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# STRENGTHENING DRINKING-WATER SURVEILLANCE USING RISK-BASED APPROACHES

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## ABSTRACT

The framework for safe drinking-water recommended by the WHO guidelines for drinking-water quality promotes a risk-based preventive management approach to ensure safety of drinking-water. Independent drinking-water surveillance is one of the core components of this framework and is an essential public health function. To be effective, drinking-water surveillance needs to be aligned with risk-based principles, including prioritization of monitoring parameters and surveillance efforts based on water safety plan outcomes. Risk-based drinking-water surveillance comprises an independent and periodic review of all aspects of drinking-water quality and public health safety in which water-quality monitoring, on-site inspections, hazard identification and risk and trend analysis are important components. Applying a risk-based approach in drinking-water surveillance helps countries to focus on the issues that are most important for the protection of public health and so maximizes the benefits that can accrue from limited resources.

## KEYWORDS

DRINKING WATER  
ENVIRONMENTAL SURVEILLANCE  
PUBLIC HEALTH SURVEILLANCE  
RISK ASSESSMENT  
RISK MANAGEMENT  
WATER QUALITY  
WATER SUPPLY

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# Introduction

## The Protocol on Water and Health

The Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Water Courses and International Lakes (United Nations Economic Commission for Europe & WHO Regional Office for Europe, 1999) has the objective of:

*... protect[ing] human health and well-being, both individual and collective, within a framework of sustainable development, through improving water management, including the protection of water ecosystems, and by preventing, controlling and reducing water-related diseases (Article 1).*

The Protocol is the first international agreement of its kind, adopted specifically to attain an adequate supply of safe drinking-water and adequate sanitation for everyone and effectively protect water used as a source of drinking-water.

The Protocol sets several requirements for surveillance of drinking-water. In particular, Parties to the Protocol shall:

- establish targets for the standards and levels of performance that need to be achieved or maintained for a high level of protection against water-related disease, including on the quality of drinking-water supplied, taking into account the WHO guidelines for drinking-water quality (Article 6, paragraph 2 (a));
- establish and maintain a legal and institutional framework for monitoring and enforcing standards for the quality of drinking-water (Article 6, paragraph 5 (c));
- collect and evaluate data on common indicators, including on the quality of the drinking-water supplied (Article 7); and

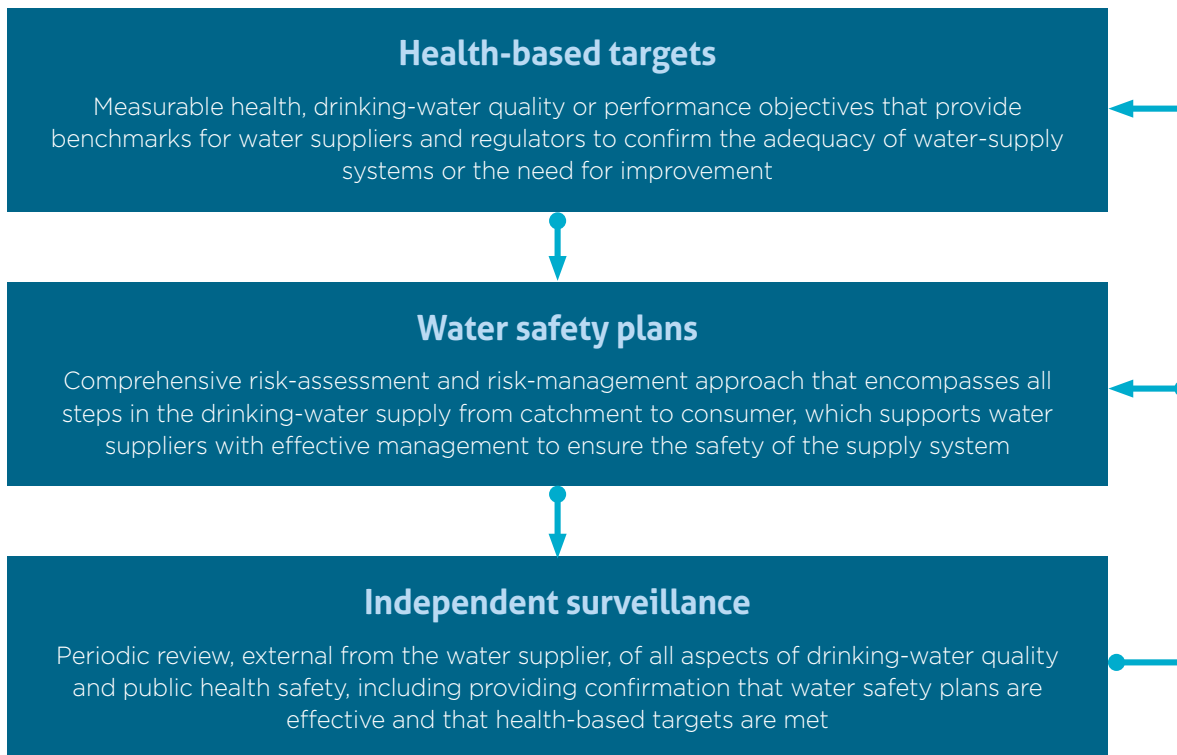
- promote the operation of effective networks to monitor and assess the provision and quality of water-related services, and development of integrated information systems (Article 14 (h)).

## WHO framework for safe drinking-water

The framework for safe drinking-water recommended by the WHO guidelines for drinking-water quality (WHO, 2017a) promotes a risk-based preventive management approach to ensure safety of drinking-water (Fig. 1).

Independent drinking-water surveillance is one of the core components of this framework and is an essential public health function. To be effective, drinking-water surveillance needs to be aligned with risk-based principles, including prioritization of monitoring parameters and surveillance efforts based on water safety plan (WSP) outcomes. This requirement applies to both small and large water supplies, recognizing that there is a difference, usually due to available resources. The framework includes also the principle of setting health-based targets. These can relate to reductions in the rate of a waterborne disease or the setting of drinking-water quality standards for chemical contaminants. Surveillance seeks, at least in part, to ensure that progress is being made in meeting these targets.

WHO has recommended a risk-based approach to standard-setting, particularly in resource-limited countries (WHO, 2018). This approach helps to develop drinking-water quality standards appropriate to the circumstances in a country, focusing on the parameters that are of highest concern in the national context, to provide a basic set of norms that can be changed or expanded over time as circumstances allow.

**Fig. 1.** WHO framework for safe drinking-water

Source: modified from WHO (2017a).

While the requirements and framework for the risk-based approach specified in the WHO guidelines for drinking-water quality may be set out by national authorities, the individual water supplier and surveillance agency are responsible for determining the details of how this is implemented, adapting as necessary to the local circumstances of each supply.

## Drinking-water surveillance

WHO (1976) defines surveillance as “*the continuous and vigilant public health assessment and review of the safety and acceptability of drinking-water supplies*”.

Surveillance is the responsibility of national, subnational and/or local authorities. Drinking-water surveillance involves more than just water-quality monitoring: it is the independent and periodic review of all aspects of drinking-water quality and public health safety in which water-quality monitoring, on-site inspections, hazard identification and risk and trend analysis are important components. While it will include review of water suppliers’

monitoring records and an assessment of how well supplies are meeting the standards set in the country, both individually and overall, it should also include audits of how well water suppliers are implementing their WSPs and, where possible, assessment of waterborne disease in the population. The latter is a powerful tool for measuring progress against national and local health targets established by national authorities.

**Risk-based drinking-water surveillance is considered best practice within the framework for safe drinking-water (Fig. 1). It reflects a shift in focus from overreliance on compliance-testing of a predetermined list of water-quality parameters to promoting a proactive approach to identifying, controlling and monitoring critical risks in water supply. Applying a risk-based approach in drinking-water surveillance helps countries to focus on the issues that are most important for the protection of public health and so maximizes the benefits that can accrue from limited resources.**

## What is this publication about?

Supporting countries in building effective systems for surveillance of drinking-water is a priority area of work under the Protocol on Water and Health. A regional meeting on effective approaches to drinking-water quality surveillance, held in Oslo, Norway in May 2015 recognized the importance of, and need for, the application of risk-based approaches in standard-setting and surveillance (WHO Regional Office for Europe, 2015).

This publication provides a rationale for decision-makers to promote and support uptake of risk-based approaches in regulations and surveillance practice. It has been designed around six key messages that underlie the concept of risk-based approaches in drinking-water surveillance and is supported by practical examples for illustration purposes.

Using this concise format, the publication aims to support decision-makers, regulators

and national and subnational professionals in the fields of public health, environment and water management to better understand and appreciate the added value of risk-based drinking-water surveillance and thereby strengthen surveillance systems for better protection of public health.

The publication provides a strong rationale for the application of risk-based approaches to surveillance and the prioritization of surveillance efforts that consider local hazards and available resources. Risk-based surveillance is an important building block towards reaching global and regional policy commitments, such as United Nations Sustainable Development Goal 6 on clean water and sanitation and the Declaration of the Sixth Ministerial Conference on Environment and Health (Ostrava Declaration), which collectively call for the adoption of risk-based approaches in ensuring the provision of safely managed drinking-water for all that protects health and well-being.

# Overview of the key messages

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## **Key message 1: Surveillance is a core public health function**

Drinking-water surveillance is a fundamental activity for the continuing protection of public health through the delivery of safe drinking-water.

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## **Key message 2: Risk-based surveillance is a governmental responsibility**

It is a responsibility of the government to establish legal and regulatory requirements for implementation of risk-based drinking-water surveillance that adequately protects public health.

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## **Key message 3: Risk-based surveillance points at what needs to be looked at**

Risk-based drinking-water surveillance identifies the hazards that pose the greatest risks to the population and supports the development of appropriate and efficient monitoring programmes for individual supplies.

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## **Key message 4: Microbiological drinking-water quality is a key focus of risk-based surveillance**

Identifying microbiological hazards and risks before they affect public health is an essential part of risk-based surveillance.

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## **Key message 5: Only monitor what is necessary**

Monitoring of chemicals needs to be selective. Risk-based drinking-water surveillance directs water-quality monitoring towards the most important, relevant parameters for system performance and public health protection.

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## **Key message 6: Risk-based surveillance aids forward-thinking and anticipation of change**

Hazards and risks change over time. Surveillance agencies have an important supporting role in predicting, identifying and tracking long-term changes and associated risks for drinking-water supply.

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# Key message 1: Surveillance is a core public health function

## Drinking-water surveillance is a fundamental activity for the continuing protection of public health through the delivery of safe drinking-water.

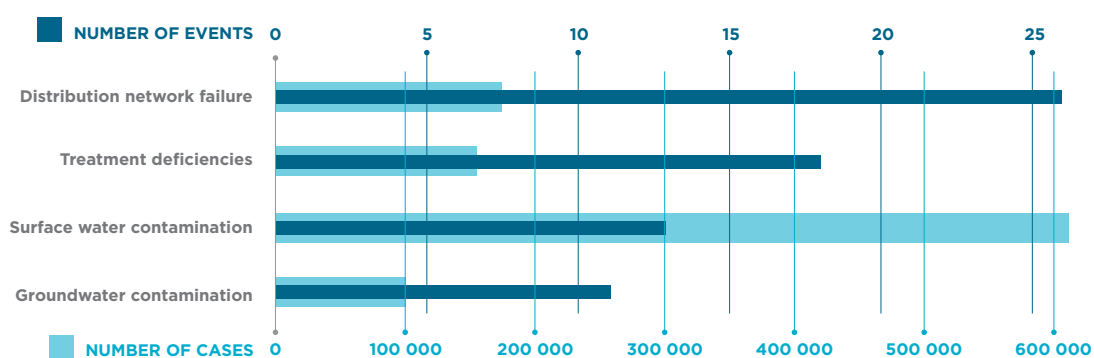
Public health surveillance has been defined as “the continuous, systematic collection, analysis and interpretation of health-related data needed for the planning, implementation, and evaluation of public health practice” (Langmuir, 1963). Such surveillance supports the tracking of progress towards specified health targets, setting priorities and informing public health policy and strategies.

Drinking-water surveillance can be defined as the “continuous and vigilant public health assessment and review of the safety and acceptability of drinking-water supplies” (WHO, 1976).

### Safe drinking-water is vital for good health

Drinking-water can be a vehicle for the transmission of disease, so the provision of safe drinking-water has a vital public health function. In the pan-European region,<sup>1</sup> waterborne outbreaks of disease continue to occur and place significant burdens on communities (WHO Regional Office for Europe, 2016a). As shown in Fig. 2, contamination of water sources (such as intrusion of animal faeces due to heavy rain and discharges of wastewater), treatment deficiencies (malfunctioning of the disinfection equipment, for instance) and distribution network failures (including

**Fig. 2.** The number of events of waterborne disease outbreaks and the number of cases of illness among consumers in Europe, North America and New Zealand, 2000–2014



Source: modified from Moreira & Bondelind (2017). Reproduced from *Journal of Water And Health* volume 15, issue number 1, pages 83–96, with permission from the copyright holders, IWA Publishing.

<sup>1</sup> This publication uses the term pan-European region to refer to the Member States of the WHO European Region and Liechtenstein. The WHO European Region comprises the following 53 countries: Albania, Andorra, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Luxembourg, Malta, Monaco, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Republic of Moldova, Romania, Russian Federation, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tajikistan, Turkey, Turkmenistan, Ukraine, United Kingdom and Uzbekistan.

cross-connections, pipe breaks and wastewater intrusion) frequently cause waterborne disease outbreaks and illness among consumers (see Case study 1 from Hungary).

By providing drinking-water, every supplier assumes responsibility for protecting public health. It is vital for suppliers to apply good practice to make sure they operate in such a way as to minimize risks to health and maximize the

acceptability of drinking-water to consumers. It is incumbent upon the supplier to produce and supply drinking-water that is as safe as can be achieved in particular circumstances. This is best achieved by adopting the WHO-recommended WSP approach (Box 1), which has been taken up in many drinking-water regulations across the pan-European region (see Case study 2 from the United Kingdom (England and Wales) and Case study 3 from Belarus).

### Box 1. Protect rather than detect – the WSP approach

The WSP approach is recommended in the WHO guidelines for drinking-water quality as a core pillar of the framework for safe drinking-water (Fig. 1). WSPs provide the most effective means of consistently ensuring the safety of a drinking-water supply through the use of a comprehensive risk-assessment and risk-management approach that encompasses all steps in the water supply, from catchment to consumer (WHO, 2017a).

The WSP approach presents a proactive and preventive means of assuring safe drinking-water. Essential requirements of the WSP approach are to:

- identify systematically any hazards that may have adverse impacts on health (such as pathogens or chemicals) and hazardous events that introduce hazards to the supply system or fail to remove them (such as rainfall events and treatment failures) for each supply stage, from source-water catchment, through water abstraction, to treatment, storage and distribution to the point of use;
- assess the levels of health risks associated with exposure to the identified hazards under different scenarios and risks of exceeding drinking-water standards: risk assessment identifies the requirement for improvement interventions and management attention to mitigate the identified risks;
- establish effective measures to control the risks identified: control measures (or preventative measures or barriers to contamination) prevent hazards gaining access to water (through the catchment or distribution system, for instance) or remove or minimize hazards from the water (such as through treatment); control measures can start with catchment controls, continue through the various stages of treatment barriers and include maintaining high-quality drinking-water as it flows through distribution and storage systems, including the plumbing systems in buildings;
- establish management and operational monitoring procedures to ensure the chosen control measures operate optimally at all times; and
- establish procedures for verification monitoring (in addition to those used in operational monitoring) to determine whether the performance of the drinking-water supply is in compliance with the water-quality standards and is acceptable to consumers, and procedures for auditing to confirm the WSP's completeness, adequate implementation and effectiveness.

The WSP process leads to the development of supply-specific profiles that identify chemical, microbiological, physical and radiological hazards of local relevance and concern, including the events and routes through which the hazards can enter the supply. These profiles allow the water supplier to identify appropriate management interventions and control measures to minimize the risks of the hazard reaching the consumer in concentrations that are likely to cause adverse effects, including rejection of aesthetically unacceptable water.

Further details of the WSP approach and its core requirements are set out in the WHO guidelines for drinking-water quality (WHO, 2017a) and supporting technical guidance documents, such as the *Water safety plan manual: step-by-step risk management for drinking-water suppliers* (WHO, 2009) and the *Water safety plan: a field guide to improving drinking-water safety in small communities* (WHO Regional Office for Europe, 2014).

## Functions of drinking-water surveillance

Surveillance contributes to the protection of public health by promoting improvement of the quality, quantity, accessibility, reliability, affordability and continuity of drinking-water supplies. It is an essential part of ensuring that public health is protected against the threats that can come from drinking-water. The authorities responsible for drinking-water surveillance need to be independent of water suppliers, and their roles cover the following areas (WHO, 2017a):

- ensuring public health oversight of organized drinking-water supplies;
- providing public health oversight and information support to populations
- without access to organized drinking-water supplies, including communities and households;
- building and maintaining public trust in drinking-water supplies to maximize the benefits of safe and acceptable supplies;
- promoting incremental improvement of drinking-water supplies;
- consolidating information from different sources to enable understanding of the overall drinking-water supply situation for a country or region as a whole or as part of the development of coherent public health-centred policies and practices; and
- participating in the investigation, reporting and compilation of outbreaks of waterborne disease.

### Case study 1

## A drinking-water outbreak in Miskolc, Hungary, following an extreme precipitation event

Miskolc is a city of approximately 80 000 inhabitants located in north-eastern Hungary. It relies on karstic water for its drinking-water supply. Following an extreme precipitation event, it experienced a multi-aetiological drinking-water outbreak affecting over 3500 people.

The water of the karstic spring generally is delivered without treatment, except for safety chlorination. The water supply was monitored regularly according to the frequency defined in drinking-water legislation. Samples were tested routinely for turbidity, microbiological and chemical parameters. Increased turbidity was observed during a week of extreme precipitation, but faecal indicators were not detected, so normal operation was continued.

The water supply was resampled following the three-day Pentecost holiday, but by the time the results arrived (two days later), general practitioners had already reported increased incidence of gastrointestinal illness. A boil water advisory was issued and the consumption of water restricted. The advice was upheld until the operation of the water supply returned to normal. Epidemiological investigation confirmed the consumption of tap water as the source of infection.

The cause of the outbreak was the extreme precipitation, which changed the underground current in the karst and washed contamination into the water source. Routine testing for faecal indicators was insufficient in preventing the outbreak. Turbidity was found to be indicative of events leading to the deterioration of water quality. Online turbidity monitors were installed and a control value was assigned to the measurements as an early warning of potential contaminations.

Further information on the case study can be found in Dura et al. (2010).

## Case study 2

# Introduction of risk assessments improves compliance in the United Kingdom (England and Wales)

The Drinking Water Inspectorate for England & Wales (DWI) is an independent regulator. Legislation and regulations clearly specify WSP requirements for water companies (public supplies) and local authorities (private supplies). Water companies report summary information to DWI, which assesses the implementation of the WSP approach. Feedback information is provided to the water company and any actions identified to deal with unmitigated risks are set out in legally binding documents (notices). Ongoing audit focuses on validation of existing control measures and identification of additional risk mitigation.

Local authorities in England and Wales are responsible for implementing the Private Water Supplies Regulations 2009. Their regulatory duties include risk assessment for each supply in their area (primarily through on-site visits), monitoring each supply for compliance with drinking-water standards, and investigating and taking enforcement action where a risk to human health is identified or non-compliance is found. Risk assessments are reviewed if new information becomes available (but at least once every five years). DWI's role with regard to private water supplies is to oversee the risk assessment approach taken and provide technical support, respond to enquiries, and provide training and advice to local authorities.

A risk assessment tool for local authorities has been developed, and the DWI website includes a specific section on small private supplies (DWI, 2019). The tool pre-identifies most hazards associated with different private water-supply types. It features sections that can be selected depending on the components that make up the supply (borehole source, ultraviolet treatment and tank storage, for example). Any hazard that has not been pre-identified can be added to the tool by the risk assessor. The assessor must then work through the risk assessment and score the likelihood of a hazard manifesting in the supply for the supply components selected.

The risk assessment in the tool is based on a 5x5 matrix in which the severity and likelihood scores are multiplied together to give a risk score for the different hazards. The severity score is predefined, but the assessor needs to gauge the likelihood of the hazard manifesting in the supply. A document gives detailed guidance on how the likelihood score should be chosen. The risk assessment tool produces an overall risk rating of the supply and any high or very high risks are recorded on the risk register. Should any high or very high risks exist, the risk assessment tool prompts the assessor to specify the required mitigation measures to reduce the risk to an acceptable level within a specified timeframe. These mitigation measures are recorded in an action plan that can be used to form a programme of improvement works for the supply operator to implement.

Experience in England and Wales shows that the introduction of WSPs to legislation has resulted in improved compliance, especially for small private supplies, and informs prioritization of attention and surveillance activities. WSP outcomes are also used to justify investment needs.



### Case study 3

## Implementation of a risk-based approach in drinking-water legislation in Belarus

While Belarussian sanitary-epidemiological legislation contained some elements of health-risk analysis, there was no requirement for a comprehensive risk-assessment scheme in drinking-water supply. The traditional surveillance system primarily was based on checking compliance with water-quality standards and sanitary norms.

The Law of the Republic of Belarus of 2012 on “Sanitary and Epidemiological Welfare of the Population” was amended in 2016. It now provides a framework for the application of risk assessment as a basis from which to take measures to prevent and minimize identified risks (risk management) and to inform stakeholders about the risk-assessment outcomes. The new Law on Drinking Water Supply of 2019 includes requirements on health-risk assessment in water-supply systems to guarantee the safety of drinking-water supplied to consumers.

A number of supporting by-laws have been developed, including Guideline No. 027-1215 “Method of risk analysis in drinking-water supply systems” (2019) and Guideline No. 019-1118 “Method of hygienic assessment of drinking-water” (2018) issued by the Ministry of Health, as well as Resolution No. 914 “Specific sanitary and epidemiological requirements for the maintenance and operation of sources and systems of drinking-water supply” (2018) from the Council of Ministers.

According to the new legislation, all entities that may constitute a risk to health should undergo procedures for risk assessment. The by-laws define a set of risk-assessment criteria for drinking-water service providers, large- and small-scale. These criteria cover all stages of the drinking-water supply chain and also consider water-quality monitoring data.

The risk-assessment approach allows evaluation of existing conditions in a drinking-water supply system and reveal the most vulnerable stages that require more attention and remedial measures. Outcomes of risk assessments inform the design of drinking-water quality-monitoring programmes that reflect the specificities of a water-supply system and help to plan and justify supervisory and control activities (inspections) of the responsible surveillance agency.



# Key message 2: Risk-based surveillance is a governmental responsibility

**It is a responsibility of the government to establish legal and regulatory requirements for implementation of risk-based drinking-water surveillance that adequately protect public health.**

The potential for harm when water supplies fail is significant, and those responsible for water-supply systems need to be equipped with clear strategies, rules and regulations that ensure the safety of drinking-water.

The government is responsible for setting health targets and establishing appropriate drinking-water quality standards and relevant legislation, including surveillance mandates to ensure that water suppliers are fulfilling their obligations (Box 2).

Implementation and enforcement typically is the responsibility of the ministry of (public) health and its regional or departmental offices, or an environmental protection department of local government (see Case study 2 from England and Wales).

The following factors should be considered to ensure an effective surveillance system is built and sustained:

- establish an enabling legal framework and legal support for drinking-water surveillance;
- establish a legislative and institutional basis for effective drinking-water surveillance that promotes local risk assessments as the basis for prioritizing surveillance and responses;
- review and update national drinking-water quality standards by integrating a risk-based approach;
- ensure that surveillance covers the whole of the drinking-water system, from the sources and activities in the catchment through abstraction, treatment,

## Box 2. Main activities of surveillance agencies

Surveillance agencies' main activities are to:

- investigate waterborne disease in the population, including waterborne outbreaks, and assess whether health targets are being met;
- check compliance with drinking-water quality standards through direct water-quality testing and review of water suppliers' monitoring records;
- audit WSPs and verify their effectiveness;
- conduct on-site sanitary inspections;
- provide advice and support to water suppliers, particularly for small supplies that may have only limited resources; and
- analyse water-quality trends and the outcomes from sanitary inspections and/or WSP audits locally and nationally to inform local remedial measures and wider policy for protection of water resources and drinking-water.

storage and distribution to the point of consumption;

- take into account the particular circumstances of small drinking-water supplies and establish the surveillance agency's specific responsibility for supporting small systems;
- provide clear definitions of water suppliers' and surveillance agencies' roles and responsibilities;
- promote effective coordination and collaboration between the water supplier and the public health surveillance agency and any other agencies that might play a role;
- assess human-resource and institutional capacity and identify needs for strengthening surveillance of the drinking-water supply;
- secure adequate human resource and financing for drinking-water surveillance programmes;
- implement capacity-building at different levels, including training programmes for public health officers, inspectors and water operators;
- build and sustain an inventory/information system that supports effective surveillance;
- ensure adequate reporting and flow of water-quality data among responsible parties;
- analyse and use surveillance data in improving water-quality regulations and to inform improvements by the water supplier; and
- create an enabling environment to ensure the exchange of information to support

the water supplier's responsibilities and the surveillance agency's operations.

While surveillance and establishing the framework within which surveillance authorities operate is the responsibility of the government, water suppliers are responsible for ensuring supply systems are capable of delivering safe drinking-water at all times and verifying that they do so. This includes developing and implementing a suitable WSP to manage the supply chain from catchment to tap and meeting relevant water-quality standards. In jurisdictions where water suppliers do not have the mandate or responsibility to manage drinking-water quality beyond the point of transfer to premises, it should be the responsibility of the building owner or manager to establish a building WSP to ensure safe drinking-water at the tap (WHO, 2011).

There may be a need for the surveillance agency to impose penalties on water suppliers to ensure and encourage compliance with standards and WSP principles; as such, surveillance agencies must be supported by enforceable regulations (see Case study 2 from England and Wales, Case study 4 from Portugal and Case study 5 from Norway). The system should not foster antagonism, however, and penalties should be used as a last resort. It is important that the surveillance agency should work to develop a good trusting relationship with suppliers. It is in the interests of all parties that water suppliers should feel able to communicate problems to the surveillance agency without fear of automatic prosecution or the application of sanctions.

## Case study 4

### Focusing needs in the water supply in Portugal

In 2017, water supplies operating under a WSP covered 32% of the population of Portugal. Water suppliers must submit an annual water-quality control plan to the Water and Waste Services Regulatory Authority for approval. The plan includes details of parameters, frequency of sampling and sampling points in the supply chain from source to consumer.

Since 2019, national legislation has required the implementation of a risk-based approach to establishing water-quality control plans. Once the plan is approved, monitoring data are submitted online and can be assessed by drinking-water and health authorities. If non-compliance is observed, the water supplier must inform the local public health authority, which then carries out a risk assessment to analyse the parameters, exposure time and susceptibility of exposed populations. The authority can then restrict water use, make recommendations to the public and call on the water supplier to introduce changes to treatment processes. Health authorities also assess drinking-water supply systems, with a special focus on small supplies.

The country has a mandatory disease-notification system (including for water-related infectious diseases) and a national epidemiological surveillance system.

## Case study 5

### Risk-based routine drinking-water quality-monitoring schemes in Norway

Around 4.6 million people (90% of the population) of Norway are provided with drinking-water from approximately 1500 regulated water-supply utilities. Most of these are in public ownership, but private actors operate some smaller water supplies. The Norwegian Food Safety Authority (NFSA) provides oversight to water utilities that produce more than 10 m<sup>3</sup> of drinking-water per day.

Drinking-water legislation has been in existence since the 1950s and is subject to regular updates. The latest version was brought into force in January 2017. It is based on the European Council Directive 98/83/EC, particularly its latest amendment through Commission Directive (EU) 2015/1787, and now features a distinct risk-based approach (see Case study 11 from the European Union (EU)). The overarching principle in the updated law is the requirement to conduct an “assessment and management of hazards”. This assessment shall map potential hazards from catchment to consumer and is supposed to inform all actions taken by the water utility. Water utilities are obliged to manage the risks relevant to their water-supply system systematically in terms of long-term and preparedness planning and in day-to-day operation.

**Case study 5 contd**

Water utilities shall also establish a risk-based routine monitoring plan based on the assessment of local hazards. The plan should include details of the location of representative sampling points, sampling frequencies (based on the size of the water utility) and relevant parameters. Analysis for *Escherichia coli* is mandatory, and water utilities that produce more than 10 m<sup>3</sup> of drinking-water per day have a minimum requirement to monitor for intestinal enterococci, colour, turbidity and acceptable aesthetic appearance (free from taste/odour).

The water utility is responsible for defining its risks and monitoring any relevant parameter to their system. Based on risk assessments, the NSFA can grant dispensations from meeting the standards laid down in the drinking-water legislation. If a risk assessment demonstrates that a substance does not represent a health risk, the water utility may reduce the frequency of sampling if all representative results from drinking-water quality analysis in a three year period are below 60% of the standard value (with a minimum of two samples taken); in addition, a parameter may also be excluded from monitoring if all results are below 30% of the standard value.

NFSA receives yearly reports with data on water quality and system information from the water utilities. These data are used by the NFSA to perform risk-based inspections and audits. Information retrieved from yearly reports is further analysed and made available for multiple uses, such as statistics and research.

# Key message 3: Risk-based surveillance points at what needs to be looked at

**Risk-based drinking-water surveillance identifies the hazards that pose the greatest risks to the population and supports the development of appropriate and efficient monitoring programmes for individual supplies.**

Risk-based drinking-water surveillance is considered best practice within the framework for safe drinking-water (Fig. 1). It helps to protect the health of consumers in the most resource-effective way by identifying whether the risks are under proper and continuing control and targeting resources where they will have the greatest health benefit. The outcomes of risk-based drinking-water surveillance can inform national and subnational priorities in terms of addressing risks to drinking-water supply and putting in place effective supporting programmes.

Risk-based surveillance reflects a shift in focus from overreliance on end-product (compliance) testing of a predetermined list of water-quality parameters to promoting a proactive approach to identifying, controlling and monitoring critical risks in water supply.

Routine water-quality monitoring remains an essential part of risk-based surveillance as a means of verifying that a drinking-water supply system continuously is providing safe drinking-water. This requires, however, that the parameters, siting and frequency of the sampling reflect the characteristics and hazards of the water-supply system in their local context.

## The difference between pathogens and chemicals

While pathogens are recognized as the primary cause of waterborne morbidity and disease,

chemicals cannot be ignored. Pathogens cause illness and even death in humans due to exposure through drinking-water, sometimes by a single exposure. By contrast, only a small number of chemicals – arsenic, fluoride, nitrate/nitrite and lead – are known to cause disease through drinking-water, almost invariably following long-term exposure. Other chemicals, both inorganic and organic, may adversely affect health, but most available information relates to laboratory studies in animals that are used to identify concentrations of these chemicals that are considered safe. In addition, advanced analytical techniques can measure a wide range of chemicals, mostly in wastewater-impacted waters, typically at very low concentrations. Other chemicals that are not of direct concern for health can affect acceptability to consumers and may cause them to turn to other sources that may not be microbiologically safe.

Pathogens are usually present in source waters from human and animal faecal matter and include bacteria, viruses and parasites, although a few, such as *Legionella*, can also proliferate in distribution systems. Where there is potential for pathogens to be present, it is important that appropriate barriers are put in place and are functioning efficiently at all times, as pathogen numbers can vary significantly, frequently over a short time. The traditional approach to measuring faecal-indicator bacteria in drinking-water means that an event in which pathogen contamination breaks through will be picked up only by chance; by the time a laboratory result is

obtained and reported, the contaminated water will probably have been drunk. Outbreaks are often detected by consumers falling sick (see Case study 1 from Hungary).

Most source waters will contain a range of chemicals and microorganisms that are naturally present or arise from discharges, including from industry, agriculture and sewage. Surface water is generally at greater risk than groundwater, but groundwater also varies in its vulnerability. Pathogens and chemical contaminants can also arise in treatment, in distribution and in plumbing systems in buildings (such as *Legionella* and lead).

### Identifying surveillance priorities

Surveillance goes beyond simply checking for compliance of drinking-water with the standards, which has limitations in confirming the safety of a water supply. It also aims to build an understanding of the entire water-supply system, local risks and causes for contamination from catchment to the point of consumption, and how these risks are being managed against the core principles of a WSP (Box 1). Risk assessment drives the purpose and focus of water-quality monitoring and control measures to mitigate contamination risks effectively at all times.

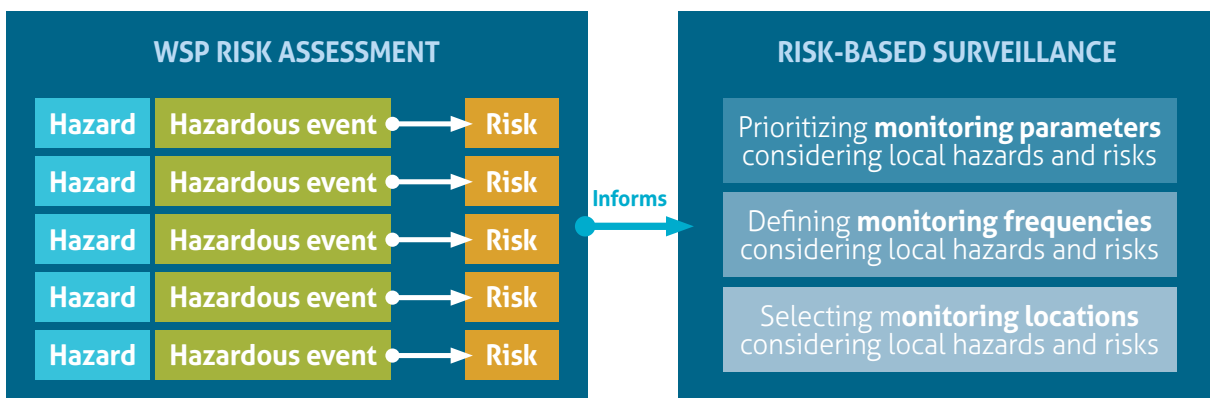
The chemical and microbiological quality of water can and does change between the point the water enters the building and the consumer’s tap. Systematic management of water in buildings by the owner or manager through, for example, a building WSP is a vital

part of maintaining drinking-water safety; consequently, it should be subject to surveillance attention. A preventative risk-based approach is especially important in buildings, as it virtually is impossible to monitor every tap.

WSPs draw on in-depth knowledge of a water-supply system and provide an important mechanism for identifying surveillance priorities (Fig. 3). The outcomes of a WSP, including those from available building WSPs in the supply area, identify the main hazards and hazardous events (and their health risks) in the catchment and throughout the supply chain up to the point of consumption. This, in turn:

- identifies the water-quality parameters that are most significant to protect health and which therefore should be the focus of surveillance;
- identifies where to sample, including in high-risk areas of the distribution system such as dead ends or remote zones and in buildings that host vulnerable members of the population (schools, hospitals and nursing homes, for example) or where people will be present for extended periods of time (like hotels);
- informs sampling frequencies for high-risk parameters, including consideration of seasonal/climatic variations that may lead to changes in the quality of source waters and/or in the distribution system; and
- points to the most appropriate operational monitoring to ensure that the barriers/ treatments to the high-risk parameters are working properly at all times.

Fig. 3. WSPs inform risk-based surveillance





Risk-based surveillance uses these outcomes to prioritize surveillance efforts based on public health risks and target resources where most needed, thereby leading to the greatest benefit for health while employing the most efficient use of available resources. It also informs which substances should be included in standards on a country-wide basis as part of the risk-based standard-setting process.

A further consideration in risk-based surveillance is the size of the population supplied. Surveillance attention frequently prioritizes central water supplies that serve water to large population groups in urban centres. Small rural supplies usually do not receive the same level of attention and support due to the difference in the number of people exposed to possible contaminated water and, consequently, the scale of health consequences.

This principle is reflected typically in the regulatory frameworks that drive the activities of surveillance agencies and water suppliers and define the number of samples taken and frequency of sampling. The WHO guidelines for drinking-water quality recommend increasing the sampling frequency and the number of samples as the population supplied increases. For large water supplies, sample numbers can be large, and the frequency of sampling high. At the opposite end of the scale populated by small water supplies, the number of samples can be small – often a single sample – and the frequency of sampling extremely low – perhaps once every few years. This may be adequate to assess water quality for chemical contaminants with stable concentrations, but where there is significant variation in the interval between sampling events, such as with microbiological contaminants, the quality of the water will be unknown if reliance is placed on these monitoring data alone (see Key message 4).

Because the risk-based approach to managing drinking-water quality focuses on developing an understanding of prevailing hazards and their prevention, the apparent imbalance between small and large supplies in terms of surveillance attention and sampling intervals is countered

by shifting from overreliance on monitoring to identifying and prioritizing small systems that require increased attention and interventions.

## Risk-based surveillance includes WSP auditing

The central role of WSPs in a risk-based approach means the surveillance agency has a key role in auditing the WSP associated with a particular supply. Such audits provide an independent and systematic check of a WSP to confirm its completeness, adequate implementation and effectiveness. They make sure that the WSP is sufficiently comprehensive in terms of hazard analysis and risk assessment, that established control measures are adequate and that they work at all times. Audits may confirm compliance with regulatory WSP requirements, support the continuous improvement of a WSP, offer opportunities to provide technical guidance and support to WSP teams, and address gaps in understanding. WHO's practical guide to auditing WSPs provides further information (WHO, 2015a).

The outcomes of an audit help surveillance authorities to prioritize their attention and resources on the supplies that show critical gaps in the WSP and/or its implementation, indicating risks that are not addressed adequately and are likely to compromise public health if not properly rectified. Audit outcomes can guide prioritization of supplies that need to improve to ensure better water-quality risk management is in place and/or identification of areas requiring attention during future audits. A collective analysis of WSP audit outcomes at subnational or national level can also inform broader policy-making and improvement programming in the field of water and health, particularly in the context of small supplies.

## Risk-based standard-setting

One of the primary means by which surveillance agencies determine that drinking-water does not pose an unacceptable risk to the health of consumers is by monitoring against national standards that define the

admissible concentrations of a range of biological, chemical and physical parameters. The list of standards or guidelines for chemical parameters is often quite long, reflecting a wide range of circumstances and the potential for contamination in different places; monitoring all of these would require significant resources and would record mostly zeros.

WHO has recommended a risk-based approach to standard-setting for national authorities, particularly in resource-limited countries (WHO, 2018), that supports incremental improvement over time. This helps to develop a set of standards appropriate to the circumstances in a country by focusing on the most important parameters based on risk to health, occurrence in water sources or drinking-water and concentrations found. These will include microbiological contaminants that primarily come from faecal contamination and will also include a number of chemical contaminants, particularly the few that have been shown to cause human health effects through drinking-water. The standards provide a basic set of norms that can be amended or expanded over time as circumstances allow, including in response to long-term impacts of climate change and other environmental and socioeconomic changes. The overall approach is supported by the application of supply-specific WSPs.

### **Incremental improvement is an important goal**

Incremental improvement towards long-term goals is an important concept in the allocation of resources to improve drinking-water safety. Risk-based surveillance is an important element in the development of strategies for incremental improvement of drinking-water supply services (WHO, 2017a).

It is possible to make step-by-step improvements over time, whether in terms of infrastructure, management procedures or increasing skills and knowledge of operators through training. One of the roles of the surveillance agency is to help water suppliers, particularly small suppliers,

to identify improvements and put ways of achieving them in place.

Improvements may require financial resources, in which case the surveillance agency is well placed to assist in ensuring that the highest priorities for protection of health are addressed first, based on the risk-assessment outcomes of the WSP and surveillance findings. The surveillance agency should also monitor whether improvements are being achieved and, based on the experiences gained and the resources available, help redefine priorities over time as improvements are made.

### **Particular considerations for small supplies**

Public health can be better protected by identifying and understanding risk factors associated with the individual drinking-water supply. While this is important for all supplies, it may be particularly relevant for small water supplies. They are often managed by communities or individuals and are not always appropriately supported financially, technically or politically in the same way as large utility-managed supplies (see Case study 6 from Serbia and Case study 7 from Germany). Small supplies are widespread and are often found in remote locations, which can make them hard to reach for surveillance activities. They are particularly vulnerable to microbiological contamination. Major risk factors include animal husbandry and other agricultural practices in close proximity to rural small water systems in combination with heavy rainfall events and inadequate treatment (WHO Regional Office for Europe, 2016b; 2016c).

Of the 175 waterborne outbreaks notified between 1998 and 2012 in Denmark, Finland, Norway and Sweden, affecting 85 995 individuals, 76% were associated with single-household supplies (Guzman-Herrador et al., 2015). Private water supplies serve approximately 0.5% of the population in England and Wales but have been shown to be responsible for 36% of waterborne disease outbreaks (Said et al., 2003). Reports of outbreaks in Canada and the United States of

America indicate that approximately 50% of cases caused by waterborne diseases occur in small, non-community drinking-water systems (Pons et al., 2015).

For these reasons, it is important that risk-based surveillance pays sufficient attention to small supplies. Surveillance authorities in some jurisdictions are directly involved in water-quality monitoring in small supplies (see, for example, Case study 8 from Lithuania on testing private wells for households with infants or expectant mothers), but they have a particular role in providing or facilitating advice

to small suppliers in view of normally limited resources and expertise. The advice may cover assistance in identifying and explaining the implications of locally relevant risks (see also Key message 4 on risk assessment tools and sanitary inspection), offering solutions on mitigating the risks and providing continuing support and information (see Case study 2 from England and Wales and Case study 7 from Germany). Policing is typically not the primary role of the surveillance authority in the context of small systems. The eventual objective is to promote incremental improvement of the system over time.

## Case study 6

# Rapid assessment of drinking-water quality and prevailing sanitary conditions in small water supplies in rural areas of Serbia

Drinking-water surveillance is conducted by the network of institutes of public health under the Ministry of Health. Drinking-water quality parameters and sampling frequency are regulated by the Rule on Hygienic Correctness of Drinking-Water for water supplies that serve more than 20 people or five households. Enforcement in rural areas, however, is weak, resulting in a lack of data on drinking-water quality and sanitary conditions in small water supplies. Challenges such as unregulated ownership of the numbers of rural small water supplies, lack of responsibility for maintenance and monitoring of facilities and testing the quality of drinking-water hamper adequate drinking-water surveillance.

Serbia has used the target-setting framework under the Protocol on Water and Health to address challenges related to small water supplies. Serbia's national targets set under the Protocol include a specific target on undertaking a systematic assessment of drinking-water quality and prevailing conditions in rural water supplies to improve the evidence base and inform surveillance attention and improvement interventions.

A national-level survey conducted in 2016 investigated two types of water-supply systems: small piped systems serving up to 10 000 people; and individual supplies serving less than five households or 20 inhabitants. In total, 1318 supplies were investigated by using standardized sanitary inspections and testing for *Escherichia coli* and 10 physicochemical parameters.

Overall, 83% of individual supplies and 63% of small piped systems investigated did not comply with national water-quality standards. About one third of all water samples taken were found to be microbiologically contaminated. The dominant risks revealed by sanitary inspection were absence of regular chlorination, non-established and unmanaged sanitary protection zones, sources of pollution placed nearby the source and unsatisfactory technical conditions.

### Case study 6 contd

Combined analysis of sanitary-inspection and water-quality data using a risk-priority matrix (Fig. CS1) revealed that 29% of small piped systems and 41% of individual supplies show a higher or urgent priority for improvement actions to prevent water contamination and protect public health (high and very high risk level).

This systematic assessment helped to establish systematic baseline information on small systems and enabled the identification of the most important causes of contamination. The outcomes of the assessment allowed public health authorities to prioritize their surveillance efforts through identifying the supply systems at greatest risk that required increased attention and guidance, including providing support to leverage local improvement action. The survey induced policy actions and measures for improving rural water supplies directed at amending and enforcing existing legislation and programmes and the development of new regulations.

**Fig. CS1.** Risk-priority matrix for piped systems (individual supplies) in Serbia

<i>E. coli</i> count (CFU <sup>a</sup> /100 ml)	Sanitary inspection score				Risk level	Action level
	0-2	3-5	6-8	9-10		
< 1	28.4% (23.1%)				Low	No action required
1-10		42.0% (36.3%)			Intermediate	Low action priority
11-100			23.2% (33.5%)		High	Higher action priority
> 100				6.4% (7.1%)	Very high	Urgent action priority

<sup>a</sup>CFU: colony-forming units.

Further information on the case study can be found in Jovanović et al. (2017) and WHO Regional Office for Europe (2017).

### Case study 7

## Addressing surveillance of private wells in Germany

Around 11% of the population of Germany are supplied by small systems that serve less than 5000 people. Another 0.7% are served by individual supplies (private wells).

The German Drinking Water Ordinance establishes the requirements for monitoring the quality of drinking-water. Whereas limit values apply to all sizes of supplies, surveillance authorities may grant deviations from the scope of chemical parameters for private wells (without commercial or public activity) if the parameter is not expected to occur at concentrations that would jeopardize compliance with the limit value.

**Case study 7 contd**

Monitoring frequency depends on the size of the supplies. The minimum requirements for private wells (without commercial or public activity) are to carry out at least an annual analysis of five compulsory microbiological parameters and further indicator parameters, with additional physicochemical parameters selected by the local surveillance authority to be analysed at least every three years. The local surveillance authority has to be notified in cases of non-compliance. National reporting on water quality is mandatory for supplies serving more than 50 people or producing more than 10 m<sup>3</sup> per day, but no such regular reporting is required for private wells; such data lie with local surveillance authorities.

Challenges related to drinking-water surveillance in small systems in Germany include a lack of attention at local level, low levels of awareness of potential risks among operators, lack of availability of consolidated data on drinking-water quality at national level to support informed policy-making and the high numbers of supplies in some districts that strain the capacity of surveillance authorities.

To address the challenges related to management and surveillance of private wells, an interinstitutional working group was established, representing all 16 federal states and other experts. The working group's mandate is to review evidence related to private wells and provide advice and support to local authorities on how to conduct effective surveillance and lever improvements. The working group has developed a specific guideline for surveillance of private wells that addresses health authorities and acts as a practical handbook with recommendations for private-well owners.

**Case study 8**

## Testing of water from dug wells used by pregnant women and infants in Lithuania

The Order of the Minister of Health on Diagnostics and Prophylactics for Poisonings Related to Nitrate and Nitrite aims to protect infants from methemoglobinemia due to elevated concentrations of nitrate or nitrite in drinking-water

Upon receipt of notification from a primary health-care institution about a pregnant woman or an infant under 6 months of age who is using water from a dug well for potable or food purposes, the National Public Health Centre (PHC) under the Ministry of Health shall, within two weeks of receipt of the notification, organize a chemical test of the dug well to determine the concentration of nitrate and nitrite in drinking-water. The PHC is obliged immediately to inform in writing people in whose wells nitrate and nitrite concentrations exceeded the limit values, explaining the possible health hazards and describing safe water-preparation methods. The PHC specialist has to send a copy of this letter to the primary health-care institution that provided the information in the first place. At least every six months, the PHC informs the municipality in which the pregnant woman or infant resides about water quality in terms of concentration of nitrate and nitrite in drinking-water so the municipality can plan long-term prevention measures for residents.



# Key message 4: Microbiological drinking-water quality is a key focus of risk-based surveillance

**Identifying microbiological hazards and risks before they affect public health is an essential part of risk-based surveillance.**

Microbiological contamination is the most common and widespread health risk associated with drinking-water and should be treated as a priority.

## Indicators of faecal pollution

Testing for faecal indicators is important to show that faecal contamination of drinking-water is being controlled effectively by barriers in the water-supply system.

The measurement of pathogenic microorganisms in water is complex and resource-intensive. Non-pathogenic bacteria that are present in large numbers in human and animal faeces therefore traditionally have been used as indicators of the presence of faecal contamination and, potentially, pathogens from faeces. The indicator organisms used have primarily been *Escherichia coli* or thermotolerant coliforms, but others, such as enterococci, are also used.

Organisms that are neither pathogenic nor indicators of faecal contamination, such as heterotrophic plate counts or total coliforms, are sometimes used as an indicator that something has changed in distribution or there has been ingress of contamination, both of which require investigation to determine the cause and, if appropriate, remedial action.

Several emerging pathogens, including *Legionella*, are not of faecal origin. Some opportunist pathogens, particularly *Legionella* and *Naegleria*, are not faecally derived but are free-living associated with biofilms and can multiply in distribution systems. *Legionella* is a particular problem in the distribution systems of buildings associated with water use where aerosols are formed, as *Legionella* causes respiratory disease. *Pseudomonas aeruginosa*, another opportunist pathogen, can also multiply in distribution systems and is of particular concern in hospitals and health-care facilities.

## Faecal indicators are useful, but limited

For most of the 20<sup>th</sup> century, the microbiological quality of drinking-water supply systems was assessed by testing water samples for compliance against standards for faecal indicators. Sampling frequencies, methodology, parametric values and compliance rates were tightly defined in regulations governing water supplies. Provided that the concentrations of parameters were within the specified limits, the water was judged to be safe.

While testing for indicators of faecal contamination is useful to assess compliance with standards and has been very successful

in helping to prevent waterborne disease, overreliance on microbiological compliance monitoring as the sole measure of safety of a drinking-water supply has limitations (Box 3).

Microbiological pathogens are not limited to bacteria, and illness may result from exposure to pathogenic viruses or protozoa, both of which have different environmental behaviour and survival characteristics than bacteria. Generally, faecal bacteria have lower persistence in the environment compared to viruses and protozoa and are more sensitive to common disinfectants. Faecal indicators found in water therefore do not necessarily correlate

well with the presence of viral and protozoal pathogens.

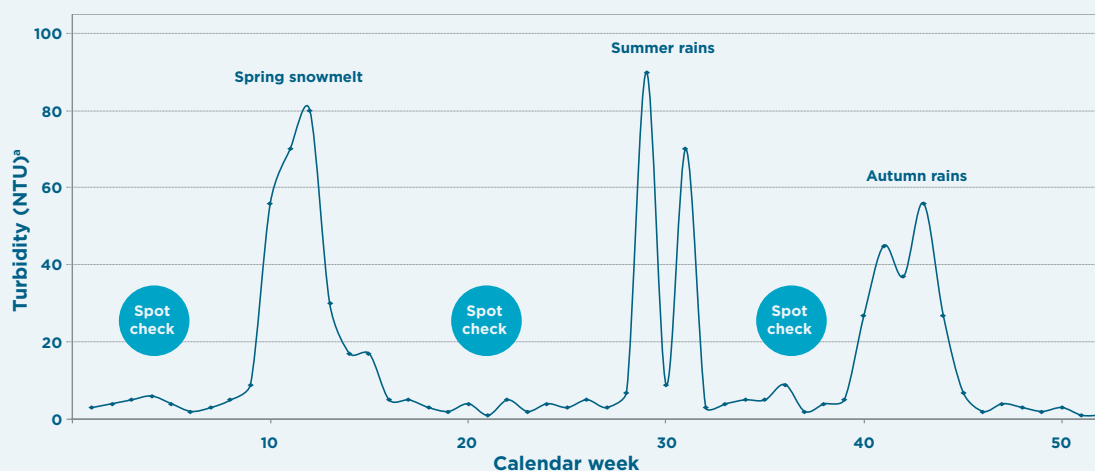
Importantly, some outbreaks of waterborne disease have occurred when water-quality testing did not detect faecal-indicator bacteria in drinking-water and showed compliance with standards, demonstrating that infrequent testing for such indicators is not always informative and may miss critical contamination events. In north-west England, for example, an outbreak of cryptosporidiosis occurred in a supply from a groundwater source in which chlorination had killed the indicator bacteria, meaning the indication of

### Box 3. Microbiological water-quality monitoring alone is too little and too late

While bacterial faecal indicators play an important role in verifying compliance with water-quality standards, overreliance on microbiological compliance monitoring has limitations that need to be kept in mind:

- the sample size is small in relation to the volume of water supplied;
- samples are relatively infrequent – numbers of pathogens vary in time and are not evenly dispersed;
- spot checks may miss critical contamination events, such as wet-weather events that affect source-water quality and possibly drinking-water quality, particularly in small supplies where sampling typically is infrequent (see Fig. B1 for a simulated example);
- viruses and protozoa are often more resistant in the environment and to disinfection than faecal-indicator bacteria;
- viruses are smaller than bacteria and more difficult to remove with conventional filtration;
- it takes time to measure indicators, so the water has probably been drunk by the time a problem is confirmed; and
- they do not reflect opportunist pathogens that can multiply in distribution systems, including in buildings.

**Fig. B1.** Simulated example of how wet-weather events can affect source-water quality vis-à-vis timing of spot-sampling



<sup>a</sup> NTU: nephelometric turbidity units.



faecal contamination was absent (Bridgman et al., 1995). The *Cryptosporidium* outbreak in Milwaukee, United States, is another example of a significant outbreak in which microbiological water-quality standards were compliant (MacKenzie et al., 1994).

It is not possible to monitor pathogens or indicators in water on a continual basis, so contamination events can happen between checks (see Case study 1 from Hungary). Concentrations of microorganisms vary with time and are not evenly spaced through the water. A sample is also very small in relation to the amount of water being supplied, so a water sample for microbiological testing will only ever give a limited snapshot of the quality.

### The importance of understanding source-water quality

Understanding source-water quality and its variations, as well as the root causes and pathways of contamination, is an important part of characterizing the risks to water supply and, therefore, of risk-based surveillance. The surveillance agency should promote the process of assessing source-water quality in close cooperation with the responsible environmental and/or water authorities and the water supplier.

Reliable information on source-water quality is needed to define treatment requirements to achieve safe drinking-water and identify catchment protection options to reduce source-water contamination, such as limiting the access of animals to water sources by installing fencing and ensuring that latrines and septic tanks are properly sited and operated (further details on catchment protection are provided by WHO (2006; 2016)). It is also important to consider the long-term impacts of climate change and other environmental and socioeconomic changes that may affect the quality of water resources.

While understanding source-water quality is an important consideration for assessing chemical contamination, it is particularly crucial for

microbiological quality. Surveillance agencies should promote and support proactive risk assessments to identify the sources of pathogens in the catchment and related hazardous events that will increase their concentration. Where available, historical data should be reviewed to provide a picture of the probable presence of pathogens and estimate their likely concentrations.

Some countries measure one or more actual pathogens as an indicator to characterize source-water quality (see Case study 9 from the Netherlands). The aim of monitoring pathogens at intervals is to obtain a better measure of probable pathogen numbers, but this is not always possible due to limitations in the availability of laboratory capacity and resources. Where this is not feasible, the use of so-called classical faecal indicators provides valuable information on background loading and contamination peaks.

Events such as heavy rainfall or snowmelt may lead to increased surface runoff and overflow of untreated wastewater. This can lead to rapid deterioration of source-water quality that may result in a challenge to drinking-water treatment. Identifying such events and responding accordingly by increasing the frequency of sampling where, for example, the source water is considered vulnerable is the first step in planning and establishing processes or procedures to mitigate the risks when the events happen. Surveillance agencies should have the authority to request or enforce such action.

### Post-treatment contamination in distribution is important

Microbiological contamination of treated drinking-water in distribution systems, including building plumbing systems, can also occur. Once pathogens have entered the distribution system, it is likely that consumers will be exposed due to lack of downstream control measures, including disinfectant residuals that may not be sufficient to overcome the contamination event (WHO, 2017a). Developing a sound

understanding of where the distribution system is vulnerable and what steps need to be taken to rectify problems is therefore an important part of risk-based surveillance.

Hazardous events associated with distribution systems are diverse. Examples include, but are not limited to, the following (WHO, 2014):

- low water pressure, especially during intermittent supply, that may allow infiltration of contaminated water into the system through breaks, cracks, joints and pinholes;
- unintended cross-connections with non-drinking-water systems (such as rainwater, greywater and wastewater);
- ingress of contaminated water into poorly maintained service reservoirs with compromised infrastructural integrity;
- contamination during repair or maintenance works;
- biofilm formation and growth of heterotrophic bacteria and amoebae; and
- growth of opportunistic pathogens in building plumbing systems due to unfavourable temperature conditions.

Risk-based surveillance should take due consideration of the network attributes and vulnerabilities of the distribution system, including consideration of flow rates, water-retention times, age and materials of pipes, seasons of low and high demand and remote sections of the system. While these should be key outcomes of a WSP of a particular water supply, the surveillance agency can support and advise in choosing suitable monitoring and inspection regimes that would best reflect the particularities of the distribution system. Guidance on selecting sampling sites and frequencies for compliance or verification monitoring purposes is available (WHO, 2014).

### **Detection of faecal indicators requires attention**

Detection of a faecal indicator in a drinking-water sample requires urgent attention by the

surveillance agency to ensure no threat to public health. An immediate investigation is essential, with the objectives of:

- confirming that the monitoring result is credible through repeat sampling and that the source of contamination is not within a single building;
- ensuring there is no failure of any barriers;
- identifying possible sources of faecal contamination;
- increasing vigilance for reports of illness in the community; and
- taking appropriate public health responses (such as boil water notices and provision of alternative supplies) if continued or significant contamination is confirmed.

There is detailed advice in the WHO guidelines for drinking-water quality (2017a) and supporting documents (WHO, 2015b; WHO, 2018; WHO Regional Office for Europe, 2019).

### **Operational monitoring is a key function**

Operational monitoring is carried out by the water supplier to ensure that all barriers or control measures throughout the water-supply chain, including water treatment, are operating efficiently at all times (Box 4). Risk-based surveillance includes assessing the suitability and summary results of operational monitoring undertaken by the water supplier as an integral part of the WSP. Regular inspections and audits of the treatment and other barriers help to assure public health

Operational monitoring does not remove the need for compliance monitoring, which is important for demonstrating compliance with standards and ensuring public confidence in the water supply. Operational monitoring, however, reduces reliance on monitoring by taking samples at the end of the process and focusing on ensuring the efficacy of treatment and management processes in day-to-day operations.

## Box 4. Examples of operational monitoring

Operational monitoring conducted by water suppliers assesses the performance of control measures at appropriate time intervals. It usually is carried out through simple observations and water-quality tests to confirm rapidly that control measures are continuing to work. Examples include:

- turbidity and rainfall in source waters to track possible contamination events;
- dosage of chemicals used in treatment, such as coagulants;
- turbidity measured post-filtration, preferably on each filter;
- head pressure loss on filters to determine when the filter requires maintenance, such as back-washing;
- chlorine residual measured after chlorination and at critical points throughout the distribution system, including in dead-end sections and low-flow zones;
- temperature in warm- and cold-water plumbing systems in buildings as an integral part of preventing and controlling *Legionella* growth; and
- inspection of protective infrastructures, such as wellheads, fences or service reservoirs.

Continuous (online) monitoring of critical water-quality parameters, such as turbidity and residual chlorine, can be an important part of ensuring that the barriers are optimized at all times. WHO has issued a technical brief that provides practical information for surveillance agencies and water suppliers on the significance of turbidity in source water and drinking-water and the implications of turbidity for water safety at each step of the water-supply chain (WHO, 2017b).

## Risk-assessment tools and sanitary inspections support surveillance

Robust, low-cost and easy-to-use risk-assessment tools will aid the identification of locally relevant risks and support WSP development, particularly for small systems. These tools can take the form of predefined risk inventories (see Case study 2 from England and Wales). Sanitary inspection is another example of an easy-to-use tool that can be applied by operators to support WSP implementation and by public/environmental health officers as part of their independent surveillance. Sanitary inspection aids on-site fact-finding, particularly in identifying sources of the most important hazards, the potential for hazardous events and pathways of contamination from catchment to consumer (Box 5). The approach for pathogens in particular allows control options to be identified to prevent or minimize contamination of the supply. Surveillance agencies readily can assess whether these control options are being maintained. The approach can also be applied

more broadly to inform regional or national priorities for improving small and larger supplies (see Case study 6 from Serbia).

Combined analysis of sanitary inspection and microbiological water-quality data is a powerful tool for identifying the most important causes of contamination and necessary improvement interventions (WHO, 2017a). Risk-priority matrices (see Case study 6 from Serbia) provide a simple grading system that is particularly useful in small supplies where the frequency of testing is low and reliance on analytical results alone is especially inappropriate. Risk-priority matrices can assist surveillance authorities in effective and rational decision-making, specifically in drawing up a list of required priority interventions to improve sanitary conditions and water quality and in estimating investment requirements. They can also help to guide public health authorities to establish surveillance priorities by identifying systems that require increased attention and guidance.

## Box 5. Sanitary inspections

Volume 3 of the WHO guidelines for drinking-water quality (WHO, 1997) describes sanitary inspections as:

*On-site inspection and evaluation by qualified individuals of all conditions, devices, and practices in the water-supply system that pose an actual or potential danger to the health and well-being of the consumer. It is a fact-finding activity that should identify system deficiencies – not only sources of actual contamination but also inadequacies and lack of integrity in the system that could lead to contamination.*

Sanitary inspection has many advantages. It is low-cost, requires no elaborate equipment and may easily be performed regularly. It can reveal conditions or practices that may cause isolated pollution incidents or longer-term pollution and the most obvious possible sources of contamination, but may not reveal all sources of contamination (such as remote contamination of groundwater). The specific functions of sanitary inspections include:

- enhancing knowledge of the water-supply system;
- identifying potential sources and points of contamination of the water supply that may be missed by water-quality analysis alone;
- quantifying the hazards attributable to the sources and supply;
- providing a clear means of explaining the hazards and related hazardous events and conditions to the operator and/or water user;
- providing clear guidance on remedial action required to protect and improve the supply; and
- providing raw data for use in systematic strategic planning for improvement.

## Case study 9

### Development of an inspectorate guideline for microbial risk assessment in the Netherlands

The Drinking Water Act (2011) in the Netherlands prescribes that *Escherichia coli* and enterococci must be absent in 100 ml of drinking-water and that the risk of infection for selected index pathogens due to the consumption of unboiled drinking-water should not exceed 10 000 individuals per year. Inspectorate Guideline 5318 (2005) was developed to support implementation of these requirements. It describes the procedures for drinking-water suppliers on conducting a quantitative microbial risk assessment (QMRA) for drinking-water, which is produced from surface water.

The main guideline provisions entail a requirement for undertaking a QMRA every fourth year for so-called index pathogens (enterovirus, *Cryptosporidium*, *Giardia* and *Campylobacter*). The guideline also defines monitoring frequencies for source waters that depend on volume of drinking-water produced. In addition to regular monitoring, a number of incidental samples must be collected at times when peak concentrations in pathogens are assumed to occur, such as times of heavy rainfall.

The guideline also describes measurements to validate treatment efficiencies for the four index pathogens based on indicator-organism removal rates. Based on the concentration of index pathogens in the source water and the reduction expected during treatment, the pathogen concentration in drinking-water can be estimated. This information is required to conduct the QMRA, the procedure for which is also described in the guideline.

### Case study 9 contd

To standardize the QMRA process performed by different drinking-water companies, a computational tool, *QMRAspot*, has been developed by the National Institute for Public Health and the Environment to calculate infectious risks for the consumption of drinking-water produced from surface water. *QMRAspot* does not require that the user has extensive knowledge of QMRA, as it provides guidance on type and format of raw data, performs mathematical analysis on the raw data and then estimates the annual infectious risk for drinking-water consumption.

The insights gained from application of the guidelines and use of QMRA methods help with systematic assessment of the safety and robustness of a drinking-water production plant and support drinking-water suppliers and policy-makers in evaluating and prioritizing preventive measures. This supports cost-effective decision-making and maintaining a balance between spending of public funds and health protection.

After more than 10 years of experience in conducting QMRA for drinking-water, the working groups on infectious risk currently are revising the guideline, which is expected to be launched by the end of 2019.



# Key message 5: Only monitor what is necessary

**Monitoring of chemicals needs to be selective. Risk-based drinking-water surveillance directs water-quality monitoring towards the most important, relevant parameters for system performance and public health protection.**

A risk-based approach to surveillance enables the best use of financial, technical and personnel resources by directing them to the areas where health risks can be prevented. This is particularly important when considering chemical contaminants. A key part of the process of establishing risk-based surveillance is setting appropriate national standards built around the principle of reflecting what is considered important in any particular country (WHO, 2018). Appropriate standards form the foundation for establishing risk-based monitoring programmes for individual drinking-water supplies (see Key message 3).

## Setting appropriate standards for chemicals and establishing monitoring programmes

While the WHO guidelines for drinking-water quality include guideline values for more than 90 chemicals, not all chemicals will be present in all water supplies. It therefore is important to direct monitoring resources where they will achieve the greatest benefit in assuring public health and confidence in the water supply rather than attempting to measure a long list of substances that are not there. Routine monitoring for substances for which results are always negative is generally a waste of valuable resources (see Case study 10 from Jersey). The drinking-water surveillance authority will almost invariably have to play a major role in prioritizing monitoring for chemicals.

Many chemicals can potentially be present in water, but most will either not be present at all

or present at concentrations well below those of concern. To ensure resources are used efficiently and cost-effectively, national standards should prioritize the chemical parameters that are of public health significance in the national context. It is important to reassess periodically the contaminants of interest and keep lists of contaminants up to date. This is also an important part of gradual improvement as knowledge increases and facilities improve.

New or emerging substances and groups of substances may be detected in water sources and drinking-water, often at very small concentrations. They include, but are not limited to, pharmaceuticals, microplastics and industrially derived micropollutants. WHO has carried out detailed reviews of the occurrence and possible risks of some of these substances (WHO, 2012; 2017a; 2019). Although these substances sometimes receive media attention and concern the public, the available body of evidence does not always indicate that they will have an impact on human health through drinking-water. In such cases, the setting of water-quality standards and associated routine monitoring requirements would not be appropriate. Considering new and emerging hazards should not detract from dealing with the hazards that constitute the greatest risk to health, but investigative monitoring of these substances may be appropriate under certain circumstances. If data confirm that they are of national or subnational concern, they may be considered for future standard-setting as part of gradual improvement.

Occasionally, chemical contaminants that are of interest in a small number of specific circumstances may be present, and it may not be appropriate to include them in standards. Likewise, some substances are encountered primarily as a consequence of spills that are not predictable. Setting standards and routine monitoring requirements for such substances is not a reliable way of protecting against accidents and will dilute resources. Recommendations for safe levels in drinking-water for such chemicals may then be obtained from the WHO guidelines for drinking-water quality or an alternative appropriate source.

Standards should also allow for incremental improvement. A standard for a substance may become tighter over time to allow for steps to be taken to meet it while considering the resources available to enforce the standard; the European Union (EU) Drinking Water Directive of 1998, for example, set a standard of 25 µg/L for lead that reduced to 10 µg/L after 15 years (EU, 1998).

## Identifying monitoring priorities

Monitoring of chemicals needs to be selective. One of the significant benefits of adopting WSPs is that knowledge of chemical hazards provides much of the evidence for selecting and prioritizing parameters and developing risk-based monitoring programmes for a

specific supply (Fig. 3). To make supply-specific decisions concerning choice of parameters and frequency of monitoring, it is important that regulations make provision for flexibility and establish clear criteria for decisions to be made, including a requirement for proper justification and documentation of the decisions taken.

The criteria for prioritizing chemical parameters include:

- understanding the chemicals that actually are present and/or are likely to occur (Box 6);
- information on their concentrations and the stability of their concentrations in water;
- assessment of their public health significance, including the likelihood of exceeding national standards or international guidelines; and
- assessment of the likelihood of affecting the acceptability of the water to consumers.

Chemicals known to cause health effects through drinking-water (arsenic, fluoride, nitrate/nitrite and lead) should initially be considered for a monitoring programme or programme of investigation. Other substances may be present at concentrations close to or above drinking-water standards or guidelines; while they may not pose a direct threat to

### Box 6. Sources of chemicals in drinking-water

Chemicals in drinking-water may come from a number of sources. It is beneficial to identify and list substances according to the sources, such as chemicals that:

- naturally occur in source water and are released from rocks and soils and algal toxins in surface water;
- come from industrial activities released to source waters from manufacturing, processing and mining;
- come from agricultural activities reaching source waters as a result of application of manure, fertilizer and pesticides;
- come from human settlements resulting in source-water contamination from sewage, waste disposal, urban runoff and fuel leakage;
- are used in drinking-water treatment and disinfection processes; and
- come from contact with materials during distribution, such as from storage tanks and pipes, including domestic plumbing (WHO, 2007).



health, concentrations above the standards or WHO guideline values will erode the margin of safety and, more importantly, may erode public confidence in the water supply. Even arsenic, fluoride, nitrate/nitrite and lead, however, need not necessarily be monitored frequently if they are not present at concentrations of concern, but are close to national standards or the WHO guideline values.

Where there is reason to suspect that water-soluble and persistent substances are present and can contaminate local water sources (such as some perfluorinated chemicals deriving from firefighting foams), it might be appropriate to carry out some investigative analysis to assess the risk associated with the consumption of contaminated drinking-water. General routine monitoring, however, may not be advisable, as analysis is complex and expensive.

The choice of parameters also needs to take account of specific circumstances, such as the use of chemical disinfectants and extraction of groundwater or surface water. Some substances rarely seen in surface water are persistent in groundwater when present (trichloroethene used in metal degreasing, for example), while cyanobacterial toxins will affect still and slow-flowing surface-water sources only. Inorganic or organic disinfection by-products that require surveillance attention can be formed in supplies where chemical disinfectants are used in water treatment. While it is important to make efforts to keep these as low as reasonably practical, disinfection should never be compromised in trying to meet standards for these substances.

The surveillance authority should take note of substances that may not be of particular significance for health, but which adversely affect acceptability through taste, odour, discolouration or turbidity, as this may drive consumers to alternative supplies that aesthetically are more acceptable but microbiologically are less safe.

Small supplies generally have fewer resources and limited access to trained staff. It is important that sampling and monitoring requirements

for chemicals are proportionate in terms of the number of parameters and the frequency of sampling. This would include the number of chemicals for consideration and may be limited to those few that are of direct health concern and those that can give rise to loss of acceptability. The surveillance agency plays an important role in providing advice on the selection of critical parameters for monitoring. In the context of small supplies, risk-based drinking-water surveillance also plays a critical role in protecting the health of vulnerable groups (see Case study 8 from Lithuania).

## Monitoring frequencies and sampling locations

The setting of national water-quality standards is closely associated with the suggested frequency of monitoring. Generally, the frequency should reflect the size of the population served by a water supply and the stability of the concentrations of chemicals in water. Monitoring would be infrequent, or even unnecessary, if concentrations are well below the standard and are not increasing with time. Where concentrations do not vary much, only occasional sampling, perhaps annually or even less frequently, would be needed, depending on resources. The formulation of clear criteria for reducing the frequency of monitoring of the substances that were shown not to be present, or even exempting those from monitoring, is an important part of regulations to allow for risk-based prioritization in monitoring programming (see Case study 5 from Norway, Case study 11 from the EU, Case study 12 from Hungary and Case study 13 from the Netherlands).

The selection of the most appropriate sampling point is also an important consideration in setting standards that support risk-based surveillance. Generally, the sampling point depends on source and characteristics of the substance. If a parameter changes in distribution (a chlorination by-product such as trihalomethanes, for instance), it may be appropriate to take samples at the tap or at a remote part of the distribution system (unless there is a short distribution system, as is the

case with some small supplies). If a parameter (such as arsenic or fluoride) does not change in distribution, a single sample at the point immediately after treatment should be able to reflect concentrations at the tap over the area supplied.

A different approach is required for substances that come from plumbing in buildings, including metals such as lead or copper. Concentrations vary significantly depending on the materials in contact with water, the water quality and the period over which the water has been in contact with the metals, so protocols for taking samples need to recognize this variation. Generally, risk-based surveillance protocols will need to reflect a reasonable worst-case situation (to give the greatest chance of demonstrating whether a problem exists) to identify the presence of metals at elevated concentrations and the need for appropriate management and corrective action. For lead, for example, the priority would be to identify if lead is present and then determine the risk of exposure and the best risk-reduction strategy for the circumstances. Because lead concentrations in water depend on the contact time with the leaded material as well as the plumbosolvency of the water, routine monitoring may not be particularly helpful.

### Exceedance of a national standard or international guideline value

Exceedance of the water-quality standard or guideline value for a chemical contaminant does not necessarily mean there is a threat to health. The risk to health will depend on the extent to which the standard is exceeded and for how long, and on the sensitivities of specific user groups. An example is methaemoglobinaemia, which can be caused in bottle-fed infants by nitrate/nitrite. The risk is increased by the presence of pathogens

that can cause diarrhoea and organisms that can reduce nitrate to nitrite. Another example is lead, which can adversely affect learning in children. The problems arising from lead plumbing and solder can be managed in various ways, including ensuring that plumbing to drinking-water points in buildings used to a significant extent by children are lead-free.

Most guideline values for chemicals have a large margin of safety and are intended for long-term, potentially lifetime, exposure. This means that short-term exceedances of the guideline or standard value do not normally represent a discernible increase in risk to the health of consumers. WHO (2018) provides guidance on how to determine whether the risk of a chemical exceeding the standard is serious or not.

If the exposure is relatively minor and short-term, the key is to determine why it happened and see whether it is likely to occur repeatedly. If so, it is appropriate to put in place improvements to the way the hazard is managed as part of the WSP. If this is not possible, it may be appropriate to allow a derogation from the standard. It is important, however, that the derogation is conditional and a plan to reassess the situation at intervals is in place. The surveillance agency will be responsible for deciding whether urgent action is needed or not and establishing a concentration that is above the standard, but which should not be exceeded (see Case study 4 from Portugal). The WHO guidelines for drinking-water quality (WHO, 2017a) contain additional advice on chemicals and what to do in cases of exceedance of the guideline value.

Further guidance on the identification of monitoring priorities, monitoring frequencies and sampling locations, and on exceedances of national standards, is provided by WHO (2017a; 2018).

## Case study 10

# Risk-based monitoring of chemical parameters in Jersey

Jersey primarily uses surface water, as groundwater sources on the island are very limited and there is a fluctuating population with increases during the summer holiday months when tourist numbers rise. The island has limited heavy or manufacturing industry but an extensive agriculture sector, including dairy-based farming and a significant distinctive early potato-growing industry. The problems of source-water contamination relate to microbiological contamination from agriculture and septic tanks, and chemical contamination with nitrate and a range of pesticides.

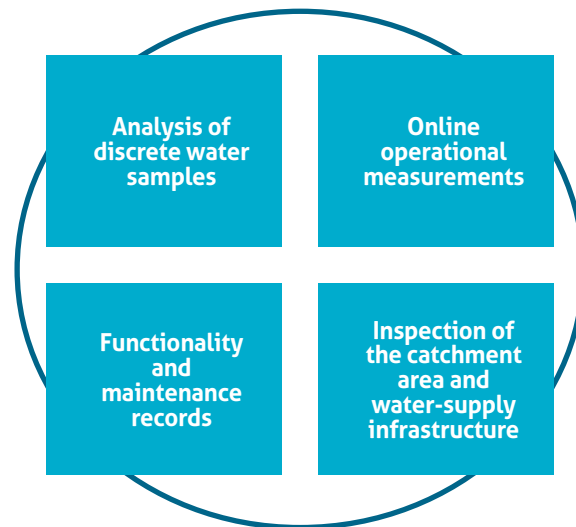
Most of the results of extensive chemical monitoring in drinking-water to meet the requirements of the drinking-water regulations of the United Kingdom, adopted in Jersey law, resulted in non-detects or very low levels of chemicals, but the cost of monitoring was significant. A risk-based approach to monitoring was introduced, which reduced the number of determinations and the cost of carrying out drinking-water compliance monitoring by over 50%.

The problem of raw water contamination with pesticides remained, however. The reduction in cost of the monitoring programme released funds to increase the monitoring of raw water, which allowed better quality management by changing the streams from which water was abstracted into reservoirs and identification and management of historic contamination by pesticides that were no longer used. The data were also pivotal in persuading the agricultural industry to adopt better catchment practices to prevent or minimize contamination.

## Case study 11

# Incorporation of risk-based monitoring provisions in the EU Drinking Water Directive

The Commission Directive 2015/1787 of 6 October 2015 amended Annexes II and III of the EU Drinking Water Directive 98/83/EC (EU, 2015). Annex II lays down the requirement for drinking-water quality-monitoring, including parameters to be monitored, monitoring frequency and the point of sampling. The amendment replaced the previous rigid monitoring scheme and allows the competent (surveillance) authorities to establish a more flexible, risk-based monitoring programme that offers the potential to derogate from the default list of parameters and minimum sampling frequencies for compliance monitoring, provided a risk assessment is performed. The monitoring programmes do not rely solely on compliance monitoring but may also include elements of operational monitoring and sanitary inspections (Fig. CS2).

**Case study 11 contd****Fig. CS2.** Elements of monitoring programmes under Annex II of the EU Drinking Water Directive

While the minimum frequency of sampling for *Escherichia coli* must not be reduced under any circumstances, the frequency of other parameters may be reduced provided the results obtained from points representative of the whole water-supply system have been less than 60% of the parametric value for at least three years and the concentration has been reasonably stable (no increasing trend). A parameter may be removed from the list if the results obtained have been less than 30%.

The precondition and rationale for granting derogations from the parameters and frequencies is a risk assessment. This should consider the local conditions for a particular water supply, informed by the results of source-water monitoring and confirming that no factor that can reasonably be anticipated is likely to cause deterioration of the quality of the water. The risk assessment should be based on the general principles set out in relation to international standards, which include the WHO guidelines for drinking-water quality. Risk assessments must be approved by the relevant competent (surveillance) authority and a summary of the results must be made available.

**Case study 12**

## The Hungarian monitoring exemption system for chemical parameters

Hungary has adopted the possibility of derogating from the drinking-water monitoring scheme introduced by the Commission Directive 2015/1787 of 6 October 2015 amending Annexes II and III to Council Directive 98/83/EC on the quality of water intended for human consumption (see Case study 11 from the EU).

**Case study 12 contd**

Drinking-water suppliers can apply for exemption from monitoring certain parameters if they can confirm that they are not present in their water supply. The following criteria apply:

- the drinking-water source should be a protected groundwater source, confirmed by tritium measurement; and
- the results of the last three analyses were not higher than the limit of quantification (as defined in the legislation) or 30 % of the parametric value; and
- the water supply's WSP should justify that pollution cannot reasonably be expected.

If the criteria are met, the exemption is granted by the chief medical officer of the state. The range of parameters is limited to pollutants related to the source water but covers both naturally occurring (such as arsenic, boron or selenium) and anthropogenic (pesticides, for example) substances. Drinking-water suppliers still have to measure every parameter once every three years, but if the result remains negative, the derogation will be granted further. This scheme allows monitoring efforts to be focused on relevant parameters.

**Case study 13**

## Development of an inspectorate guideline for risk-based monitoring in the Netherlands

To ensure good quality of drinking-water, the Drinking Water Act (2011) in the Netherlands requires a pre-set list of parameters and sampling frequencies to be measured. The Commission Directive 2015/1787 amended Annexes II and III of the Drinking Water Directive 98/83/EC and introduced the possibility of following a risk-based approach for designing water-quality monitoring programmes, which was adopted by the Netherlands (see Case study 11 from the EU).

A national guideline is being developed to support uptake of the risk-based monitoring approach. The objectives of the guideline will be to provide a uniform format for establishing supply-specific risk assessments and instituting monitoring programmes for drinking-water companies, and define procedures for the process of approval, thereby ensuring a uniform level of protection for all citizens. Special attention will be given to anthropogenic substances, for which a separate strategy has been developed.

The working group on risk-based monitoring consisted of organizations that included drinking-water service providers and laboratories, the National Institute for Public Health and the Environment and the KWR Water Research Institute. The Human Environment and Transport Inspectorate and the Ministry of Infrastructure and Water Management were also involved.

In accordance with the WSP approach, the guideline will stipulate seven steps that drinking-water service providers shall follow. They include undertaking a risk assessment for every aspect of the water-supply system, including consideration of the vulnerability of source water, presence of contaminant sources in the catchment area, formation of contaminants during drinking-water treatment and the trend in concentrations over recent years.

**Case study 13 contd**

Based on the risk assessment, water suppliers propose a list of parameters to be monitored alongside their testing frequencies. Screening methods and effect-directed analysis (such as non-target analysis, biomonitoring and bioassays) and online monitoring procedures can also be part of the monitoring programme. The guideline will define clear criteria that can be used to justify the suggested monitoring frequencies; these will align fully with the provisions of the Commission Directive 2015/1787.

The suggested monitoring programme will need to be approved by the Human Environment and Transport Inspectorate. Drinking-water companies will need to evaluate and possibly revise the risk assessment and the corresponding monitoring programme every year. The risk assessment and the monitoring programme will need to be documented.

# Key message 6: Risk-based surveillance aids forward-thinking and anticipation of change

**Hazards and risks change over time. Surveillance agencies have an important supporting role in predicting, identifying and tracking long-term changes and associated risks for drinking-water supply.**

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Drinking-water supply systems potentially are vulnerable to the impacts of long-term changes that can affect drinking-water quantity and quality. Planning for adaptation to climate, environmental and other human-made change and building resilient water supplies requires the cooperation of a number of stakeholders at local and national levels; surveillance agencies have an important role to play in supporting these processes. A risk-based approach supports forecasting of, and adaptation to, changing external circumstances.

## Changes in circumstances and their implications

Climate change is an example of a change in circumstance. It may result in shifting patterns of hydrological conditions and extreme events, including increased drought, temperatures, heavy rainfall, flooding and sea-level rises (WHO, 2017c). It may be difficult to predict the nature and extent of change in the local water-supply context, but impacts that add pressures on water systems can be expected. Changing patterns of hydrology and weather can alter the presence of hazards, and the significance of risks from those hazards, in the drinking-water catchment area and throughout the water-supply chain. These changes can affect both the quantity and quality of water resources available for drinking-water supply and also lead to significant disruption to

water operations. Examples of climate change impacts are shown in Table 1.

Other pressures on water availability and drinking-water service provision are due in many areas to increased demand from urbanization, irrigated agriculture, tourism and industry, with the biggest problems often arising from combinations of these developments. While increased demand for water can result in exploitation of resources and issues related to the allocation of resources for drinking-water production, it can also lead to changes to the hazards presented and their associated risks. For example, over-abstraction of groundwater can result in the oxidation of strata in the aquifer and the release of naturally occurring contaminants, some of which are of concern to health. Extended dry periods increase this pressure and can also result in cracking of the surface layers, allowing easy transference of contamination from the surface to groundwater when rainfall arrives, often concentrated in a shorter period of heavier rain. Urbanization can lead not only to increased demand, but also to more sealed surfaces, which results in heavy rainfall causing overflows of drainage and sewer systems. Pressure on existing water resources can mean that new and possibly lower-quality sources will need to be considered. Such steps need careful planning to ensure that public health is not adversely affected.

**Table 1.** Examples of climate change impacts on drinking-water supply

Event	Potential impacts
<b>Increased temperatures</b>	<ul style="list-style-type: none"> <li>• Increased formation of cyanobacterial blooms in freshwater</li> <li>• Increased risk of wildfires degrading water quality in moorland and forested and peaty catchments</li> <li>• Proliferation of opportunist pathogens (such as <i>Legionella</i>) and heterotrophic bacteria within water-storage and distribution systems</li> <li>• Reduced stability of chlorine residual in distribution</li> <li>• Increased formation of some disinfection by-products</li> <li>• Higher water demand</li> </ul>
<b>Drought</b>	<ul style="list-style-type: none"> <li>• Increased competition for scarce water resources, potentially leading to lower water availability</li> <li>• Reduced groundwater tables causing wells to dry up, increasing travel distances to collect water</li> <li>• Decreased dilution in source waters and increased concentration of pollutants and nutrients</li> <li>• Release of contaminants from reservoir sediments into water body, such as benthic nutrients and metals</li> </ul>
<b>Sea-level rise</b>	<ul style="list-style-type: none"> <li>• Increased saline ingress of coastal aquifers</li> <li>• Intrusion of seawater into distribution networks</li> <li>• Inundation of water-supply infrastructures</li> </ul>
<b>Precipitation and flooding</b>	<ul style="list-style-type: none"> <li>• Flood damage to water and sanitation infrastructure</li> <li>• Overwhelmed containment systems discharging untreated storm- and wastewater into source waters</li> <li>• Heavier rainfall events and storm runoff causing increased loading of pathogens and suspended sediment in surface waters</li> <li>• Overwhelmed drinking-water treatment systems becoming less effective</li> </ul>

Sources: WHO (2017c); WHO Regional Office for Europe (2011).

Long-term changes in land use and human activity in drinking-water catchments are important considerations. The expansion of urban areas and industrial activity, alterations in the pattern and timing of crops in agriculture, intensification of animal husbandry or the increased reuse of wastewater can all induce changes in the use or release of (emerging) chemicals in the catchment environment, introduce new sources and pathways for microbiological contamination of water resources and/or alter water-use patterns.

## What does risk-based surveillance add?

Those responsible for drinking-water safety, including surveillance agencies, need to have a good understanding of how climate, environmental and socioeconomic change are affecting, and are likely to affect, water resources and therefore drinking-water supply systems. This will inform changes to policies, programmes and infrastructure to prepare for,

and cope with, changing freshwater quantity and quality (WHO, 2017a). They also need to understand how changing demand through urbanization, agriculture, tourism and industry is likely to occur and impact on water supply.

Adaptive risk management will require long-term planning, as required policy and infrastructure changes will take time to formulate and put in place. Mitigation measures can range from flood protection through increased capacities of water treatment to regulating land use in the catchment area. Such planning is an important step in preventing problems, or at least mitigating the effects if they cannot completely be prevented.

Risk-based surveillance has an important supporting role in predicting, identifying and tracking long-term changes and associated risks for drinking-water supply. Surveillance agencies are in a good position to promote collaboration with other sectors and, in concert with other relevant agencies, provide essential



information to aid strategic and operational decision-making and planning at national and local levels for improved water-supply system resilience and preparedness. They can also advise water suppliers on taking appropriate adaptation steps.

In the context of responding to long-term change, the supporting role of surveillance agencies may include:

- advocating and proactively participating in long-term planning processes to ensure continuing access to freshwater sources for drinking-water purposes, manage water demand among competing needs, review the resilience of supply systems and implement control measures to maintain water quality;
- promoting consideration of the hazards and health risks resulting from long-term changes in the local WSPs of water suppliers (specific guidance on developing climate-resilient WSPs and managing and adapting to extreme weather events is

provided by WHO (WHO, 2017c; WHO Regional Office for Europe, 2011);

- engaging with other sectors and agencies (including environment, water resource management, meteorology and agriculture) and supporting collation and analysis of data over time to identify possible new hazards, trends and peaks in concentrations, and inform water suppliers accordingly (other sectors may already have data available that the water-supply sector can access); and
- advising policy-makers and regulators if regulations and water-quality standards merit updates in response to observed changes in terms of, for example, additional parameters or parametric values.

Prioritizing the development of risk-based surveillance programmes is likely to be a critical component in promoting more effective and resilient water supplies, not least because it changes the mindset of surveillance agencies, water suppliers and communities towards looking forwards.

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<sup>2</sup> All weblinks accessed 3 October 2019.

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The framework for safe drinking-water recommended by the WHO guidelines for drinking-water quality promotes a risk-based preventive management approach to ensure safety of drinking-water. Independent drinking-water surveillance is one of the core components of this framework and is an essential public health function.

To be effective, drinking-water surveillance needs to be aligned with risk-based principles, including prioritization of monitoring parameters and surveillance efforts based on water safety plan outcomes. Applying a risk-based approach in drinking-water surveillance helps countries to focus on the issues that are most important for the protection of public health and so maximizes the benefits that can accrue from limited resources.

The Protocol on Water and Health promotes establishing and maintaining a legal and institutional framework for monitoring and enforcing standards for the quality of drinking-water. Supporting countries in building effective systems for surveillance of drinking-water is therefore a priority area of work under the Protocol.

This publication provides a rationale for decision-makers, regulators and professionals in the fields of public health, environment and water management to promote and support uptake of risk-based approaches in regulations and surveillance practice. It has been designed around six key messages that underlie the concept of risk-based approaches in drinking-water surveillance and is supported by practical examples for illustration purposes.

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