et al. (1989). Impact of wastewater treatment on helminth eggs. *Water Science and Technology*, 21(3):295−297.

Shereif MM, Mancy KH (1995). Organochlorine pesticides and heavy metals in fish reared in treated sewage effluents and fish grown in farms using polluted surface waters in Egypt. *Water Science and Technology*, 32(11):153–161.

Sin AW (1987). The culture of silver carp, bighead, grass carp and common carp in secondary effluents of a pilot sewage treatment plant. *Resources and Conservation*, 13:231–246.

Skillicorn P, Journey W, Spira W (1993). *Duckweed aquaculture: a new aquatic farming system for developing countries.* Washington, DC, The World Bank.

Slabbert JL, Morgan WSG, Wood A (1989). Microbiological aspects of fish cultured in wastewaters — the South African experience. *Water Science and Technology*, 21:307–310.

Sobsey M (1989). Inactivation of health related microorganisms in water by disinfection processes*.* *Water Science and Technology*, 21(3):179–195.

Son TQ et al. (1995). *Application of hazard analysis critical control point (HACCP) as a possible control measure against* Clonorchis sinensis *in cultured silver carp* Hypophthalmichthys molitrix. Paper presented at the 2nd seminar on foodborne zoonoses: Current problems, epidemiology and food safety, 6–9 December 1995, Khon Kaen, Thailand [cited in Garrett, Lima dos Santos & Jahncke, 1997].

Sornmani S (1988). *Improvement of community health through the control of liver fluke infection by means of primary health care approach in Thailand*. Bangkok, Mahidol University, Faculty of Tropical Medicine.

Squire L, Van Der Tak HG (1975). *Economic analysis of projects*. Baltimore, MD, Johns Hopkins University Press.

Steffens W, Wirth M (1997). Cyprinids as a valuable source of essential fatty acids for human health: a review. *Asian Fisheries Science*, 10:83–90.

Strauss M (1985). Health aspects of nightsoil and sludge use in agriculture and aquaculture — Part II: Survival of excreted pathogens in excreta and faecal sludges. *IRCWD News*, 23:4−9. Duebendorf, Swiss Federal Institute for Environmental Science and Technology (EAWAG) / Department of Water and Sanitation in Developing Countries (SANDEC).

Strauss M (1996). Health (pathogen) considerations regarding the use of human waste in aquaculture. *Environmental Research Forum*, 5–6:83–98.

Strauss M, Blumenthal UJ (1990). *Human waste use in agriculture and aquaculture — utilization practices and health perspectives*. Duebendorf, Swiss Federal Institute for Environmental Science and Technology (EAWAG) / Department of Water and Sanitation in Developing Countries (SANDEC) (IRWCD Report No. 05/90).

TDR (2004). *TDR diseases*. Geneva, World Health Organization, Special Programme for Research and Training in Tropical Diseases (http://www.who.int/tdr/diseases).

Thilsted SH, Roos N, Hassan N (1997). The role of small indigenous fish species in food and nutrition security in Bangladesh. *Naga, The ICLARM Quarterly*, 20(3/4):82–84.

UNEP (2002). *Environmentally sound technologies for wastewater and stormwater management, an international source book*. London, IWA Publishing on behalf of the United Nations Environment Programme.

United Nations (1993). *Agenda 21. The United Nations Programme of Actions for Sustainable Development*. New York.

United Nations General Assembly (2000). *United Nations Millennium Declaration*. Resolution A/RES/55/2. New York, NY, United Nations (http://www.un.org/millennium/declaration/ares552e.pdf).

USEPA (1992). *Technical support document for land application of sewage sludge*. Prepared for Office of Water, United States Environmental Protection Agency, by Eastern Research Group, Lexington, MA.

USFDA (1998). *Fish and fishery products hazard and control guide*, 2nd ed. Washington, DC, United States Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Seafood.

van der Hoek W et al. (2005). Skin diseases among people using urban wastewater in Phnom Penh. *Urban Agriculture Magazine*, 14:30–31.

Venugopalan V (1984). Foreword. In: Roy AK et al., eds. *Manual on the design, construction and maintenance of low-cost waterseal latrines in India.* Washington, DC, The World Bank, Technical Advisory Group (TAG Technical Note No. 10).

Vo QH (1996). *Wastewater reuse through aquaculture in Hanoi: status and prospects* [Master's Thesis]. Bangkok, Asian Institute of Technology (AE-96-26).

von Sperling M, Bastos RKX, Kato MT (2004). *Removal of* E. coli *and helminth eggs in UASB–polishing pond systems.* Paper presented at the 6th International Water Association international conference on waste stabilization ponds, Avignon, 27 September − 1 October.

von Sperling M et al. (2003). Evaluation and modelling of helminth egg removal in baffled and unbaffled ponds treating anaerobic effluent. *Water Science and Technology*, 48(2):113−120.

Warnes S, Keevil CW (2003). *Survival of* Cryptosporidium parvum *in faecal wastes and salad crops.* Carlow, Teagasc Irish Agriculture and Food Development Authority (http://www.teagasc.ie/publications/2003/conferences/cryptosporidiumparvum).

Wei DX (1984). [*Clonorchis sinensis* and clonorchiasis.] In: Wu ZJ, Mao SP, Wang JW, eds. [*Chinese medical encyclopaedia, parasitology and parasitic diseases.*] Shanghai, Shanghai Publishing House for Sciences and Technology, pp. 63–65 (in Chinese).

WHO (1973). *Reuse of effluents: Methods of wastewater treatment and health safeguards. Report of a WHO Meeting of Experts.* Geneva, World Health Organization (Technical Report Series No. 517).

WHO (1984). *The role of food safety in health and development. Report of a joint FAO/WHO Expert Committee on Food Safety.* Geneva, World Health Organization (WHO Technical Report Series No. 705).

WHO (1988a). *Environmental management for vector control*. Geneva, World Health Organization.

WHO (1988b). *Health education in food safety.* Geneva, World Health Organization (unpublished document WHO/EHE/FOS/88.7).

WHO (1989). *Health guidelines for the use of wastewater in agriculture and aquaculture*. Geneva, World Health Organization (WHO Technical Report Series No. 776).

WHO (1995). *Control of foodborne trematode infections.* Geneva, World Health Organization (WHO Technical Report Series No. 849).

WHO (1999). *Food safety issues associated with products from aquaculture: report of a joint FAO/NACA/WHO study group*. Geneva, World Health Organization (WHO Technical Report Series No. 883).

WHO (2000). *Human health and dams, the World Health Organization's submission to the World Commission on Dams (WCD).* Geneva, World Health Organization (Document WHO/SDE/WSH/00.01).

WHO (2001). *Disease fact sheet: Schistosomiasis*. Geneva, World Health Organization, Water, Sanitation and Health Electronic Library.

WHO (2002). *Prevention and control of schistosomiasis and soil-transmitted helminthiasis. Report of a WHO Expert Committee.* Geneva, World Health Organization (WHO Technical Report Series 912).

WHO (2003a). *Guidelines for safe recreational water environments. Vol. 1. Coastal and fresh waters*. Geneva, World Health Organization.

WHO (2003b). *The World Health Report 2003: Shaping the future*. Geneva, World Health Organization.

WHO (2003c). *Typhoid vaccines. Fact sheet*. Geneva, World Health Organization (http://www.who.int/vaccines/en/typhoid.shtml).

WHO (2004a). *Guidelines for drinking-water quality*, 3rd ed. Geneva, World Health Organization.

WHO (2004b). *The World Health Report 2004: Changing history.* Geneva, World Health Organization.

WHO (2005a). *Guidelines for safe recreational water environments. Vol. 2. Swimming pools and similar recreational water environments.* Geneva, World Health Organization.

WHO (2005b). *Water related diseases: Japanese encephalitis.* Geneva, World Health Organization (http://www.who.int/water_sanitation_health/diseases/encephalitis/en/).

Yates MV, Gerba CP (1998). Microbial considerations in wastewater reclamation and reuse. In: Asano T, ed. *Wastewater reclamation and reuse.* Lancaster, PA, Technomic Publishing Company, pp. 437−488.

Zhou HY, Cheung RYH, Wong MH (1999). Bioaccumulation of organochlorines in freshwater fish with different feeding modes cultured in treated wastewater. *Water Research*, 33(12):2747–2756.

Annex 1
Wastewater-fed fish pond design

The design procedure given below for wastewater-fed fish ponds is based on the concept of *minimal* wastewater treatment in waste stabilization ponds for *maximal* production of microbially safe fish (Mara et al., 1993; Mara, 1997).

Waste stabilization ponds

Waste stabilization ponds are a low-cost (and usually the lowest-cost) wastewater treatment option. They comprise a series of anaerobic and facultative ponds, followed sometimes by one or more maturation ponds; however, in the case of minimal pretreatment prior to fish ponds, maturation ponds are not normally required. Both anaerobic and facultative ponds are simple earthen impoundments in which the wastewater is treated by natural processes for which no electrical energy is required.

In anaerobic ponds, the wastewater is treated by a combination of sedimentation and anaerobic digestion. Most trematode eggs settle out in this pond (the few that remain are removed in the receiving facultative pond).

Wastewater treatment in facultative ponds is "green treatment" achieved by the mutualistic growth of microalgae and heterotrophic bacteria (the profuse and entirely natural proliferation of the algae gives these ponds their characteristic intense green colour — hence the term "green treatment"). The algae produce oxygen from water as a by-product of photosynthesis. This oxygen is used by the bacteria as they aerobically bio-oxidize the organic compounds in the wastewater. An end-product of this bio-oxidation is carbon dioxide, which is fixed into cell carbon by the algae during photosynthesis (Figure A1.1). The permissible wastewater loadings on anaerobic and facultative ponds depend on temperature: the higher the temperature, the higher the permissible loadings. Retention times, which depend on both the wastewater flow and the wastewater loading, are relatively long: 1–3 days in anaerobic ponds and 4–10 days in facultative ponds, with minima of 1 and 4 days, respectively.

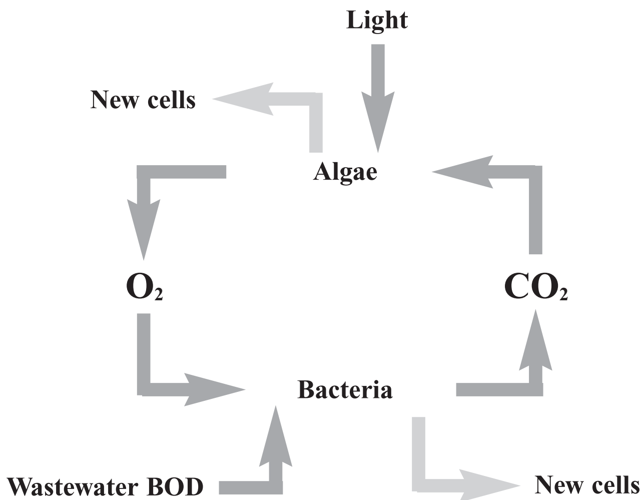


Figure A1.1
Bacterial–algal mutualism in facultative waste stabilization ponds

A fully descriptive online introduction to waste stabilization ponds for non-specialists is given by Peña Varón & Mara (2004).

Design procedure

The design steps are as follows:

1) Design a waste stabilization pond system comprising an anaerobic pond and a secondary facultative pond.
2) Determine the total nitrogen concentration in the effluent of the facultative pond.
3) Design the wastewater-fed fish pond, which receives the facultative pond effluent, on the basis of a surface loading of total nitrogen of 4 kg/ha per day (too little nitrogen results in a low algal biomass in the fish pond and consequently small fish yields; too much nitrogen gives rise to high concentrations of algae, with the resultant high risk of severe dissolved oxygen depletion at night and consequent fish kills).
4) Calculate the number of *E. coli* per 100 ml of fish pond water (this should be ≤ 1000 or $\leq 10^4$ per 100 ml, as shown in Table 4.1).
5) Determine the concentration of free ammonia (i.e. dissolved NH_3 gas) in the fish pond (this should be <0.5 mg N/l in order to avoid acute toxicity to the fish).

A design example is given in Box A1.1.

Box A1.1 Wastewater-fed fish ponds: Design example

Design a fish pond that is to receive the effluent of a secondary facultative waste stabilization pond. The untreated wastewater flow is 1000 m^3/day, and it has a BOD of 200 mg/l, a total nitrogen concentration of 40 mg N/l and an *E. coli* count of 1×10^7 per 100 ml. The design temperature is 25 °C, and the net evaporation rate is 5 mm/day. [**Notes:** (a) "BOD" is the "biochemical oxygen demand," which is a common way of expressing the concentration of biodegradable organic matter in the wastewater; a BOD of *x* mg/l means that the concentration of biodegradable organic matter in the wastewater is such that the bacteria that bio-oxidize it in a wastewater treatment plant need *x* mg of O_2 per litre of wastewater bio-oxidized; (b) net evaporation = evaporation − rainfall.]

Full design details are given in Mara (2004).

A. Design of the anaerobic pond

The anaerobic pond volume (V_a, m^3) is given by:

$$V_a = Q\theta_a$$

where Q = wastewater flow (m^3/day) [here, = 1000 m^3/day]; and θ_a = the retention time in the anaerobic pond (days) [here, taken as 1 day, which is the minimum retention time permissible in an anaerobic pond]. Thus:

$$V_a = (1000 \times 1) = 1000 \text{ m}^3$$

This is equivalent, for a depth of 3 m, to an area of 333 m^2.

The BOD removal in an anaerobic pond at 25 °C is 70%, so the BOD of the anaerobic pond effluent (which becomes the influent to the secondary facultative pond) is $(0.3 \times 200) = 60$ mg/l.

Box A1.1 (continued)

B. Design of the facultative pond

The facultative pond volume (V_f, m^3) is given by:

$$V_f = Q\theta_f$$

where Q = wastewater flow (m^3/day) [here, = 1000 m^3/day]; and θ_f = the retention time in the facultative pond (days) [here, taken as 4 days, which is the minimum retention time permissible in a facultative pond]. Thus:

$$V_f = (1000 \times 4) = 4000 \text{ m}^3$$

This is equivalent, for a depth of 1.5 m, to an area of 2667 m^2.

Reed's equation is used to determine the total nitrogen concentration in the effluent of the facultative pond (C_{Ne}, mg N/l) as follows, and assuming that there is no total nitrogen removal in the anaerobic pond:

$$C_{Ne} = C_{Ni} \exp\{-[0.0064(1.039)^{T-20}] \times [\theta_f + 60.6(\text{pH} - 6.6)]\}$$

where C_{Ni} = concentration of total nitrogen in the raw wastewater (mg N/l) [here, = 50 mg N/l]; T = design temperature (°C) [here, = 25 °C]; and the pH can be taken as 8. Thus:

$$C_{Ne} = 50 \times \exp\{-[0.0064(1.039)^{25-20}] \times [4 + 60.6(8 - 6.6)]\} = 25 \text{ mg N/l}$$

C. Design of the fish pond

The area of the fish pond (A_{fp}) is calculated on a design surface loading of total nitrogen ($\lambda_{s(N)}$) of 4 kg/ha per day, as follows:

$$A_{fp} = 10C_{Ni}Q/\lambda_{s(N)}$$

where C_{Ni} = total nitrogen concentration in the influent to the fish pond (i.e. in the effluent of the facultative pond) (mg N/l) [here, = 25 mg N/l]. Thus:

$$A_{fp} = (10 \times 25 \times 1000)/4 = 62\,500 \text{ m}^2 \text{ (6.25 ha)}$$

The retention time in the fish pond (θ_{fp}) is calculated taking the net evaporation into account, as follows:

$$\theta_{fp} = 2A_{fp}D_{fp}/(2Q - 0.001eA_{fp})$$

where D_{fp} is the liquid depth in the fish pond (m) [here, taken as 1 m]; and e is net evaporation (mm/day) [here, = 5 mm/day]. Thus:

$$\theta_{fp} = [2 \times 62\,500 \times 1]/[(2 \times 1000) - (0.001 \times 5 \times 62\,500)] = 74 \text{ days}$$

D. Check the* E. coli *count in the fish pond

The *E. coli* count in the fish pond (N_{fp}, per 100 ml) is calculated from the following equation (which takes into account its reductions in the anaerobic and facultative ponds):

$$N_{fp} = N_i/[(1 + k_T\theta_a)(1 + k_T\theta_f)(1 + k_T\theta_{fp})]$$

where N_i = the *E. coli* count per 100 ml of the untreated wastewater [here, = 1 × 10^7 per 100 ml]; and

k_T = the first-order rate constant for *E. coli* removal in ponds at T °C. Its value is given by:

$$k_T = 2.6(1.19)^{T-20} = 6.2/\text{day for } T = 25 \text{ °C}$$

Box A1.1 (continued)

Thus:

$$N_{fp} = (1 \times 10^7)/\{[1 + (6.2 \times 1)]\ [1 + (6.2 \times 4)]\ [1 + (6.2 \times 74)]\} = 120 \text{ per 100 ml}$$

This is <1000 per 100 ml and therefore satisfactory.

E. Check the free ammonia concentration in the fish pond

The total ammonia concentration is the concentration of dissolved ammonia gas (NH_3) plus the concentration of dissociated ammonium ions. The percentage (p) of free ammonia in aqueous solutions depends on the in-fish pond pH and the absolute temperature (T, K), as follows:

$$p = 100/[10^{(pK_a - pH)} + 1]$$

where pK_a is given by:

$$pK_a = 0.09018 + (2729.92/T)$$

where T is the absolute temperature in Kelvin (K = °C + 273).

The pH in wastewater-fed fish ponds is ~7.5. Thus, for this pH and a temperature of 298 K (= 25 °C), these two equations give:

$$pK_a = 0.09018 + (2729.92/298) = 9.25$$

$$p = 100 / [10^{(9.25 - 7.5)} + 1] = 1.75\%$$

Thus, the free ammonia concentration (at this pH and temperature) is 1.75% of the total ammonia concentration. The total nitrogen concentration in the influent to the fish pond is 25 mg N/l; in the fish pond, it is less than this, and the total ammonia concentration in the fish pond is less than its total nitrogen concentration. Therefore, since 1.75% of 25 mg N/l is 0.44 mg N/l, the free ammonia concentration in the fish pond is less than this and thus below the toxicity threshold of 0.5 mg N/l.

Note: The total pond area is 6.55 ha, of which 0.3 ha is for the anaerobic and facultative ponds and 6.25 ha for the fish pond. The wastewater pretreatment ponds thus occupy only 5% of the total pond area. Thus, both subsistence and commercial fish farmers should always be encouraged to pretreat wastewater before using it to fertilize their fish ponds.

Fish yields

Good fish pond management can be achieved by having small ponds, preferably ≤1 ha, that can be stocked with fingerlings at the rate of $3/m^2$, fertilized with facultative pond effluent and then harvested three to four months after stocking. During this time, the fingerlings will have grown from ~20 g to ~200 g. Partially draining the pond will ensure that almost all the fish can be harvested. This cycle can be done 2 or 3 times per year (allowing for pond maintenance periods). Allowing for a 30% fish loss due to mortality, poaching and consumption by fish-eating birds, and assuming that the ponds (including the anaerobic and facultative ponds) are properly operated and maintained, the annual yield could be as high as 8–12 t of fish per hectare per year, although yields of 4–8 t of fish per hectare per year are more likely.

References

Mara D (1997). *Design manual for waste stabilization ponds in India.* Leeds, Lagoon Technology International Ltd.

Mara DD et al. (1993). A rational approach to the design of wastewater-fed fishponds. *Water Research*, 27(12):1797–1799.

Peña Varón MR, Mara DD (2004). *Waste stabilization ponds: thematic overview paper.* Delft, IRC International Water and Sanitation Centre (http://www.irc.nl/page/14622).

Annex 2

FAO Code of Conduct for Responsible Fisheries: aquaculture and environmental impact

Environmentally relevant sections of Article 9, Aquaculture Development, of the FAO Code of Conduct for Responsible Fisheries

- 9.1 Responsible development of aquaculture, including culture-based fisheries, in areas under national jurisdiction

  9.1.1 States should establish, maintain and develop an appropriate legal and administrative framework which facilitates the development of responsible aquaculture.

  9.1.2 States should promote responsible development and management of aquaculture, including an advance evaluation of the effects of aquaculture development on genetic diversity and ecosystem integrity, based on the best available scientific information.

  9.1.3 States should produce and regularly update aquaculture development strategies and plans, as required, to ensure that aquaculture development is ecologically sustainable and to allow the rational use of resources shared by aquaculture and other activities.

  9.1.4 States should ensure that the livelihoods of local communities, and their access to fishing grounds, are not negatively affected by aquaculture developments.

  9.1.5 States should establish effective procedures specific to aquaculture to undertake appropriate environmental assessment and monitoring with the aim of minimizing adverse ecological changes and related economic and social consequences resulting from water extraction, land use, discharge of effluents, use of drugs and chemicals, and other aquaculture activities.

- 9.2 Responsible development of aquaculture including culture-based fisheries within transboundary aquatic ecosystems

  9.2.1 States should protect transboundary aquatic ecosystems by supporting responsible aquaculture practices within their national jurisdiction and by cooperation in the promotion of sustainable aquaculture practices.

  9.2.2 States should, with due respect to their neighbouring States, and in accordance with international law, ensure responsible choice of species, siting and management of aquaculture activities which could affect transboundary aquatic ecosystems.

  9.2.3 States should consult with their neighbouring States, as appropriate, before introducing non-indigenous species into transboundary aquatic ecosystems.

9.2.4 States should establish appropriate mechanisms, such as databases and information networks to collect, share and disseminate data related to their aquaculture activities to facilitate cooperation on planning for aquaculture development at the national, subregional, regional and global level.

9.2.5 States should cooperate in the development of appropriate mechanisms, when required, to monitor the impacts of inputs used in aquaculture.

- 9.3 Use of aquatic genetic resources for the purposes of aquaculture including culture-based fisheries

9.3.1 States should conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management. In particular, efforts should be undertaken to minimize the harmful effects of introducing non-native species or genetically altered stocks used for aquaculture including culture-based fisheries into waters, especially where there is a significant potential for the spread of such non-native species or genetically altered stocks into waters under the jurisdiction of other States as well as waters under the jurisdiction of the State of origin. States should, whenever possible, promote steps to minimize adverse genetic, disease and other effects of escaped farmed fish on wild stocks.

9.3.2 States should cooperate in the elaboration, adoption and implementation of international codes of practice and procedures for introductions and transfers of aquaticorganisms.

9.3.3 States should, in order to minimize risks of disease transfer and other adverse effects on wild and cultured stocks, encourage adoption of appropriate practices in the genetic improvement of broodstocks, the introduction of non-native species, and in the production, sale and transport of eggs, larvae or fry, broodstock or other live materials. States should facilitate the preparation and implementation of appropriate national codes of practice and procedures to this effect.

9.3.4 States should promote the use of appropriate procedures for the selection of broodstock and the production of eggs, larvae and fry.

9.3.5 States should, where appropriate, promote research and, when feasible, the development of culture techniques for endangered species to protect, rehabilitate and enhance their stocks, taking into account the critical need to conserve genetic diversity of endangered species.

- 9.4 Responsible aquaculture at the production level

9.4.1 States should promote responsible aquaculture practices in support of rural communities, producer organizations and fish farmers.

9.4.2 States should promote active participation of fish farmers and their communities in the development of responsible aquaculture management practices.

9.4.3 States should promote efforts which improve selection and use of appropriate feeds, feed additives and fertilizers, including manures.

9.4.4 States should promote effective farm and fish health management practices favouring hygienic measures and vaccines. Safe, effective and minimal use of therapeutants, hormones and drugs, antibiotics and other disease control chemicals should be ensured.

9.4.5 States should regulate the use of chemical inputs in aquaculture which are hazardous to human health and the environment.

9.4.6 States should require that the disposal of wastes such as offal, sludge, dead or diseased fish, excess veterinary drugs and other hazardous chemical inputs does not constitute a hazard to human health and the environment.

9.4.7 States should ensure the food safety of aquaculture products and promote efforts which maintain product quality and improve their value through particular care before and during harvesting and on-site processing and in storage and transport of the products.

Source: FAO (1995). *Code of conduct for responsible fisheries*. Rome, Food and Agriculture Organization of the United Nations (http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/005/v9878e/v9878e00.htm).

Annex 3
Health impact assessment

Health impact assessment (HIA) is an instrument for safeguarding the health of vulnerable communities in the context of accelerated changes in environmental and/or social health determinants resulting from development. WHO/ECHP (1999) defined HIA as "A combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population." A health impact is a change in health risk reasonably attributable to a project, programme or policy. A health risk is the likelihood of a health hazard affecting a particular community at a particular time. As a rule, assessments are prospective, but they can be retrospective. Retrospective assessments measure and record what has happened, while prospective assessments facilitate development planning and help to predict the consequences of a future project based on available evidence (WHO, 2000).

Procedures and methods

In Figure A3.1, the sequence of essential HIA procedures is presented, with an indication of when each method is applied. Effective HIA requires health hazards, risks, determinants and potential impacts to be defined and monitored (WHO, 2001). Implementation of HIA procedures should be done in such a way as to involve all relevant stakeholders — especially the local communities that will be impacted.

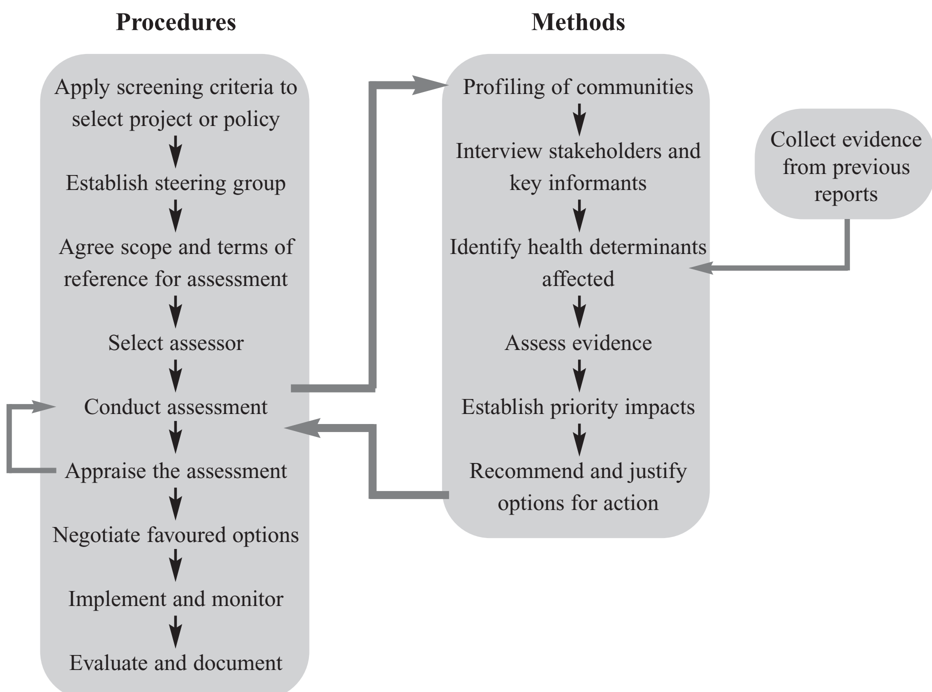


Figure A3.1
Procedures and methods of HIA (from WHO, 2000)

When policy and procedure have been established, the actual assessment can take place. It consists of inferring changes in health determinants that are reasonably attributable to the project and that could affect each stakeholder community during each stage of the project. The changes, taken together, produce health outcomes or changes in health status. These are expressed in a minimum of three ranks: no change, increased health risk and increased health enhancement. Quantification is generally difficult, either because the data are lacking or because there are no known functional relationships between cause and effect. Research is needed to improve the predictive models for other health concerns.

The best forecast of what will happen is the history of what has happened with similar waste-fed aquacultural activities in comparable regions (WHO, 2000).

The assessment would start by collecting baseline data on waste use in aquaculture and health risks over a period of at least two years prior to final agreement on project design. This will provide a profile of the existing communities, their environment, seasonal changes in health risks and the capabilities of their institutions. The data collection would be repeated after the project was operational, and the difference would provide a record of health impact and its likely causes. The record would add to the available knowledge base and improve the assessment of future projects.

The objective of an HIA is to present evidence, infer changes and recommend actions to safeguard, mitigate and enhance human health. The inferences may not always be founded on extensive data, but they must be persuasive (WHO, 2000). The output should be a public health action plan to be implemented by the project proponent in close collaboration with the health authorities.

Management of health risks and enhancements

The final stage of the assessment is to recommend and budget socially acceptable measures to safeguard, mitigate and promote human health (WHO, 2000). The most important principle for health promotion is dialogue between project proponents, health professionals and stakeholder communities at the planning stage. The technical recommendations for managing health risks are diverse. A broad classification is:

- appropriate health regulations and enforcement;
- modifications to project plans and operations;
- improved management and maintenance;
- supportive infrastructure, such as the installation or improvement of wastewater and excreta treatment and use facilities;
- timely provision of accessible health care, including diagnosis and treatment;
- special disease control operations;
- individual protective measures;
- health education;
- redistribution of risk through insurance schemes.

References

WHO (2000). *Human health and dams, the World Health Organization's submission to the World Commission on Dams (WCD)*. Geneva, World Health Organization (Document WHO/SDE/WSH/00.01).

WHO (2001). *Health impact assessment (HIA), report of an inter-regional meeting on harmonization and mainstreaming of HIA in the World Health Organization and of a partnership meeting on the institutionalization of HIA capacity building in Africa, Arusha, 31 October – 3 November 2000*. Geneva, World Health Organization.

WHO/ECHP (1999). *Gothenburg consensus paper, 1999 — Health impact assessment: main concepts and suggested approach.* Brussels, European Centre for Health Policy, World Health Organization Regional Office for Europe (http://www.phel.gov.uk/hiadocs/Gothenburgpaper.pdf).

Annex 4

Glossary of terms used in Guidelines[1]

This glossary does not aim to provide precise definitions of technical or scientific terms, but rather to explain in plain language the meaning of terms frequently used in these Guidelines.

Abattoir – Slaughterhouse where animals are killed and processed into food and other products.

Advanced or tertiary wastewater treatment – Treatment steps added after the secondary treatment stage to remove specific constituents, such as nutrients, suspended solids, organics, heavy metals or dissolved solids (e.g. salts).

Anaerobic pond – Wastewater treatment pond where anaerobic digestion and sedimentation of organic wastes occur; usually the first type of pond in a waste stabilization pond system; requires periodic removal of accumulated sludge formed as a result of sedimentation.

Aquaculture – Raising plants or animals in water (water farming).

Aquifer – A geological area that produces a quantity of water from permeable rock.

Arithmetic mean – The sum of the values of all samples divided by the number of samples; provides the average number per sample.

Biochemical oxygen demand (BOD) – The amount of oxygen that is required to biochemically convert organic matter into inert substances; an indirect measure of the amount of biodegradable organic matter present in the water or wastewater.

Buffer zone – Land that separates wastewater, excreta and/or greywater use areas from public access areas; used to prevent exposures to the public from hazards associated with wastewater, excreta and/or greywater.

Cartage – The process of manually transporting faecal material off site for disposal or treatment.

Coagulation – The clumping together of particles to increase the rate at which sedimentation occurs. Usually triggered by the addition of certain chemicals (e.g. lime, aluminium sulfate, ferric chloride).

Constructed wetlands – Engineered pond or tank-type units to treat faecal sludge or wastewater; consist of a filtering body planted with aquatic emergent plants.

Cost–benefit analysis – An analysis of all the costs of a project and all of the benefits. Projects that provide the most benefits at the least cost are the most desirable.

Cyst – Environmentally resistant infective parasitic life stage (e.g. *Giardia*, *Taenia*).

Cysticercosis – Infection with *Taenia solium* (pig tapeworm) sometimes leads to cysticerci (an infective life stage) encysting in the brain of humans, leading to neurological symptoms such as epilepsy.

Depuration – Transfer of fish to clean water prior to consumption in an attempt to purge their bodies of contamination, potentially including some pathogenic microorganisms.

Diarrhoea – Loose, watery and frequent bowel movements, often associated with an infection.

Disability adjusted life years (DALYs) – Population metric of life years lost to disease due to both morbidity and mortality.

Disease – Symptoms of illness in a host, e.g. diarrhoea, fever, vomiting, blood in urine, etc.

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[1] Sources: APHA et al. (1981); Pettygrove & Asano (1985); Asano & Levine (1998); Mara (1998); Montangero & Strauss (2002).

Disinfection – The inactivation of pathogenic organisms using chemicals, radiation, heat or physical separation processes (e.g. membranes).

Drain – A conduit or channel constructed to carry off stormwater runoff, wastewater or other surplus water. Drains can be open ditches or lined, unlined or buried pipes.

Drip irrigation – Irrigation delivery systems that deliver drips of water directly to plants through pipes. Small holes or emitters control the amount of water that is released to the plant. Drip irrigation does not contaminate above-ground plant surfaces.

Dual-media filtration – Filtration technique that uses two types of filter media to remove particulate matter with different chemical and physical properties (e.g. sand, anthracite, diatomaceous earth).

Effluent – Liquid (e.g. treated or untreated wastewater) that flows out of a process or confined space).

Encyst –The development of a protective cyst for the infective stage of different parasites (e.g. helminths such as foodborne trematodes, tapeworms and some protozoa such as *Giardia*).

Epidemiology – The study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to the control of health problems.

***Escherichia coli* (*E. coli*)** – A bacterium found in the gut, used as an indicator of faecal contamination of water.

Excreta – Faeces and urine (see also faecal sludge, septage and nightsoil).

Exposure – Contact of a chemical, physical or biological agent with the outer boundary of an organism (e.g. through inhalation, ingestion or dermal contact).

Exposure assessment – The estimation (qualitative or quantitative) of the magnitude, frequency, duration, route and extent of exposure to one or more contaminated media.

Facultative pond – Aerobic pond used to degrade organic matter and inactivate pathogens; usually the second type of pond in a waste stabilization pond system.

Faecal sludge – Sludges of variable consistency collected from on-site sanitation systems, such as latrines, non-sewered public toilets, septic tanks and aqua privies. Septage, the faecal sludge collected from septic tanks, is included in this term (see also excreta and nightsoil).

Flocculation – The agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means.

Geometric mean – A measure of central tendency, just like a median. It is different from the traditional mean (which is called the arithmetic mean) because it uses multiplication rather than addition to summarize data values.

Greywater – Water from the kitchen, bath and/or laundry, which generally does not contain significant concentrations of excreta.

Groundwater – Water contained in rocks or subsoil (aquifer).

Grow-out pond – Pond used to raise adult fish from fingerlings.

Hazard – A biological, chemical, physical or radiological agent that has the potential to cause harm.

Health-based target – A defined level of health protection for a given exposure. This can be based on a measure of disease, e.g. 10^{-6} DALY per person per year, or the absence of a specific disease related to that exposure.

Health impact assessment – A combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population.

High-growing crops – Crops that grow above the ground and do not normally touch it (e.g. fruit trees).

High-rate treatment processes – Engineered treatment processes characterized by high flow rates and low hydraulic retention times. Usually include a primary treatment step to settle solids followed by a secondary treatment step to biodegrade organic substances.

Hydraulic retention time – Time the wastewater takes to pass through the system.

Hypochlorite – Chemical frequently used for disinfection (sodium or calcium hypochlorite).

Indicator organisms – Microorganisms whose presence is indicative of faecal contamination and possibly of the presence of more harmful microorganisms.

Infection – The entry and development or multiplication of an infectious agent in a host. Infection may or may not lead to disease symptoms (e.g. diarrhoea). Infection can be measured by detecting infectious agents in excreta or colonized areas or through measurement of a host immune response (i.e. the presence of antibodies against the infectious agent).

Intermediate host – The host occupied by juvenile stages of a parasite prior to the definitive host and in which asexual reproduction often occurs (e.g. for foodborne trematodes or schistosomes the intermediate hosts are specific species of snails).

Legislation – Law enacted by a legislative body or the act of making or enacting laws.

Localized irrigation – Irrigation application technologies that apply the water directly to the crop, through either drip irrigation or bubbler irrigation. Generally use less water and result in less crop contamination and reduce human contact with the wastewater.

Log reduction – Organism removal efficiencies: 1 log unit = 90%; 2 log units = 99%; 3 log units = 99.9%; and so on.

Low-growing crops – Crops that grow below, on or near the soil surface (e.g. carrots, lettuce).

Low-rate biological treatment systems – Use biological processes to treat wastewater in large basins, usually earthen ponds. Characterized by long hydraulic retention times. Examples of low-rate biological treatment processes include waste stabilization ponds, wastewater storage and treatment reservoirs and constructed wetlands.

Maturation pond – An aerobic pond with algal growth and high levels of bacterial removal; usually the final type of pond in a waste stabilization pond system.

Median – The middle value of a sample series (50% of the values in the sample are lower and 50% are greater than the median).

Membrane filtration – Filtration technique based on a physical barrier (a membrane) with specific pore sizes that traps contaminants larger than the pore size on the top surface of the membrane. Contaminants smaller than the specified pore size may pass through the membrane or may be captured within the membrane by some other mechanism.

Metacercariae (infective) – Life cycle stage of trematode parasites infective to humans. Metacercariae can form cysts in fish muscle tissue or on the surfaces of plants, depending on the type of trematode species.

Multiple barriers – Use of more than one preventive measure as a barrier against hazards.

Nightsoil – Untreated excreta transported without water, e.g. via containers or buckets; often used as a popular term in an unspecific manner to designate faecal matter of any origin; its technical use is therefore not recommended.

Off-site sanitation – System of sanitation where excreta are removed from the plot occupied by the dwelling and its immediate surroundings.

On-site sanitation – System of sanitation where the means of storage are contained within the plot occupied by the dwelling and its immediate surroundings. For some systems (e.g. double-pit or vault latrines), treatment of the faecal matter happens on site also, through extended in-pit consolidation and storage. With other systems (e.g. septic tanks, single-pit or vault installations), the sludge has to be collected and treated off site (see also faecal sludge).

Oocyst – A structure that is produced by some coccidian protozoa (e.g. *Cryptosporidium*) as a result of sexual reproduction during the life cycle. The oocyst is usually the infectious and environmental stage, and it contains sporozoites. For the enteric protozoa, the oocyst is excreted in the faeces.

Operational monitoring – 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. for wastewater treatment turbidity). 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.

Overhanging latrine – A latrine that empties directly into a pond or other water body.

Pathogen – A disease-causing organism (e.g. bacteria, helminths, protozoa and viruses).

pH – An expression of the intensity of the basic or acid condition of a liquid.

Policy – The set of procedures, rules and allocation mechanisms that provide the basis for programmes and services. Policies set priorities, and associated strategies allocate resources for their implementation. Policies are implemented through four types of policy instruments: laws and regulations; economic measures; information and education programmes; and assignment of rights and responsibilities for providing services.

Primary treatment – Initial wastewater treatment process used to remove settleable organic and inorganic solids by sedimentation and floating substances (scum) by skimming. Examples of primary treatment include primary sedimentation, chemically enhanced primary sedimentation and upflow anaerobic sludge blanket reactors.

Quantitative microbial risk assessment (QMRA) – Method for assessing risk from specific hazards through different exposure pathways. QMRA has four components: hazard identification; exposure assessment; dose–response assessment; and risk characterization.

Regulations – Rules created by an administrative agency or body that interpret the statute(s) setting out the agency's purpose and powers or the circumstances of applying the statute.

Restricted irrigation – Use of wastewater to grow crops that are not eaten raw by humans.

Risk – The likelihood of a hazard causing harm in exposed populations in a specified time frame, including the magnitude of that harm.

Risk assessment – The overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences.

Risk management – The systematic evaluation of the wastewater, excreta or greywater use system, the identification of hazards and hazardous events, the assessment of risks and the development and implementation of preventive strategies to manage the risks.

Secondary treatment – Wastewater treatment step that follows primary treatment. Involves the removal of biodegradable dissolved and colloidal organic matter using high-rate, engineered aerobic biological treatment processes. Examples of secondary treatment include activated sludge, trickling filters, aerated lagoons and oxidation ditches.

Septage – Sludge removed from septic tanks.

Septic tank – An underground tank that treats wastewater by a combination of solids settling and anaerobic digestion. The effluents may be discharged into soak pits or small-bore sewers.

Sewage – Mixture of human excreta and water used to flush the excreta from the toilet and through the pipes; may also contain water used for domestic purposes.

Sewer – A pipe or conduit that carries wastewater or drainage water.

Sewerage – A complete system of piping, pumps, basins, tanks, unit processes and infrastructure for the collection, transporting, treating and discharging of wastewater.

Sludge – A mixture of solids and water that settles to the bottom of latrines, septic tanks and ponds or is produced as a by-product of wastewater treatment (sludge produced from the treatment of municipal or industrial wastewater is not discussed in volume 3).

Source separation – Diversion of urine, faeces, greywater or all, followed by separate collection (and treatment).

Subsurface irrigation – Irrigation below the soil surface; prevents contamination of above-ground parts of crops.

Surface water – All water naturally open to the atmosphere (e.g. rivers, streams, lakes and reservoirs).

Thermotolerant coliforms – Group of bacteria whose presence in the environment usually indicates faecal contamination; previously called faecal coliforms.

Tolerable daily intake (TDI) – Amount of toxic substance that can be taken on a daily basis over a lifetime without exceeding a certain level of risk.

Tolerable health risk – Defined level of health risk from a specific exposure or disease that is tolerated by society, used to set health-based targets.

Turbidity – The cloudiness of water caused by the presence of fine suspended matter.

Ultraviolet radiation (UV) – Light waves shorter than visible blue-violet waves of the spectrum (from 380 to 10 nanometres) used for pathogen inactivation (bacteria, protozoa and viruses).

Unrestricted irrigation – The use of treated wastewater to grow crops that are normally eaten raw.

Upflow anaerobic sludge blanket reactor – High-rate anaerobic unit used for the primary treatment of domestic wastewater. Wastewater is treated during its passage through a sludge layer (the sludge "blanket") composed of anaerobic bacteria. The treatment process is designed primarily for the removal of organic matter (biochemical oxygen demand).

Validation – Testing the system and its individual components to prove that it is capable of meeting the specified targets (e.g. microbial reduction targets). Should take place when a new system is developed or new processes are added.

Vector – Usually blood-sucking insect that carries disease from one animal or human to another (e.g. certain mosquito species).

Vector-borne disease – Diseases that can be transmitted from human to human by insects (e.g. malaria) or other invertebrates.

Verification monitoring – 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).

Waste-fed aquaculture – Use of wastewater, excreta and/or greywater as inputs to aquacultural systems.

Waste stabilization ponds (WSP) – Shallow basins that use natural factors such as sunlight, temperature, sedimentation, biodegradation, etc., to treat wastewater or faecal sludges. Waste stabilization pond treatment systems usually consist of anaerobic, facultative and maturation ponds linked in series.

Wastewater – Liquid waste discharged from homes, commercial premises and similar sources to individual disposal systems or to municipal sewer pipes, and which contains mainly human excreta and used water. When produced mainly by household and commercial activities, it is called domestic or municipal wastewater or domestic sewage. In this context, domestic sewage does not contain industrial effluents at levels that could pose threats to the functioning of the sewerage system, treatment plant, public health or the environment.

Withholding period – Time to allow pathogen die-off between waste application and harvest.

The third edition of the WHO ***Guidelines for the safe use of wastewater, excreta and greywater*** has been extensively updated to take account of new scientific evidence and contemporary approaches to risk management. The revised Guidelines reflect a strong focus on disease prevention and public health principles.

This new edition responds to a growing demand from WHO Member States for guidance on the safe use of wastewater, excreta and greywater in agriculture and aquaculture. Its target audience includes environmental and public health scientists, researchers, engineers, policy-makers and those responsible for developing standards and regulations.

The Guidelines are presented in four separate volumes: ***Volume 1: Policy and regulatory aspects; Volume 2:Wastewater use in agriculture; Volume 3: Wastewater and excreta use in aquaculture; and Volume 4: Excreta and greywater use in agriculture.***

Volume 3 of the Guidelines informs readers on the assessment of microbial hazards and toxic chemicals and the management of the associated risks when using wastewater and excreta in aquaculture. It explains requirements to promote safe use practices, including minimum procedures and specific health-based targets. It puts trade-offs between potential risks and nutritional benefits in a wider development context.

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