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Service activities relating to drinking water supply, wastewater and stormwater systems — Guidelines for the implementation of continuous monitoring systems for drinking water quality and operational parameters in drinking water distribution networks

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 224, *Service activities relating to drinking water supply, wastewater and stormwater systems*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Cases of drinking water contamination around the world have raised awareness of water utilities' exposure to risk. Contamination can arise from many causes, including societal mishaps, errors in operation, maintenance or management by the water utility, natural disasters, vandalism, sabotage, criminality and terrorist activity. The distributed nature of drinking water systems makes them especially vulnerable to contamination and can permit the rapid dispersion of a contaminant. The velocities and volumes of water in a drinking water distribution network can result in contamination affecting significant numbers of users in a short time (e.g. tens of minutes). Recognition of these risks has raised awareness of the need to consider the use of continuous monitoring systems to rapidly detect potential contamination events.

The occurrence of an event can rarely be predicted. However, the more frequently relevant data can be collected and examined, the greater is the chance of quickly detecting an event's occurrence. This supports consideration of the adoption of continuous monitoring systems to provide the data streams that can be used in event detection.

A contamination event can make a waterworks or a drinking water distribution network unusable for a time and require implementation of contingency plans. Such plans could involve, for example, accessing an alternative source water or providing an alternative water service other than via the drinking water distribution network.

To date, very few water utilities have installed continuous monitoring systems either in part or throughout their drinking water distribution network(s). This situation can result from a rational decision based on risk assessment and, in some cases, a cost-benefit analysis. However, it should be acknowledged that circumstances can change – gradually over time or rapidly in the face of events. Water utilities wishing to explore such an option can face uncertainties and gaps in their knowledge on how to proceed. In such circumstances water utilities typically face three main challenges:

— which types of measuring devices (MDs) to install in each continuous monitoring station;

— how many continuous monitoring stations to install per drinking water system;

— where to locate the continuous monitoring stations in the drinking water distribution network in order to achieve the best results.

The installation of continuous monitoring systems could reduce the risk to public health and mitigate the impact on users and other stakeholders during a contamination event. The value of continuous monitoring systems can be determined using appropriate risk assessment and cost-benefit analysis. Such an evaluation should take into account existing controls and establish the additional risk mitigation that might be achieved and likely costs.

Advances in MD technology have recently made the adoption and deployment of continuous monitoring more practicable. MDs are not limited to the measurement of drinking water quality alone. Continuous measurement of operational parameters such as water flow and water pressure can improve the water utility's capability to interpret results from the measurement of drinking water quality.

This document provides water utilities, their contractors, consultants and regulators with guidelines for the installation of continuous monitoring systems in drinking water systems, including guidance on their appropriate selection, maintenance and optimal calibration.

These guidelines can aid a water utility's processes for risk assessment and cost-benefit analysis. Taken together these can help a water utility's top management take informed, risk-based decisions on the worthwhileness of investment in a continuous monitoring system.

The guidance provided in this document is intended to be universally applicable, regardless of the structure and size of a water utility's drinking water system. An event detection process (EDP) that relies upon grab samples and intermittent data inputs could be implemented at lower cost. However, where a water utility's assets, finances, management system and technical capability make it practicable, the ability to provide continuous data streams offers advantages for event detection.

To gain experience, initial deployment could be limited to higher-risk areas within a wider drinking water system.

Service activities relating to drinking water supply, wastewater and stormwater systems — Guidelines for the implementation of continuous monitoring systems for drinking water quality and operational parameters in drinking water distribution networks

1 Scope

This document specifies guidelines for the implementation of continuous monitoring systems for drinking water quality and operational parameters in drinking water distribution networks.

It provides guidance for determining the:

— effective number of continuous monitoring stations in the drinking water distribution network;

— location of monitoring stations in the drinking water distribution network;

— types of operational and drinking water quality parameter measuring devices (MDs) that can be installed in a continuous monitoring station;

— quality control, maintenance and calibration requirements of the continuous monitoring system.

This document excludes guidance on the design, structure, number and type of MDs to be installed in a continuous monitoring system.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 24513, *Service activities relating to drinking water supply, wastewater and stormwater systems — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 24513 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
accuracy
measurement accuracy
accuracy of measurement
closeness of agreement between a measured quantity value and a true quantity value of a measurand

[SOURCE: ISO/IEC Guide 99:2007, 2.13, modified]

3.2
capability
quality of being able to perform a given activity

[SOURCE: ISO 15531-1:2007, 3.63, modified]

3.3
continuous monitoring
continuous near-real-time measurements of one or more sampling characteristics

Note 1 to entry: To determine the status, it is possible that one or more relevant parameters need to be checked, supervised, critically observed or measured compared with one or more pre-defined indicators.

Note 2 to entry: *Measuring device* (3.14) which provides a non-continuous but regular output signal at a given frequency can be used for the purpose of continuous monitoring.

Note 3 to entry: The location where a measuring device is installed shall be defined as a continuous monitoring station.

[SOURCE: ISO 2889:2010, 3.22, modified]

3.4
drinking water
DEPRECATED: potable water
water intended for human consumption

Note 1 to entry: Requirements for drinking water quality specifications are generally laid down by the national relevant authorities. Guidelines are established by the World Health Organization (WHO).

3.5
drinking water distribution network
asset system for distributing *drinking water* (3.4)

Note 1 to entry: Drinking water distribution networks can include pipes, valves, hydrants, washouts, pumping stations, reservoirs, and other metering and ancillary infrastructure and components.

Note 2 to entry: Pumping stations and reservoirs can be sited either in the *waterworks* (3.23) or in the drinking water distribution network.

3.6
drinking water system
asset system providing the functions of abstracting, treating, storing, distributing or supplying of *drinking water* (3.4)

3.7
event
situation when a behaviour deviates from the normal

Note 1 to entry: An event can be one or more occurrences and can have several causes.

Note 2 to entry: An event can consist of something not happening.

Note 3 to entry: An event can sometimes be referred to as an “incident” or “accident”.

Note 4 to entry: An event without consequences can also be referred to as a “near miss”, “incident”, “near hit” or “close call”.

3.8
event detection
recognition of event indicator or information about a new situation, or both

Note 1 to entry: New situations can be sorted into one of the following:

— event indicator or situation, or both, are considered known and non-hazardous;

— event indicator or situation, or both, are considered hazardous, but a procedure to handle them already exists;

— event indicator or situation, or both, are considered unknown, and a procedure for them does not yet exist.

3.9
event detection process
EDP
set of interrelated or interacting activities which transforms inputs (data or information on an actual or suspected *event* (3.7)) into outputs (to support the *water utility's* (3.22) operational activities)

3.10
event indicator
signal to the *water utility* (3.22) or one or more *stakeholders* (3.20) of expectations of service performance

Note 1 to entry: The signal can exist yet remain unobserved for a period.

3.11
maintenance
combination of all technical, administrative and managerial actions during the life cycle of an asset intended to retain it in, or restore it to, a state in which it can perform the required function

3.12
management
coordinated activities to direct and control a *water utility* (3.22)

Note 1 to entry: Management can include establishing policies and objectives, and *processes* (3.17) to achieve these *objectives*.

Note 2 to entry: The word "management" sometimes refers to people, i.e. a person or group of people with authority and responsibility for the conduct and control of a service. When "management" is used in this sense, it should always be used with some form of qualifier to avoid confusion with the concept "management" as a set of activities defined above. For example, "management should …" is deprecated whereas "crisis management team should …" is acceptable. Otherwise different words should be adopted to convey the concept when related to people, e.g. managerial or managers.

Note 3 to entry: The term "management" can be qualified by a specific domain it addresses. Examples include public health management, environmental management and *risk* (3.18) management.

3.13
measurement
process (3.17) to determine a value

3.14
measuring device
MD
component, or a group of components, used in an in-line or online operating position, which continuously (or at a given frequency) gives an output signal proportional to the value of one or more measurands in waters which it measures

Note 1 to entry: The device can be portable or fixed in position.

Note 2 to entry: The term "in-line measuring device" is often used for a measuring device used in an in-line position. The term "online measuring device" is often used for a measuring device used in an online position.

[SOURCE: EN 17075:2018, 3.1]

3.15
monitoring
determining the status of a system, a *process* (3.17) or an activity

Note 1 to entry: To determine the status, there can be a need to check, supervise or critically observe.

3.16
operation
action(s) taken in the course of normal functioning of *drinking water* (3.4) or wastewater systems

EXAMPLE Monitoring and regulation or diversion of drinking water or wastewater.

3.17
process
set of interrelated or interacting activities that use inputs to deliver an intended result

Note 1 to entry: Whether the “intended result” of a process is called an output, product or service depends on the context of the reference.

Note 2 to entry: Inputs to a process are generally the outputs of other processes and outputs of a process are generally the inputs to other processes.

Note 3 to entry: Two or more interrelated and interacting processes in series can also be referred to as a process.

Note 4 to entry: Processes in an organization are generally planned and carried out under controlled conditions to add value.

Note 5 to entry: A process where the conformity of the resulting output cannot be readily or economically validated is frequently referred to as a “special process”.

Note 6 to entry: In benchmarking, organizational and technical processes and combinations of both are considered. A process within the meaning of benchmarking comprises a combination of one task with one plant or object (e.g. operate sewer network, treat wastewater, treat *drinking water* (3.4), provide domestic connection, further train staff, purchase material).

Note 7 to entry: In service standards, the term “process” can have a broader meaning than its narrower interpretation in management system standards. For example, it can also include some elements.

3.18
risk
combination of the likelihood of a hazardous *event* (3.7) and the severity of consequences, if the hazard occurs in the *drinking water system* (3.6), wastewater system or stormwater system

Note 1 to entry: Risk is often characterized by reference to potential events and consequences or a combination of these.

Note 2 to entry: The English term “likelihood” does not have a direct equivalent in some languages; instead, the equivalent of the term “probability” is often used. However, in English, “probability” is often narrowly interpreted as a mathematical term. Therefore, in risk management terminology, “likelihood” is used with the intent that it should have the same broad interpretation as the term “probability” has in many languages other than English.

Note 3 to entry: Risk can also be defined as the effect of uncertainty on objectives, where uncertainty is the state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence or likelihood.

3.19
sensor
electronic device that senses a physical condition or chemical's presence and delivers an electronic signal proportional to the observed characteristic

[SOURCE: ISO/IEC TR 29181-9: 2017, 3.14, modified]

3.20
stakeholder
interested party
person or organization that can affect, be affected by or perceive itself to be affected by a decision or activity

EXAMPLE *Users* (3.21) and building owners, relevant authorities, responsible bodies, operators, employees of the operator, external product suppliers and providers of other services, contractors, communities, customers and environmental associations, financial institutions, scientific and technical organizations, laboratories.

Note 1 to entry: Stakeholders will typically have an interest in the performance or success of an organization.

Note 2 to entry: For the application of this document, environment is considered as a specific stakeholder.

3.21
user
DEPRECATED: consumer
person, group or organization that benefits from *drinking water* (3.4) delivery and related services, wastewater service activities, stormwater service activities or from reclaimed water delivery and related services

Note 1 to entry: Users are a category of stakeholder.

Note 2 to entry: Users can belong to various economic sectors: domestic users, commerce, industry, tertiary activities or agriculture.

Note 3 to entry: The term “consumer” can also be used, but in most countries the term “user” is more common when referring to public services.

3.22
water utility
whole set of organization, processes, activities, means and resources necessary for abstracting, treating, distributing or supplying *drinking water* (3.4) or for collecting, conveying, treating, disposing or reusing of wastewater or for the control, collection, storage, transport and use of stormwater and for providing the associated services

Note 1 to entry: Some key features of a water utility are:

— its mission, to provide drinking water services or wastewater services or the control, collection, storage, transport and use of stormwater services or a combination thereof;

— its physical area of responsibility and the population within this area;

— its responsible body;

— the general organization with the function of operator being carried out by the responsible body, or by legally distinct operators;

— the type of physical systems used to provide the services, with various degrees of centralization.

Note 2 to entry: Drinking water utility addresses a utility dealing only with drinking water; wastewater utility addresses a utility dealing only with wastewater; stormwater utility addresses a utility dealing only with stormwater.

Note 3 to entry: When it is unnecessary or difficult to make a distinction between responsible body and operator, the term “water utility” covers both.

Note 4 to entry: In common English, “water service” can be used as a synonym for “water utility”, but this document does not recommend using the term in this way.

3.23
waterworks
asset system for collecting, treating, pumping and storing *drinking water* (3.4)

Note 1 to entry: asset types can include catchments, impounding reservoirs, dams, springs, wells, intakes, transmission mains, filters, tanks, dosing equipment, metering and ancillary infrastructure.

Note 2 to entry: Pumping stations and reservoirs can be sited either in the waterworks or in the *drinking water distribution network* (3.5).

4 Principles

Compliance with the requirements for monitoring of drinking water quality and operational parameters is predominantly achieved using spot sampling and laboratory analysis. The use of MDs for the continuous monitoring of the drinking water distribution network can be an effective means for the real-time identification of changes indicating potential contamination of drinking water quality or events interfering with the operation of a drinking water system. Such real-time identification of events can improve drinking water supply integrity.

Some MDs can measure several parameters at the same time and can use data analysis tools to facilitate the reading and understanding of the measurements.

The use of MDs for the continuous monitoring of the drinking water system can provide an effective supplementary measure within the organization and management of water services.

Although the cost of acquiring MDs will typically be reduced with wider uptake, it should be recognized that their deployment can be costlier than using sampling and laboratory analysis. Any decision made to apply MDs should be based on a cost-benefit analysis to ensure that no unjustified cost is transferred to users. While their deployment should reduce the risk of harm for users, it will not remove the risk entirely. The installation of MDs should be carefully planned and should only be considered if the water utility has high confidence that the MDs will reliably detect the chosen parameter(s) to be monitored. A risk evaluation should be carried out to evaluate the significance of false-positive and false-negative results from the MD.

The use of MDs can be justified if the system is of added value for risk management and more cost-effective than the conventional monitoring methods.

Guidance is given on how to deploy a continuous monitoring system. In order to select the location for MDs properly, the identification of critical control points in the drinking water system is important. Generally, MD deployment is more likely in larger water mains than further downstream in the narrow pipes serving individual locations.

Avoidance of harm to service users is the primary reason for the deployment of MDs to detect hazards arising in the drinking water distribution network. Continuous monitoring can reduce the risk of harm to users and improve response capability by providing real-time indication of a potentially hazardous event in a drinking water distribution network.

Research into water security has identified the following critical factors:

— efforts to determine which MDs are useful for detection;

— methods to minimize the time from an event's occurrence to its detection;

— determination of the size of the populations affected;

— minimization of the size of the affected population;

— demand for water that would occur prior to detection and maximization of the likelihood of detection.

There is the potential of severe public health consequences from the intentional or accidental introduction of contaminants into the drinking water distribution network. Also, the deterioration of drinking water quality that can occur due to an event or condition in the drinking water distribution network, even when no outside contaminants are introduced, can adversely affect public health. Monitoring plays a crucial role in the provision of reliable drinking water supply to users. While grab samples and laboratory analysis provide information as to the general status of drinking water quality, they are not designed to, nor are they capable of, detecting unforeseen or transient events in a timely manner. As a supplement to laboratory analysis, the continuous monitoring of drinking water quality and drinking water distribution network operational parameters provide a valuable means to detect unforeseen and transient events, to help respond to drinking water quality problems and to limit the consequences of drinking water quality problems.

5 Considerations for the justification of need for continuous monitoring

5.1 General

Continuous monitoring of key drinking water quality and distribution network operational parameters can serve as an indicator of the presence of contamination in the drinking water via their response or via their deviation from normal signal levels. The measured parameters can be biological, chemical or physical in nature.

Furthermore, when the contaminant being detected is unexpected, either via accidental release or deliberate contamination, continuous monitoring is a practical method to facilitate rapid detection and to give the chance of a timely response.

Continuous monitoring, field testing and laboratory analysis (offline monitoring) all have advantages and disadvantages. Depending upon the local context and situation, it is often desirable to employ continuous monitoring, field testing and laboratory analysis methods in a complementary manner to make use of the advantages and compensate for the disadvantages of each.

Some examples of the advantages and disadvantages of continuous monitoring against field testing and laboratory analysis monitoring are described in Table 1.

5.2 Cost-benefit

The number of measurements should be optimized to ensure adequate coverage of the network, thus minimizing costs while securing an acceptable level of benefits. Dual use benefits are an important attribute of continuous monitoring. The types and locations for installing MDs should be chosen not only for achieving the goals of water security but also for helping to achieve objectives such as compliance and system optimization.

Continuous monitoring systems can be complex. They typically include sampling, analysis, communication, data storage and data interpretation.

The MDs and data systems require periodic updating and replacement. Continuous monitoring systems require staff trust in instrument readings and a different skill set than sampling and laboratory testing to perform operation and maintenance of MDs. Continuous monitoring systems can have high investment costs and significant operation and maintenance costs.

While continuous monitoring can be expensive, when all its attributes are considered its potential cost-benefits, particularly in relation to reduced staff and labour costs, should be examined accurately.

Table 1 — Examples of the comparison of monitoring locations and methods in various aspects

Aspect	Type of monitoring		
	Sampling and laboratory analysis	**Field testing**	**Continuous monitoring**
Parameters that can be monitored	High number of parameters can be monitored, including all regulated parameters	Not all parameters can be accurately measured in the field	Limited number of parameters can be measured due to technology constraints
Number of sampling points	Limited based on collection time and laboratory throughput	Limited based on labour and throughput	Limited by cost and maintenance
Frequency of testing	Limited based on time and laboratory throughput	Limited based on labour and testing capacity	Can be limited due to lack of energy supply and other possible constraints depending on technology
Time to results	Long, can be several hours up to days	Moderate, depending on the test	Short, almost instantaneous real-time
System and equipment needs	High, but most utilities already have in place (e.g. analysers, labware, facility)	Low equipment needs but high labour cost	High (site, power, communications, data handling)
Chemical (reagents) needs	Moderate: types of reagents are high, but volumes are usually moderate	Low volumes and low number of types of reagents	Moderate: usually lower volume of reagents per test but higher number of tests
Maintenance and calibration	High, but relatively routine and part of standard operation procedures	High: usually done back at the utility not in the field	Moderate: relatively routine and part of standard operation procedures
Data reliability	High, if it is calibrated and maintained properly, if good laboratory practices are followed; meets regulatory requirements	Moderate, if it is calibrated and maintained properly, if good practices are used may or may not meet regulatory needs	High-low: may vary depending on the MD and if it is calibrated and maintained properly
Ability to detect drinking water quality event	Low: good accuracy but limited samples, just offers a snapshot	Low: just offers a snapshot of conditions	Moderate: continuous real-time but only a limited number of parameters available
Staff skill level required	High: requires skilled professionals	Moderate: easier tests mastered with limited training	Moderate except for calibration and maintenance, which can require a higher skill level
Occupational health and safety issues	High: hazardous chemicals and testing procedures	Moderate: limited number of parameters and designed to be less hazardous for field use	Low except for calibration and maintenance, which can be contracted out, also requires fewer personnel

5.3 Risks of continuous monitoring

A robust and comprehensive model of the drinking water distribution network as well as a thorough risk analysis should be used in the selection and optimization of locations for MD placement.

Continuous monitoring systems are an effective means of determining the occurrence and the location of drinking water quality events in a timely manner, and only a limited number of parameters is required. However, due to limitations in MD technology, not all contaminants can be detected at levels that would be detrimental to public health.

See advantages (positives) and disadvantages (negatives) of continuous monitoring systems in Annex A.

5.4 Local contexts

Continuous monitoring systems have advantages and disadvantages compared with laboratory analysis (offline monitoring). Both should be used complementarily. When installing a continuous monitoring system, it should be judged whether it can be used sustainably considering local contexts and situations. The following points should be considered:

— required number of MDs;

— requirements for maintenance and calibration;

— requirements for minimizing exposure to environmental impacts (e.g. weather, radiation from solar rays);

— responsibilities for maintenance and calibration.

6 Choosing parameters to be monitored

There is no single parameter or combination of parameters that if measured will provide a universal solution for achieving an acceptable monitoring system for all deployment sites. In most cases the best choice will be the monitoring of a suite of different parameters that can detect the contaminants that represent the highest risks in an individual site's profile.

Characteristics of effective MDs should include:

— cause no adverse effects, either directly or indirectly, on drinking water quality;

— be appropriate for the intended identification of contaminants and operational deviations;

— provide reliable results;

— be aware of local laws and regulatory requirements for contact with drinking water;

— be selected to meet the needs for the detection of drinking water contamination and operational events.

For a brief description and functions of commonly used and installed drinking water quality parameter MDs in water utilities see Annex B.

The parameters to be measured should be identified together with their characteristics in relation to contamination monitoring. The functionality and capabilities of the MDs used to measure these parameters should be assessed (singly and in combination) for their relevance to the drinking water distribution network in general and their proposed installation locations in particular.

Some considerations include:

— What is the goal of the drinking water monitoring programme? Drinking water quality parameters can generally be divided into three types:

  — parameters useful for the detection of system upsets and events;

  — parameters useful in the day-to-day monitoring and control of drinking water quality;

  — parameters that are dual use and serve both of the previous functions.

  Based on a drinking water system's risk profile and monitoring capabilities, dual-use parameters can be a choice that offers both the capability of detecting unusual drinking water quality events and controlling and improving daily drinking water quality.

— What is the risk profile of the system being monitored? What is the population density and type of user in the service area? For example, if the system is located in a heavily industrialized area with a large petrochemical presence it can be sensible to measure parameters like total organic carbon

(TOC) in drinking water, whereas in a system located on a pristine low-risk water source with little industry in the area, monitoring these parameters would make less sense.

— What type of MD should be used to measure a given parameter at a specific location? MDs may use different methods for a particular parameter, for example an electrochemical probe or a colorimetric method for residual chlorine. Different methods will have different detection levels, and accuracy statements, calibration intervals and maintenance profiles with associated costs. It is important to investigate MD options when choosing which parameters to monitor as different methods may or may not make monitoring for a given parameter practical at a given location.

  What type of disinfectant is being utilized? In networks where disinfection residual is being used, different parameters and MD types will be required, depending on the type of residual disinfectant utilized. Networks utilizing free chlorine will need to monitor different parameters and use different MDs than networks that utilize monochloramine as a disinfectant residual. In networks that do not utilize a residual disinfectant it would make little sense to monitor for these parameters in the distribution network.

— How can the MD performance be ensured? There are several possibilities to check and ensure that the performance is adequate and fits the needs of the system in relation to parameters such as accuracy, repeatability, reliability and other confidence, maintenance and operational parameters, thus greatly improving user confidence when purchasing MDs:

  — testing;

  — approval arrangements;

  — references from other water utilities that have installed the relevant MDs (see Annex C).

NOTE Not all drinking water quality parameter MDs for specific purposes are reviewed in this document. For more information, see “Monitoring water quality in the drinking water network” published by the federation of Canadian Municipalities[10], which includes a more complete review of water quality continuous MDs.

MDs can be responsive to changes in operational parameters of the drinking water distribution network. Therefore, if continuous measurement devices for operational parameters are installed in a drinking water distribution network, their readings should be taken into consideration when analysing the drinking water quality parameters' readings.

See how operational parameters can influence drinking water quality measurements on Table 2.

Table 2 — Operational parameter measurements that can influence drinking water quality measurements

Operational parameter measured by the MD	Influence on drinking water quality measurements
Flow	Flow meter data can be used for the identification and analysis of drinking-water-quality-related factors, e.g. total water quantity, water direction, change in water direction and information about different water sources mixture. Flow meter data can also help in the correct operation of the drinking water distribution network, e.g. controlling the dosage of added chemicals to the water. Flow meter function data can supply information about factors that can affect the reliability of data received from the MDs, particularly turbidity.
Pump operation data	Pumps' operation data can provide information about factors affecting drinking water quality in a drinking water distribution network, such as quantity of water, which is crucial to decide on the necessary dosage of required chemicals addition. This data can help to calculate and control water spreading and water velocity in case of a drinking water distribution network contamination. Pumps can provide indication about added/subtracted water sources (if they introduce water from a different source). This data can also be used to decide on the necessary steps to reduce contamination spreading in the drinking water distribution network. Pump operation can affect the reliability of data received from the MDs.
Valve situation data	Valve and check valve position data can provide information about factors affecting drinking water quality, such as water velocity or water flow direction, if the water supplied is diluted with water from other sources. Valve situation data can be used to control contamination spreading.
Pressure	Pressure data contributes to the analysis of hydraulic parameters, for example water direction and if a mixture of water of different sources is occurring.
Air valve data	Air pressure valve position and function data can supply information about factors that can significantly affect the reliability of data received from the MDs, particularly turbidity.
Temperature	Temperature measurements can be an indicator of change of the water source, of the mixing of more than one water source and of air inputs.

7 Locating the continuous monitoring stations in the drinking water distribution network

7.1 General

7.1.1 Network layout

There are two alternative approaches for locating the continuous monitoring stations in the drinking water distribution network:

— Development or implementation of an existing hydraulic or statistical model of the drinking water supply network (preferred).

— The pragmatic approach.

7.1.2 Development or implementation of an existing hydraulic or statistical model of the drinking water distribution network (preferred)

A model should be developed to determine the optimal types of MDs and number and locations for monitoring stations in the network. The model should be capable of identifying the costs of installation and operation of the monitoring stations for different levels of drinking water quality protection (including types and numbers of MDs) within the network.

The water utility should have a model of the current layout of the relevant elements of the drinking water system's assets, e.g. physical pipes, storage and equipment. For simplicity, the model should be constructed of nodes where each node is defined by a group of users and includes the following:

— Probable directions of the flow of drinking water during various time periods, e.g. days of the week, hours of each day.

— An estimation of drinking water consumption in each of the nodes during various times of the day and week to capture high, low and steady consumption.

— An estimation of the travel time of drinking water between each mode in the system.

The water utility should periodically review and verify the accuracy of the model and its related information.

The water utility should develop a standard operation procedure for isolating sections of the drinking water system to contain and minimize the further spread of drinking water which is suspected of not satisfying the relevant drinking water quality criteria.

7.1.3 The pragmatic approach

Many water utilities do not have calibrated hydraulic models for their drinking water distribution networks and many have not digitized their data on their drinking water distribution networks. Where information about the exact layout of the drinking water system does not exist, the water utility should prepare alternative methods for the estimation of such isolation and containment methods. In such a situation, pragmatic ways should be sought to determine the number and location of monitoring stations in an undigitized drinking water distribution network and/or a network that has no calibrated, running, hydraulic model.

7.2 Locations for monitoring stations

7.2.1 General

The water utility should decide which metrics will be used to determine the optimal location of the monitoring stations. Examples include:

— limiting the number of people exposed in a contamination event;

— minimizing time of detection;

— minimizing the total pipe length contaminated;

— giving precedence and protecting certain vital users;

— minimizing response time to a contamination event.

Criteria should be established to determine the locations of monitoring stations so as to maximize the likelihood of detecting contamination events over the greatest percentage of the network and to minimize the possible impacts of the contamination. Examples include:

— Estimated time based on flow and demand between the possible contamination event starting point and the contaminant's detection by a monitoring station in the network.

— Volume of drinking water that could be contaminated before detection based on demand predictions between a possible contamination source and the location of the monitoring station.

— Drinking water users at risk of being exposed to the contaminated drinking water based on the location in the network and the last previous location of known drinking water quality.

— Location of critical components of the drinking water distribution network such as reservoirs, pumping stations or large storage facilities.

— Location of operation parameters measured by the MDs and relevance of the readings of these MDs to the data and analysis of drinking water quality in MDs readings.

In evaluating locations against the established criteria, the water utility should base its calculations on estimates between locations of known drinking water quality and the location point being considered within the drinking water distribution network.

7.2.2 The pragmatic approach

According to the pragmatic approach, the number of users served by the drinking water distribution network should be regarded as the principal criterion to determine the number of monitoring stations to be installed in each network.

The proposed pragmatic approach may be based on the findings of drinking water distribution network modelling studies (see References [4], [5], [8], [10] and [11]). In these investigations, models of real and virtual drinking water distribution networks were built and run in order to compare the percentage of network coverage acquired as a function of the number of monitoring stations installed in a specific network.

The optimal number of monitoring stations that should be installed in a drinking water distribution network to achieve optimum coverage varies as a function of various parameters such as population size, network characteristics and shortest time for detection of events. This function may be expressed as an asymptotic curve function, so that for each drinking water distribution network there is a number of monitoring stations below which network coverage increases significantly with each added monitoring station.

The installation of additional monitoring stations above this number contributes to a small increase of the network percentage coverage, at a disproportionately high cost compared to earlier installations, making these additional monitoring stations less cost-effective.

7.2.3 The hydraulic model approach

If a water utility has a running calibrated model for its drinking water distribution network, a model run and results application may provide the optimal solution with regards to the number of monitoring stations that should be installed in the network in order to achieve optimal event detection capabilities.

The water utility should define criteria for the types of MDs required and the parameters they are capable of sensing. If the MDs and parameters at a proposed location are not detecting equivalent parameters to the nearest established monitoring location, the water utility may go further into the drinking water network to establish a comparative location for equivalent drinking water quality data (e.g. water treatment plant outlets; major service reservoir outlets; major transmission main offtakes).

7.3 Network alert definition

The water utility should define what is considered a "network alert" and what differentiates this from the more frequent regular alerts likely to be generated by a single continuous monitoring station or by individual MDs.

The water utility may define the standard operation procedure for a "network alert" situation.

For more information, see ISO/TS 24522:2019, Annex A.

7.4 Decision support tools

The water utility may use decision support tools to assist in evaluating data from MDs and determining whether a "network alert" as described in 7.3 has been flagged.

The water utility may use automatic tools to verify that the results obtained from various network location are consistent and logical. The analysis can be performed online or offline.

For more information, see ISO/TS 24522.

7.5 Periodic evaluation of the continuous monitoring system

The water utility should perform periodic testing and simulations of contamination events in order to verify the efficiency of its network monitoring and related standard operation procedures.

The water utility should document the periodic testing procedures and standard operation procedures.

The water utility should define who is authorized to make changes in the criteria described in this clause and the related procedures.

8 Installation, maintenance, operation, calibration and data transmission of MDs

8.1 Installation considerations

8.1.1 General

Installation planning should consider the appropriate geographical location in the drinking water system network and the necessary installation considerations that will allow the utility to achieve reliable measurements.

8.1.2 Geographical location

The potential geographical locations, as decided according to Clause 7, should be further vetted by relevant experts to determine site-specific locations that are suitable and address the considerations of 8.1.3.

8.1.3 Site installation location

With the large variety of continuous monitoring equipment options available, the selection of optimal site installation locations should be determined by factoring in considerations such as the following:

— the physical adaption of the MD to the environmental conditions in the location site;

— connecting the MD at various sites (such as reservoirs, treatment plants, pressure reduction stations, metering points and network pipelines) could have different influences on the MD's measurements based on the site characteristics;

— the access requirements to MDs and related equipment, including occupational health and safety considerations and parking facilities, for the purpose of operational, maintenance and calibration activities;

— manufacturer's instructions and installation requirements such as waterline installation angle, types of connections, distance from the water being measured and installation accessories (e.g. water bubble valve);

— the additional requirements to support the operation of the MDs (e.g. power supply, water connection, rate of flow, drainage);

— additional site factors affecting initial installation, such as those related to underground pipes;

— the availability of low-energy MDs working on batteries or other alternative energy supplies, such as solar or hydraulic, where other power supplies are not available.

8.2 Maintenance and operational considerations

Programmes should be established for the continuing maintenance and operation of the monitoring stations. These should take into account the following requirements:

— development, training and assignment of staff to maintain event detection process (EDP) software;

— development of procedures and training staff to address MD maintenance and troubleshooting;

— training and assignment of qualified staff to address equipment malfunctions, communication problems and issues with EDP software;

— continuous monitoring of the MD outputs by qualified and trained staff with the ability to respond promptly to alarm conditions;

— maintaining environmental conditions according to manufacturers' recommendations to ensure proper operation of the MDs under various climatic conditions;

— availability of reagents for routine operation;

— availability of spare parts and equipment for equipment malfunctions, communication problems and software issues;

— relevant supply chains having the necessary resilience to overcome equipment or software malfunctions within appropriate, predetermined timeframes;

— maintenance and support agreements with outside agencies should the utility require resources beyond their normal means.

NOTE Many manufacturers offer maintenance agreements that can address some of these concerns.

8.3 Calibration considerations

Calibration practices should be established to ensure the supply of reliable and accurate data from MDs. These should take into account at least the following requirements:

— establishing the frequency of calibration according to manufacturer's recommendations, water utility policies and the conditions and environment of the MD location;

— establishing agreements with suppliers and external parties for calibration of equipment and MDs beyond the capability of utility staff;

— scheduling of calibration of portable units used by operational staff in the verification of data accuracy;

— maintaining adequate resources of equipment, accessories and reagents required for calibration activities including periods of increased calibration;

— tracking calibration results and evaluating on an ongoing basis the need for adjustments in calibration periods for the field equipment to reflect operational conditions.

In addition to the calibration of equipment and MDs, staff should be trained and procedures established for the calibration of any associated EDP software for background noises and unique monitoring station profiles to determine and update parameter values of the software used for event classification and true and false alarms.

8.4 Communication considerations

A robust and secure system for the collection and communication of continuous monitoring data from the MDs to the telemetry and supervisory control and data acquisition systems, staff and other control measures should take account of at least the following requirements:

— the protection of data during transfer to the SCADA system in accordance with established IT security arrangements;

— the hardening of SCADA systems and networks utilizing data encryption, secure communications protocols, firewalls and other technologies to reduce the possibility of system compromise during the communication of data to and from the MDs and the SCADA system;

— examining system redundancy including hardwired, cellular and multiple network capabilities and the ability to transfer communications between multiple systems to ensure continuous reliable communication between MDs and the SCADA system;

— examining alternative power sources including low-energy systems for communications equipment to reflect redundancy and varying field conditions and equipment power demands;

— establishing universal communication protocols to enable various communication systems to interface with the SCADA system;

— the ability to transfer data at determined time intervals and in real time when an event occurs;

— the establishment of and adherence to IT security protocols for software related to EDP and SCADA systems;

— backup data storage capabilities for future data retrieval in the event of a loss of communications between field and data centre equipment;

— data coding practices to aid in identifying the location and source of readings collected and improve time synchronization during communications.

Annex A
(informative)

Examples of positives and negatives of continuous monitoring systems

	Positives	Negatives
Costs	— Financial savings due to improved management of distribution network. — Savings due to public health benefits. — Savings due to a decrease in complaints due to a controlled and managed system. — May save on residual disinfection costs if system is better understood and controlled. — Potential saving in staff and laboratory tests as some of the traditional laboratory and field tests can be done with remote monitors.	— Systems can be expensive. — Systems require significant operations and maintenance commitments. — Monitoring equipment does not typically have a long lifespan (>10 years) in service, and the operator may be replacing 20 % per annum from year five.
Monitoring locations	— Can offer ability to monitor in locations not easily accessible for sampling and laboratory testing. — Can offer ability to get data from more locations.	— Not all locations at which monitoring is desirable are appropriate installation sites for MDs. Installations sites may be constrained by, for example, waste disposal, flow issues, communications or environmental conditions. — Not all sites are easily accessible for routine maintenance and calibrations. — Some locations where it may be desirable to install MDs from a logistics standpoint are not good choices due to, for example, dead zones, abnormal drinking water quality in the local area, proximity to pumping equipment. — Skilled staff are required to select sensor location; in some cases a sensor placement optimization software can help. — Due to their expense the number of monitoring sites may be limited.

	Positives	Negatives
Parameters to monitor	— These parameters are well known and understood in the water industry. — Most potential contaminants will cause a deviation in standard parameter readings.	— Where MDs are used as indicators of change rather than to measure the parameter of interest, this can lead to false assumptions and conclusions on the reason for the change. — There may be problems with drift in readings understanding when a MD is in calibration. — Operating properly can be difficult at times. — While most potential contaminants will cause a deviation in standard parameter readings, the amount of contaminant required to elicit an alert may be greater than what would be desired to protect public health.
Staff	— Reduces human error in sampling and testing protocols. — Allows monitoring of sensitive points and control points without human intervention.	— Requires staff trust in MD readings. — May require a different skill set than sampling and laboratory testing to perform operation and maintenance of MDs.
Resources	— May free up labour normally used for sampling and monitoring to perform other tasks. — More efficient operations may be possible saving costs.	— MDs require periodic updating and replacement. — Operational and maintenance costs can be substantial. — Problems recognized through monitoring that may not have been visible with traditional monitoring may require resources to remedy.

Annex B
(informative)

Examples of commonly deployed drinking water quality parameter measuring devices

B.1 General

Equipment for continuous monitoring can include one or more parameters to monitor, as well as data analysis tools to interpret and present the results in a way that is easy to understand.

This annex includes a brief description of some examples of commonly used drinking water quality parameters measuring equipment. Some devices can offer the possibility of measuring several parameters at the same time, as well as the possibility of connecting data analysis tools to obtain a faster and easier knowledge of the events that may have occurred at a given moment.

B.2 Measuring device for continuous measurement of disinfectant in drinking water

Chlorine and chlorine containing substances, such as monochloramine, hypochlorite or chlorine dioxide, are chemicals added to drinking water for disinfection and preventive purposes. They are strong oxidants that rapidly react with many organic compounds and some of the inorganic compounds in water. These chemical reactions demand active chlorine from the water, causing a drop in the measured value of active chlorine concentration levels.

The drop in the concentration of the active chlorine measurement in drinking water is proportional to the concentration of the compounds that can be oxidized and that are present in the chlorinated drinking water. The drop of active chlorine concentration in water ("chlorine demand") is a time-dependent variable and may serve as an indirect indication of the oxidable matter present in the monitored water.

"Active chlorine demand" threshold values may be established for alert- or alarm-raising purposes. This may be done based on laboratory tests results or in a pragmatic manner based on field experience.

Disinfection residual can be detected via a variety of methods, the most common methods being colorimetric and electrochemical methods. Each method has strengths and weaknesses that should be considered as they relate to an individual utility's needs before they are deployed.

NOTE Both free and total chlorine measurements can have value depending upon whether the system is free chlorine or combined chlorine (monochloramine) based. Monochloramine response time is longer than the free chlorine response time to many organics.

B.3 Measuring device for continuous measurement of turbidity in drinking water

Measurements of turbidity serve as an indirect indication of suspended matter concentration in drinking water. Turbidity is a physical property that is measured by determining the amount of light that is scattered, usually at right angles from the source, by suspended particles found in the water. The scattered light can be detected either in a small portion of the field set at 90° from the incident light or in a full 360° radius at 90° from the incident light. The higher the turbidity, the greater the scattering of the light that has been passed through the sample correlating to a higher suspended matter concentration in the water.