
**Event detection process: Guidelines
for water and wastewater utilities**

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

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

This document has been created in response to an international demand for guidelines on the development of an event detection process (EDP) for drinking water and wastewater utilities (water utilities). The EDP is a key element of a water utility's wider event detection system. That system relies on, and is interrelated to, the water utility's sensor and sampling systems.

This document aims to support water utilities in the development of an EDP that monitors the relevant variables across their water/wastewater services and evaluates changes in those variables that can suggest an event has either occurred or could be imminent.

This document aims to be consistent with both the World Health Organization (WHO) Water Safety Plan approach for water supply and the WHO Sanitation Safety Planning approach for wastewater collection, treatment and disposal or reuse. Both take a risk-based approach to evaluating uncertainty about the quality and significance of data that suggests the occurrence of an event.

NOTE 1 This document addresses a wider range of event causation than that implied by the definition of 'hazard' in the WHO manuals.

For example (water): a change in the hardness of the water supplied could remain within acceptable limits for public health purposes but could still represent a change in water quality of material interest to some service users (e.g. breweries).

For example (wastewater): ingress of a volatile chemical into the wastewater system ought not to represent a direct health hazard in all circumstances, but, depending on its concentrations, could result in an explosion within the network or fire damage to the wastewater infrastructure.

Outputs from an EDP could help inform those within the water utility responsible for identifying events and alerting individuals responsible for event response decision-making. Such alerts could be required despite uncertainty about the quality and reliability of the data currently available.

Event response decisions can be based on those decision makers' knowledge, experience and assessment of the cause(s) and effect(s) of the event as it unfolds – including consideration of the EDP's outputs where appropriate.

At the discretion of the water utility, design of the EDP could incorporate elements of automated decision-making.

NOTE 2 If automated decision-making is proposed, consideration could require distinguishing between situations where automation could be appropriate and those where it would not be. For example, automation with low-impact outcomes could be acceptable but automation with high-impact outcomes could require greater caution. When considering automation, it is advisable to consider the appropriateness of inputs, the complexity of the system, the nature of the water utility and the effect of time delays.

A decision on whether to implement the water utility's procedure for dealing with an abnormal situation could be required in response to an identified or suspected event.

Such a decision could depend upon the confidence in the EDP's classification and output and the process underpinning it.

The guidelines could be of particular use to those water utilities that wish to enhance their ability to recognize abnormal events as a means to: maintain or improve public health provision; improve their operational processes; enhance the levels of their service provision; or reduce risks to the continued delivery of existing service levels.

In addition, development of an EDP can be a valuable aid to organizational learning and memory. The existence of an effective and efficient EDP provides a significant control against the risk of loss of individuals' knowledge and expertise by increasing a water utility's independence from such vulnerable resources. Regular use and review of an EDP's successes and failures can contribute to organizational learning and a reduction in the time taken to detect an event.

Event detection process: Guidelines for water and wastewater utilities

1 Scope

This document provides guidance for water utilities on the detection and classification of water and wastewater events.

The following subjects are within the scope of this document:

- publicly and privately owned and operated water utilities. It does not favour any particular ownership or operating model;
- all aspects of the drinking water system and the wastewater system;
- all causes of abnormal changes in water and/or wastewater service provision capable of detection by monitoring systems including accidents, unexpected operational changes, natural hazards and intentional disruption.

This document is independent of the measurement methods used to collect the data.

The document focuses on events which could imminently affect the water utility's interested parties.

The following are outside the scope of this document:

- methods of design and construction of drinking water and wastewater systems;
- plumbing and drainage systems not under the control of the water utility.

This document does not include details about action taken as a result of event detection. For such details see ISO 24518 and EN 15975 Part 1.

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, *Activities relating to drinking water, wastewater and stormwater services — 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

classification

category that the *event* (3.5) falls into

3.2 continual improvement

recurring activity to enhance *performance* (3.15)

Note 1 to entry: The *process* (3.16) of establishing *objectives* (3.13) and finding opportunities for improvement is a continual process through the use of audit findings and audit conclusions, analysis of data, management reviews or other means and generally leads to corrective action or preventive action.

Note 2 to entry: The nature of the activity can differ between cycles of recurrence.

[SOURCE: ISO 9000: 2015, 3.3.2, modified — Note 2 to entry replaced.]

3.3 documented information

information required to be controlled and maintained by an *organization* (3.14) and the medium on which it is contained

Note 1 to entry: Documented information can be in any format and media and from any source.

Note 2 to entry: Documented information can refer to:

- the management system, including related *processes* (3.16);
- information created in order for the *organization* (3.14) to operate (documentation);
- evidence of results achieved (records).

3.4 effectiveness

extent to which planned activities are realized and planned results are achieved

3.5 event

situation where 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”.

Note 5 to entry: For the purposes of this document, “normal” refers to what is expected.

3.6 event detection

recognition of *event indicator* (3.9) and/or information about a new situation

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

- event indicator and/or situation(s) are considered known and non-hazardous;
- event indicator and/or situation(s) are considered hazardous, but a procedure to handle them already exists;
- event indicator and situation(s) are considered unknown, and for which a procedure does not yet exist.

3.7 event detection process EDP

set of interrelated or interacting activities which transforms inputs [data or information on an actual or suspected *event* (3.5)] into outputs [to support the *water utility's* (3.19) operational activities]

3.8**event identification table****EIT**

table developed by the *organization* (3.14) that contains examples of proven connections between changes in water measurements and possible causation types

3.9**event indicator**

signal to the water utility or one or more *stakeholders* (3.18) that an *event* (3.5) can have occurred with the potential to cause a significant deviation in the users' expectations of service *performance* (3.15)

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

3.10**influence matrix table****IMT**

table developed by the *water utility* (3.19) that contains suspected connections between *event indicators* (3.9) and *performance measurements* (3.11) based on scientific knowledge and water industry experience

3.11**measurement**

process (3.16) to determine a value

3.12**monitoring**

determining the status of a system, a *process* (3.16) or an activity

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

3.13**objective**

result to be achieved

Note 1 to entry: An objective can be strategic, tactical or operational.

Note 2 to entry: Objectives can relate to different disciplines (such as finance, health and safety, and environmental goals) and can apply at different levels [such as strategic, organization-wide, project, product and *process* (3.16)].

Note 3 to entry: An objective can be expressed in other ways, for example as an intended outcome, a purpose, an operational criterion, an event detection objective or by the use of other words with similar meaning (e.g. aim, goal or target).

Note 4 to entry: In the context of an event detection system, event detection objectives are set by the *water utility* (3.19), consistent with the event detection management policy, to achieve specific results.

3.14**organization**

person or group of people that has its own functions with responsibilities, authorities and relationships to achieve its *objectives* (3.13)

Note 1 to entry: The concept of organization includes, but is not limited to, sole-trader, company, corporation, firm, enterprise, authority, partnership, association, charity or institution, or part or combination thereof, whether incorporated or not, public or private.

Note 2 to entry: For the purposes of this document the organization responsible for *event detection* (3.6) will usually be part of a wider organization [the *water utility* (3.19) responsible for the provision of drinking water/wastewater services].

3.15

performance

measurable result

Note 1 to entry: Performance can relate either to quantitative or qualitative findings.

Note 2 to entry: Performance can relate to the management of activities, *processes* (3.16), products (including services), systems or *organizations* (3.14).

3.16

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* (3.14) 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”.

3.17

risk

combination of the likelihood of a hazardous event and the severity of consequences, if the hazard occurs in the drinking water system or wastewater system

Note 1 to entry: Risk is often characterized by reference to potential *events* (3.5) 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 has 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* (3.13), where uncertainty is the state, even partial, of deficiency of information related to understanding or knowledge of an *event* (3.5), its consequence or likelihood.

3.18

stakeholder

interested party

person or *organization* (3.14) that can affect, be affected by or perceive itself to be affected by a decision or activity

EXAMPLE Users 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* (3.14), laboratories.

Note 1 to entry: Stakeholders will typically have an interest in the *performance* (3.15) or success of an organization.

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

3.19**water utility**

whole set of *organization* (3.14), *processes* (3.16), activities, means and resources necessary for abstracting, treating, distributing or supplying drinking water, for collecting, conveying, treating, disposing of and reusing wastewater or for the control, collection, storage, transport and use or disposal of stormwater and for providing the associated services

Note 1 to entry: Some key features for 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* (3.14) with the function of operator being carried out by the responsible body, or by legally distinct operator(s);
- 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 not necessary or it is 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.

4 Principles of an event detection process**4.1 Design phase****4.1.1 General**

The water utility should determine the scope of the event detection process (EDP)'s detection capabilities. This should include:

- all credible events identified via the risk assessment process;
- the ability to respond promptly to unanticipated events (actual or suspected).

The scope should be available as documented information.

The range of complexity of the EDP chosen can vary from manual data analysis of paper-based historical records through to a fully computerized system. The level of complexity chosen should be consistent with the water utility's local conditions, to avoid unrealistic assumptions about the adequacy of the EDP's outputs.

The EDP's design should be based on a methodology to detect the possibility of the occurrence of events; perform analysis of incoming data to identify and classify possible events; and contain a validation process to constantly ensure quality of detection and classification.

Events can be water- or wastewater-related, and have water or wastewater quality consequences or other consequences (e.g. physical ones such as pressure or flow fluctuations, or operational ones such as chlorinous taste or foul odour complaints).

An EDP should aim to detect the occurrence of an event, provide guidance as to the event's likely cause and assist in the classification of the event's severity, urgency and possible consequences (see [Figure 1](#)).

The extent to which an EDP should be capable of distinguishing between the severity and urgency components of abnormal conditions should be a key consideration in the design phase.

Such guidance should permit the description of one or more possible risks (by postulating one or more chains of cause/effect/consequence).

The effectiveness of the EDP’s design and the efficiency of its application should thus reduce the uncertainty surrounding possible alternative causes of an event pending actual confirmation of the cause.

To be successful, event detection should rely on the water utility’s prior establishment of effective control over and conformity with warning values and limit values and their incorporation into operating procedures.

Since the EDP is based mainly on statistical analysis, the water utility should be aware that the existence of an EDP cannot guarantee that the event’s causation and consequences for service provision will always be recognized before any interested party is affected or that the cause will always be quickly identified.

Risk 1 permutations: There is a risk that [select one from multiple causes] will disrupt the disinfection process leading to illness in the community.				
Risk 2 permutations: There is a risk that [select one from multiple causes] will result in a chlorine leak causing a poisonous gas hazard in the vicinity.				
Risk 3 permutations: There is a risk that [select one from the multiple causes] will result in decrease of treatment plant flow, decreased biomass activity and a deterioration in effluent quality.				
Possible Cause(s)	Event(s) (Hypothesized or Suspected)		Potential Consequence(s)	
	Indicator(s)	Effect(s)		
Risk 1: Power supply interruption Equipment failure Chlorine supply depleted Malicious interference	Telemetry alarms Disinfection process problem = ON Low Chlorine alarm = ON	Free Chlorine level in water is low	→	Illness in the community → Injury / death; Reputation damage.
Risk 2: Equipment failure Accidental damage Malicious interference	Telemetry Alarms Chlorine leak alarm = ON Low Chlorine alarm = ON	Chlorine leak	→	Poisonous gas hazard → Injury / death; Corrosive asset damage; Reputation damage; Illness in the community.
Risk 3: Failure of wastewater treatment plant. Occurrence in collection area of domestic wastewater	Telemetry Alarms Wastewater treatment plant inlet pump low flow alarm equals = ON Changes in the acidity of the wastewater =ON	Flow to treatment plant inlet is low Treatment plant biomass decreased activity	→	Wastewater system blockage or collapse → Traffic disruption, flooding and public health risk; Raw sewage released to the environment / high effluent levels. Effluent quality deteriorates → Flow through the wastewater treatment plant has to be restricted.

Key

	Event Indicator listed in IMT
	Known / suspected relationships between changes in event indicator measurements and a suspected event's effects as listed in the IMT
	Effects' combination listed in IMT
	Known / suspected connections between the occurrence of combinations of effects and the possible causative event type(s)

Figure 1 — Illustration of the relationship of the influence matrix table (IMT) to the event identification table (EIT) in the event detection process (EDP)

4.1.2 Influence matrix table and EDP

Event indicators are a list of measurable indicators based on available knowledge that would change when an identified risk actually occurs ([Annex A](#) contains examples of some typical event indicators that could be used as EDP system inputs).

System inputs should be used to construct a tool (e.g. table or flow chart) – described henceforth as an influence matrix table (IMT) – related to the water utility's function(s). The IMT should describe

the relationship(s) between individual inputs (event indicators) and their hypothesized, suspected or “known” (in a probabilistic sense) effect(s). [Annex B](#) contains examples of water and wastewater IMT. The relationship between the IMT and the event identification table (EIT) is described here. Their relative positioning within the EDP is described in [5.2.3](#) and [5.2.4](#), and illustrated in [Figure 3](#).

The content of the IMT should provide inputs to the process of constructing an EIT in three stages.

Firstly, the IMT should contain an “if”/“then” relationship(s) between changes in event indicator measurements and the effects becoming evident in the system they are indicative of.

Secondly, the water utility can then, by identifying a further set of “if”/“then” effect combinations, postulate possible causes for these simultaneous effects — progressively refining its analysis by causation type(s) (identifying unique or possible alternative causation options).

Thirdly, the IMT should contain a value and timestamp a value.

[Table C.1](#) in [Annex C](#) contains examples of simultaneous relationships which could form part of an EIT's content.

It can be seen in [Figure 1](#) that the IMT is the starting point, first to look “downstream” in the indicator/effect relationship(s) and then, by combining knowledge of simultaneous effects causation, to look “upstream” to (with increasing maturity as the EDP develops) hypothesize, propose or predict a suspected event's cause.

NOTE The probability of successfully identifying causation is likely to increase with the developing maturity of the EDP. This maturity is likely to arise from refinement of the “if”/“then” rules created in the IMT and the EIT. The former's rules are likely to have a high degree of commonality across water utilities and be relatively easy to establish from literature. The latter will vary between water utilities depending on a range of factors and require more local knowledge. Ultimately a fully mature EDP will be unique to an individual water utility. By that stage the IMT and the EIT ought to be capable of referencing specific locations and indicator measurements associated with a prediction of causation of individual events affecting the water utility.

4.1.3 EDP inputs

The EDP requires one or more inputs before it can generate an output. The input(s) derived from operating a water supply/wastewater system could depend on the:

- size of the system,
- system management resources available;
- system management resources' capabilities;
- economic state of the system;
- size and structure of the water utility's service area;
- infrastructure of the water utility's service area;
- technical state of the system and the level of automation.

4.1.4 EDP design

The design considerations of the EDP should include:

- preferred time frame in which each event should be detected and classified;
- severity and order of priority in which events should be handled;
- number of inaccurate event detection alerts to be tolerated (by location and type) over a defined period of time [known as false positive (FP) or false negative (FN) alarms — see [Annex D](#)].

NOTE Acceptable levels of FP and FN alarms could change over time due to changes in the hazard(s) to which the water utility is exposed.

Some of the event indicators listed in [Annex A](#) are among those that could be identified and used to establish a target service level for detection by the EDP.

The EDP target service level for detection should be a sub-set of the utility's general objectives regarding the provision of water/wastewater services. For further details see ISO 24510, ISO 24511 and ISO 24512.

4.1.5 EDP target service level design

Given the potential for an event to escalate into a crisis, the EDP target service level for event detection should be designed to support achievement of the minimum levels of service determined by the utility.

Considerations should include:

- the EDP's required availability and the acceptability of any planned unavailability;
- the availability of staff competent to operate the EDP and interpret its outputs within and outside normal working hours;
- the EDP's resilience to loss or disruption of its normal operating facilities;
- the water utility's capability to restore an acceptable level of the EDP's functionality within the maximum tolerable period of disruption determined by the water utility's business continuity management policy.

For further details see ISO 24518, ISO/TS 24520 and EN 15975-1.

4.2 Detection phase

4.2.1 General

There may be several ways to detect an event's occurrence based on the event indicators. [Clause 5](#) contains a methodology for constructing an EDP that seeks to capture all these opportunities.

Awareness of and access to regular performance measurements undertaken by the water utility should support the detection of water/wastewater quality changes.

4.2.2 Validation process

Data's suitability as a dataset input could require a two-step validation process before any further analysis.

Failure to satisfy all of Step 1's validation should preclude progress to Step 2.

Step 1: The readings should represent actual reflections of field values. The six basic data validations are:

- physical limits are not violated;
- data are not 'frozen';
- essential data are not absent;
- rates of change in that variable remain credible;
- duration of the change in the variable is significant;
- no fixed repetitive patterns are present.

Step 2: Each variable presented should then be analysed separately to see how it is now behaving compared with historical data trends. In this process, relevant seasonal factors, hours of the day or day of the week (e.g. reflective of industrial routines) should be considered together with human behaviour. Technical problems or changes in the operational processes should also be considered where appropriate.

If any variable is deviating from its historical trend, normal boundaries, rate of change or develops fixed repetitive patterns (given local consideration of time and season), then reference should also be made to the EIT to see if it contains rules justifying an alert based on this variable.

Visible inspection of the single data charts may support abnormal condition identification. Design of the EDP should not preclude continued access to visible inspection of data charts (see EDP verification methods in [Annex F](#)).

In the case of wastewater, information regarding abnormal discharge of industrial material to the public network should also be taken into consideration.

4.2.3 Further event monitoring

Decisions on further event monitoring to be undertaken should be made, based on the initial alert, ongoing uncertainties and accumulating knowledge of the unfolding event.

If no escalation is required it may still be desirable to undertake further monitoring as part of the water utility's quality assurance process using the 'Plan, Do, Check, Act' cycle. For further details see ISO 24510, ISO 24511 and ISO 24512.

If escalation is required, the type and extent of further monitoring should be established as part of the operational management system. Where the event may require a crisis management response, the escalation should form part of the 'pre-crisis phase' of the crisis management system. For further details of how the EDP should align with the crisis management system see ISO 24518.

4.3 Ongoing activities

4.3.1 Post-event EDP evaluation

Post-event evaluation of the EDP should establish whether the prediction was accurate, inaccurate or ambiguous. This evaluation should consider both inputs and outputs, and possible uniqueness of the water utility, in an attempt to establish the validity of the output. This should result in an updating of the documented information and continual improvement of the EDP.

NOTE [Annex C](#) illustrates varying levels of complexity in the EDP for both water and wastewater utilities.

4.3.2 Periodic reviews

The vulnerability of the drinking water/wastewater system should be periodically reviewed. This review should include consideration of the list of potential risks derived from the methodology identified in [4.1.2](#).

NOTE For more details of this approach see the WHO *Guidelines for drinking-water quality*^[22] (or the WHO *Guidelines on sanitation and health*^[23]) and EN 15975-2.

The detection process should be evaluated periodically in order to address two aspects:

- does it look at the most relevant event indicators with respect to the possible risks it tries to assess?;
- what is the reliability of its answers?

Assuming satisfactory answers to these two questions, the process can be utilized with confidence to classify events as positive (i.e. a real event) or negative (i.e. a non-real event), before the actual result is obtained.

4.3.3 Validation of links between phenomena and risk materialization

Validation (of [4.3.1](#) and [4.3.2](#)) requires the validation of the links between:

- the phenomena believed to be responsible for the observed event indicator(s), and
- the materialization of the risks the water utility wishes to prevent.

For details about the validation process, see [5.7](#).

4.3.4 Estimation

Aspect two (of [4.3.2](#)) requires estimating the chances that the answer is right, based on historical, documented information for both positive and negative classifications.

4.3.5 Decision-making

Based on this estimation, a decision should be made whether or not to escalate awareness of the classification to the appropriate decision maker. The outcome of this classification activity should:

- trigger updating of the documented information;
- where escalation is deemed necessary, provide an input to the proper decision-making process.

4.3.6 Guidance on interpretation

Guidance on interpretation of outcomes from the classification activity should be provided to determine the urgency with which an input to the proper decision-making process should be made.

5 The event detection cycle and the role of the EDP

5.1 The EDP's application of the event detection cycle (the EDP cycle)

A water utility may manage an ongoing process of water and wastewater event identification control — the “event detection cycle”. This process should consist of the following three types of activity (repeated as necessary), which should be performed in the following order:

- defining monitored information and a decision-making process;
- identifying and classifying events;
- periodically documenting and reviewing the quality of classification and decisions.

Development and deployment of an EDP can significantly enhance, accelerate and improve the accuracy of these cyclical activities.

The following provides general guidance on the EDP's development, its use in event detection, the documenting, classification and evaluation of the EDP's outputs and those outputs' expression and presentation. Additionally, guidance is provided on governance issues around access, user training and qualification, operation and testing.

[Figure 2](#) illustrates the EDP cycle. “Develop” ([Figure 3](#)) is the phase in which IMT and EIT are created; “Detect” ([Figure 4](#)) is the phase in which the IMT and EIT are used to detect events; “Document” ([Figure 4](#)) is the phase where the events are documented and “Classify and evaluate” ([Figure 5](#)) is the phase where the efficiency of the process is evaluated. Where needed, the “cycle is repeated by refinement of the “Develop” phase.

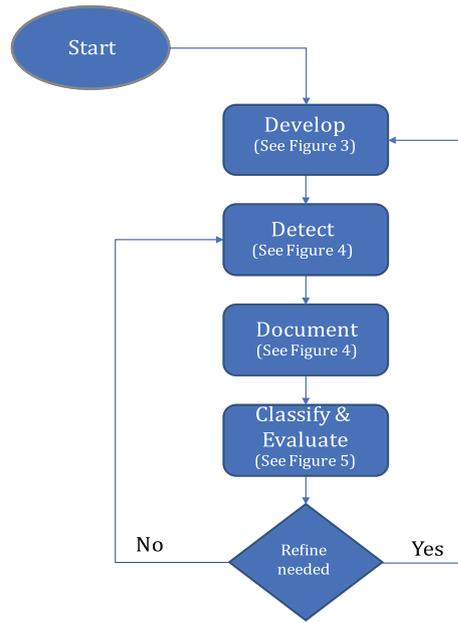


Figure 2 — EDP cycle

5.2 Development and regular review of an EDP-based event detection capability

5.2.1 General

The procedure for development and regular review of an EDP-based event detection capability is illustrated in [Figure 3](#).

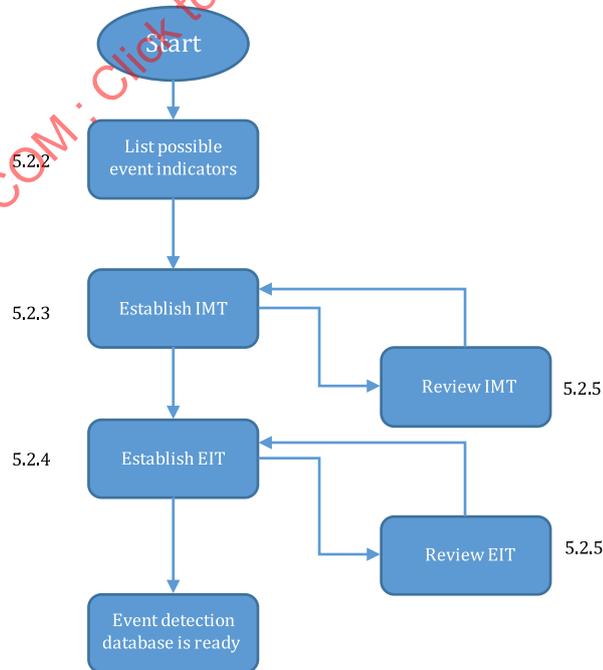


Figure 3 — Development of event detection capability

5.2.2 Listing of possible event indicators

The EDP should include a procedure for establishing and maintaining one or more lists of all possible event indicators relating to changes in performance. Examples of such lists are given in [Annex A](#). Separate lists should be made for drinking water and wastewater systems.

5.2.3 IMT establishment

The EDP should include a procedure for establishing and maintaining an IMT. This table should document known or suspected connections between event indicators and performance measurements. The connections documented in the table should aim to describe the direction, speed and strength, within a predefined time frame, of the changes that could potentially occur in both indicators and measurements. For example, a slow drop in 'event indicator 1' and a rapid rise in 'event indicator 2' should reflect a change in 'water quality measurement 3' within 6 h.

[Table B.1](#) in [Annex B](#) contains examples of relationships that could form part of an IMT's content.

5.2.4 EIT establishment

The EDP should contain a procedure for establishing and maintaining an EIT. The EIT should support the identification of an event's possible cause (e.g. burst pipe) based on the IMT table. The EIT should document established connections between the following inputs, measurements and outputs:

- IMT inputs;
- causation type outputs;
- confidence in the identification of the suspected causation type.

Entries in the EIT should refer both to static connections between inputs and outputs and the process dynamics (with reference to the time frame and the lag time between the occurrence of inputs and changes in the outputs).

NOTE 1 Static connection is always true, whereas dynamic connection is true within a specific context.

NOTE 2 If the number of records is large enough, the EIT can be constructed using association rules construction methodology. Such methodology can be found in Reference [7].

5.2.5 IMT and EIT periodic review

The IMT and EIT should be reviewed periodically by internal and/or external experts. These reviews should be documented. The water utility's own reviews should include quantitative analyses which examine the robustness of the connections using standard proven quantitative methods. The time intervals between these reviews, the individuals to be involved in them, and the extent of the individuals' independence from one another, should be determined (in liaison with other interested parties as necessary).

The water utility could have a requirement to report event data to one or more stakeholders outside the water utility.

5.3 Deployment of an event detection procedure

5.3.1 General

The procedure for deployment of EDP-based event detection is shown in [Figure 4](#). The figure includes the "detect" and "document" phases illustrated in [Figure 2](#).

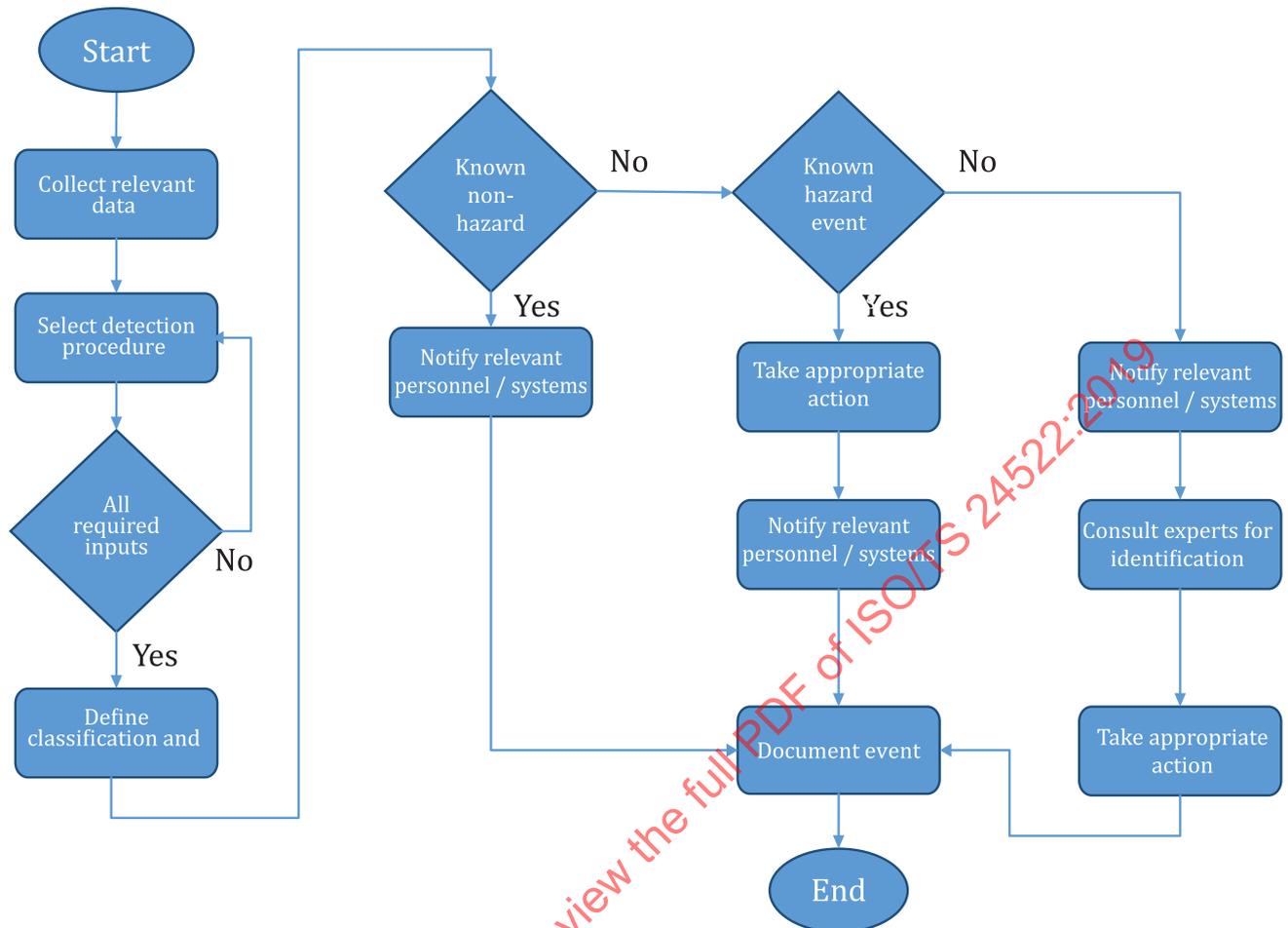


Figure 4 — Event detection procedure

5.3.2 Defining the possibility of an event's occurrence

The EDP should include a procedure for defining the probability of an event's occurrence. This definition should explain how actual field measurements together with the EIT are used to estimate the probability of an event, as in the following example.

EXAMPLE Based on historical records, in the case of a chlorine drop of more than 0,5 mg/l in one hour and a rise in turbidity of 0,8 NTUs at the same time, and where no operational change was made during the two hours immediately prior to these observed changes, four out of five cases were classified as a TRUE intrusion of contamination caused by a pipe break.

5.3.3 Nature of water/wastewater measurement sampling considerations

The EDP should consider the nature of water/wastewater measurement sampling. This can include the method of sampling (e.g. automatic or manual); the frequency of sampling (e.g. every minute, once a day, once a week); the sampling location; the sampling method; and the process for evaluating the results (e.g. manual or automated).

NOTE For guidance on water quality sampling, both in general and in a series of different environments, see the relevant parts of ISO 5667-20.

5.3.4 Results assessment

The EDP should contain a procedure for assessing results that might require an alert output when the result is based on more than a single source of information.

5.3.5 Missing inputs

The EDP should contain a procedure to address the situation of missing inputs.

5.3.6 Unfamiliar combination of inputs

The EDP should contain a procedure to address the situation where an unfamiliar combination of inputs occurs.

NOTE An unfamiliar combination is such that the inputs cannot be identified as similar (with acceptable levels of confidence) to known combinations already listed in the EIT.

5.3.7 Deviation from normal frequency detection

The detection process should monitor current events and be able to detect a deviation in the frequency of events from the normal frequency.

Water utility systems will usually experience some frequency of events during their normal operation. The EDP should be able to accommodate this situation yet still alert that a possible event could have occurred when the frequency of events becomes unusually high. The detection described in this subclause refers both to the number of events per time unit and to the duration time between events.

The EDP should include a procedure that enables a measurement to be made of the similarity between the current event and past events whose outputs are known and have been classified (non-hazardous events/hazardous events).

This similarity should take into consideration substantial changes that might have occurred in the monitoring system, for example the replacement of equipment.

The definition of similarity may be based on any statistical method used to correlate between two sets of records where each record has multiple parameters.

5.3.8 Measurement grouping

A definition should be made of how to aggregate several measurements into a single measurement while keeping the severity ranking of situations. One such method is called "measurements grouping into single statistic measurements". The method is adopted in the procedure described in 5.4.1 to 5.4.6. See Annex E for a fuller explanation of this method.

5.4 Classification of events and evaluation of the classification procedure

5.4.1 General

The EDP should contain a procedure that supports the classification of events (see Figure 2).

The procedure for event classification and the evaluation of the classification procedure is shown in Figure 5.

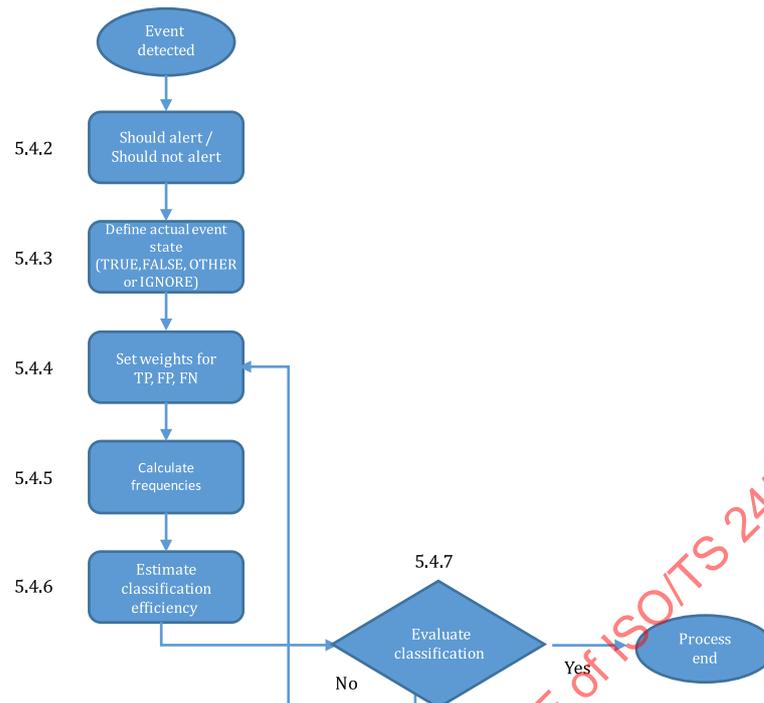


Figure 5 — Event classification and classification process evaluation

5.4.2 Process-based classification

Each event detected by the event detection procedure (see 5.3) should generate a result designated as either 'SHOULD ALERT' or 'SHOULD NOT ALERT'. This classification is termed a process-based classification. Examples of such classification are given in Annex G and Annex H.

5.4.3 Actual classification

Each event should also be classified, in accordance with the event detection procedure (5.3), as 'TRUE', 'FALSE', 'OTHER' or 'IGNORE'. This classification is termed an **actual classification**. The following four cases illustrate the distinctions between these classifications.

- A 'TRUE' classification could be assigned to an event if the value of a measurement violates the thresholds, for example the value of free chlorine decreases below the regulatory recommendation of the health authority of 0,2 mg/l, although the dosing chlorine system was working properly, and there is evidence of increase in bacteria counts, which, taken together, could indicate a penetration of wastewater into the drinking water system.
- A 'FALSE' classification could be assigned to an event if the value of a measurement violates the thresholds, for example the value of free chlorine decreases below the regulatory recommendation of the health authority of 0,2 mg/ml, but the reason for the deviation is extreme high temperatures which cause extreme degradation of the chlorine residual. In this case, a change of the dosing system set-up can solve the problem.
- An 'OTHER' classification could be assigned to an event if the value of a measurement violates the thresholds, for example the value of free chlorine decreases below the regulatory recommendation of the health authority of 0,2 mg/ml, due to water utility maintenance work.
- An 'IGNORE' classification could be assigned to an event if the value of a measurement violates the thresholds, for example the value of free chlorine decreases below the regulatory recommendation of the health authority of 0,2 mg/ml, due to a malfunctioning of the chlorine sensor.

NOTE Event classification in automatic systems will occur automatically after an appropriate amount of correct manual classifications.

5.4.4 Assignment of weights

The classification evaluation procedure described in [5.4.7](#) should enable different weights to be assigned for each one of the combinations listed in [5.4.5](#).

Under normal conditions FALSE NEGATIVE ([5.4.5](#)) should get higher importance (weight) than FALSE POSITIVE ([5.4.5](#)). The first can generate damage to humans and property. The second can cause the water utility extra work.

5.4.5 Frequency calculations

Each event should be identified as one of the following categories based on the outcome of the classifications in [5.4.2](#) and [5.4.3](#):

- 'TRUE POSITIVE' — when both classifications agree that an alert was justified,
- 'TRUE NEGATIVE' — when both classifications agree that an alert was not justified,
- 'FALSE POSITIVE' — when the process-based classification generated a 'SHOULD ALERT' result but the actual classification generated a 'SHOULD NOT ALERT' result, and
- 'FALSE NEGATIVE' — when the process-based classification generated a 'SHOULD NOT ALERT' result but the actual classification generated a 'SHOULD ALERT' result.

5.4.6 Classification efficiency estimation

The EDP should include, when needed, a procedure for the classification process's evaluation, using known statistical methods. The evaluation should consolidate the frequencies of the four (or fewer) situations into a single measurement that enables relevant stakeholders to rank the performance of the EDP. See [Annex E](#) for an explanation of this consolidation procedure. This procedure may vary based on the differences between classification of water and wastewater events.

5.4.7 Classification evaluation

The evaluation procedure of the EDP based on [5.4.1](#) to [5.4.6](#) should be reviewed periodically. This review should be documented.

5.5 Notification to relevant personnel/systems

The EDP process generates outputs, some of which can be escalated for consideration by an appropriate decision maker. Where the decision maker judges it necessary, some of these outputs can be further escalated.

Development and maintenance of the procedure for escalation of the outputs from the EDP should form part of the water utility's pre-crisis phase preparedness (see ISO 24518 and ISO 24520).

5.6 Documentation of events

5.6.1 General

Events and their classification should be documented as near as possible to the time of their occurrence. When possible, the documentation should be done automatically. This initial documenting and any later change to this documentation should be auditable.

5.6.2 Time stamps

The occurrence of an event and the documentation of an event should both have individual time stamps. The documentation of an event can have a time stamp that is later than the event's time stamp.

5.6.3 Subsequent documentation

Any change to event details subsequent to an event's original documentation should also be documented, but original data should not be eliminated.

5.6.4 Responsible person documentation

It should be possible to identify who the responsible person is for each entry within the documented items.

5.6.5 Documentation authority

A procedure should be established to determine who is authorized to insert, update or delete any documentation item from the historical log.

5.6.6 Data security

Detection process documentation should be prepared and maintained according to appropriate data security standards. For a water utility using IT systems, IT security could be in accordance with, for example, ISO/IEC 27001.

5.7 Validation process — Periodic evaluation of the detection process

5.7.1 General

The EDP should contain a procedure to evaluate the content of the EIT periodically, based on actual field events. For this purpose, experts (including external experts where appropriate) should classify actual events and match their estimation with the content of the EIT (see [Annex F](#)).

NOTE 1 Some events are likely to be generic (i.e. they apply to any water utility). For example:

- 1) Increased turbidity measurements allied to low/no chlorine residual indicates organic contamination.
- 2) An increase in total organic carbon (TOC) and conductivity combined with a decrease in pH could indicate a non-treated flow of wastewater from metal processing.

NOTE 2 Some events could only be applicable to a limited number of water utilities (or could be unique to one). For example:

- 1) Events related to penetration of sea water into an aquifer are unlikely to be applicable to a water utility located in an inland mountainous region.
- 2) A large influx of industrial waste would be unlikely in a wastewater treatment facility in a rural setting serving only domestic users.

5.7.2 Confidence-level assignment

Based on the above procedure ([5.7.1](#)) each entry in the EIT should be assigned a confidence level. The confidence level should define the connection between the output (i.e. the actual measured values post-event) and the likelihood that such an output would be repeated if the same input criteria were to occur at a later date. The confidence level should be expressed in percentages. For example, if input X1 has a

value > A, input X2 has a value > B and input X3 has a value < C, then for 9 out of 10 events, the result will be Y.

NOTE Non-quantitative outputs can be translated into measurable values by using Boolean representation (TRUE, FALSE) of different categorizations. For example, the existence of a chlorine leak can be represented by an integer variable saying 0 = no probability; 1 = low probability; 2 = moderate probability; 3 = definite.

5.8 Periodic system evaluation — System functionality

Functionality of the event detection system should be periodically verified. This verification should include data integrity testing. To evaluate the overall functionality of the entire system, close attention should be paid to the EDP, which is the fundamental part of the detection system. Such evaluation should include:

- instrument calibration and response;
- training and proficiency of personnel involved in data collection;
- integrity of data transfer;
- integrity of data analysis, alarm output and alerts.

Further verification testing should be performed via the analysis of historical or artificial data sets known to contain event signatures and/or via the introduction of surrogate agents to the system. See [Annex F](#) for further guidance.

5.9 EDP development — General principles and governance

5.9.1 EDP operation

Operation of the EDP should be simple and user-friendly.

5.9.2 Access to the EDP

Access to the EDP should be restricted to trained, security approved operators who should be authorized to:

- input data and orders needed for the implementation of the methodology, and amend the process to take into account the lessons learned;
- implement the changes required for improving the methodology's detection capabilities (e.g. changing threshold values, relationships between parameters' readings, sensitivities);
- run simulations;
- test the security of the system (using external experts as necessary);
- access historical data and analyse the data according to the water utility's needs.

Differing levels of authorization can be required based on the significance of the activity being undertaken.

5.9.3 User training and qualification

Understanding and interpretation of the EDP should be based on user training and qualification processes.

Users should be able to perform their roles competently during circumstances up to and including a crisis. Training topics should include:

- water quality science;

- water quality measurement;
- the context of such measurement within the water utility, including:
 - 1) knowledge of the physical, topographic, hydraulic and schematic layout(s) of the water utility's system(s);
 - 2) sources of risk within these areas;
 - 3) the siting, nature and capabilities of individual measurement devices employed.
- the water utility's EDP;
- event detection science and mathematical/statistical treatment of data;
- event detection history across both the water utility and, more widely, within other water utilities;
- process-based and actual event classification within the water utility's EDP;
- event detection recording, review and escalation procedures;
- EDP event post-escalation response procedures;
- EDP verification and maintenance procedures;
- EDP validation procedures.

Training methods should include classroom, desktop or simulation exercises as appropriate.

The frequency of both initial and refresher training should be adequate to satisfy the water utility's competency requirements for individual EDP roles.

5.9.4 Testing and certification

Competency should be established through completion of a suitable testing and certification process.

The process should ensure that:

- certification levels reflect the varying levels of skill, responsibility and authority necessary to carry out EDP duties efficiently and effectively;
- only individuals who are certified as competent are allowed to perform those EDP duties;
- re-certification of individuals is conducted with an appropriate frequency.

5.9.5 EDP output expression

The EDP outputs should be expressed in measurements that can be evaluated by non-scientific personnel; for example, severity is low, medium or high. Statistical terms calculated by the EDP should be expressed in simple terms that can be evaluated by non-scientific personnel.

5.9.6 EDP output presentation

The presentation of the EDP outputs should permit the spatial interpretation of the event in terms of geography, topology and time.

For example, events could be presented on a geographic information system (GIS) map showing the drinking water distribution/wastewater network.

Annex A (informative)

Examples of typical event indicators that could be used as EDP inputs

A.1 General

Event indicators can include reports (e.g. verbal, written, electronic); complaints (e.g. change in service level experienced, emergency services calls); observations (e.g. site inspections); analytical results (e.g. field analysis, laboratory analyses, online data streams); experiences (e.g. taste and/or odour); or even, for experienced operators, a feeling that something is wrong (e.g. wildlife behaviour; change in noise level). See [A.2](#) and [A.3](#).

Some event indicators can be common to the water and wastewater functions (e.g. weather reports) but affect the functions in different ways (e.g. increased raw water turbidity versus increased stormwater discharges). Some can involve identical water quality parameters which require different interpretations for water and wastewater functions (e.g. conductivity and turbidity). Some can initially appear unique to that function but, in practice, can impact the other function (e.g. compromise of catchment controls may impact wastewater irrigation options; wastewater treatment failure prior to discharge into a water source upstream of a water supply intake can introduce additional hazards into the water source).

A.2 Potential event indicators — Water

The event indicators listed below are based on common water industry experience and can act as a useful guide to potential inputs to the event detection process. However, the list is not exhaustive. Continual improvement can refine the content to reflect any unusual circumstances to which a water utility is exposed.

The applicability of the following indicators can be evaluated:

- algal growth;
- animals in water supply;
- biological process compromised;
- catchment control compromised;
- data stream from online analysers;
- discoloured water;
- disinfection process compromised;
- flooding;
- illness in user community;
- laboratory report;
- on-site inspection;
- report of asset damage;

- report of chemical spill;
- security alert;
- stakeholder's report;
- taste and odour;
- telemetry alarm;
- threat report;
- water source observation;
- weather report.

A.3 Potential event indicators — Wastewater

The event indicators listed below are based on common water industry experience and can act as a useful guide to potential inputs to event detection. However, the list is not exhaustive. Continual improvement can refine the content to reflect any unusual circumstances to which a water utility is exposed.

The applicability of the following indicators can be evaluated:

- asset damage;
- biological process compromised;
- chemical spill;
- data stream from online analysers;
- digestion process compromised;
- flooding or unusually large flows;
- illness among service users or the community from potential contact with wastewater;
- on-site inspection;
- laboratory report;
- odour;
- security alert;
- sludge disposal route compromised;
- stakeholder's report;
- telemetry alarm;
- threat report;
- unusual object(s) in effluent;
- unusually coloured effluent;
- wastewater discharge observation;
- weather report.

A.4 Examples of detection methodologies, monitoring, processes and test methods

A.4.1 Examples primarily for drinking water

A.4.1.1 General

There are a number of instruments and measurement methods that can provide useful information in event detection. The following examples are not exhaustive and others could be used.

A.4.1.2 Toxicity monitoring

The purpose of a toxicity monitoring system is not to detect each chemical substance, but to monitor the safety of drinking water in a holistic manner. Continuous biological monitoring enables rapid detection of toxic substances in water and can provide a real-time, online, early warning of contamination.

Toxicity is the ability of a substance to cause a living organism to undergo adverse effects upon exposure. These effects can include negative impacts on survival, growth, behaviour and reproduction. Toxicity tests are an attempt to measure toxicity in a sample by analysing the results that exposure produces on standard test organisms.

Toxicity testing in the realm of event detection can be a useful tool due to its ability to detect a wide variety of potential hazards. A variety of organism-based, enzyme system and other toxicity measuring systems are available.

- Toxicity tests are fairly adept at detecting chemical toxins, but they are, for the most part, ineffective against biological agents such as bacteria and viruses.
- Organism maintenance can be problematic.
- All toxicity-testing methods require knowledge of a baseline. Determining what the baseline is so that deviations can be detected requires time and effort.
- Some toxicity methods can be too sensitive when testing in the drinking water distribution network. Water treatment chemicals or simply common constituents of drinking water, such as trace metals that are not toxic to humans, can adversely affect them.
- The variable environment at the site of monitoring can be problematic in toxicity monitoring.
- Toxicity tests can be difficult to interpret.

A.4.1.3 Bulk parameter monitoring

Bulk parameter monitoring is the method of monitoring a number of common event parameters and then looking for anomalies that can be indicative of an event. These measurements can be compiled in the lab, in the field or with online instrumentation. A variety of instrument manufacturers have developed multiple-parameter performance monitors for both source water and water in the drinking water system. These systems encompass a diverse selection of different sensors and can be tailored to meet monitoring needs. Locally developed systems comprised of a few or many different sensors can be constructed and can be used in conjunction with results from other monitoring systems in an event detection system.

Decisions on which parameters to include in such a system are a matter of individual water utility choice. Parameters that are commonly part of such systems can include disinfectant residual (chlorine, where appropriate), pH, conductivity, turbidity and TOC (either conventional digestion or UV methods). Other parameters can be included if they fit the needs and capabilities of the water utility and address their concerns.

A.4.1.4 Gas chromatography

Gas chromatography methods are traditionally thought of as laboratory methods. Various manufacturers have modified gas chromatography methods to be online tools that work in a batch mode. Small, portable, gas chromatography methods are also available. One of the main benefits of this type of method is that, unlike toxicity and bulk parameter monitoring, it is not inferential in nature, but gives a true identification of the compounds present.

A drawback to this technique is the limited scope of compounds that are detected. Only volatile organics are amenable to being analysed by this method.

A.4.1.5 Ultraviolet absorbance and fluorescence

The tendency of various compounds to absorb light in the UV spectrum, and for some materials to fluoresce when exposed to this light, can be utilized as a detection mechanism.

Simple measurements of absorbance and fluorescence can be used, but various manufacturers have developed instruments that use algorithms to interpret the incoming absorption spectra to determine when a contaminant is present. These systems can detect organics that have an absorption or fluorescence signal in the wavelength range being monitored. The identification of a single substance or group of substances is limited to those that are detectable in the monitored spectrum and implemented in the set-up procedure.

A.4.1.6 Optical methods

There are a number of optical measurements based on particle counting, index of refraction, intrinsic fluorescence and other methods that can be utilized to characterize potential contaminants in the drinking water system. Many of these methods require the utilization of fluorescent labels to detect the various pathogens. Others utilize the intrinsic fluorescence of biological organisms. These methods appear to have some efficacy in monitoring water for contaminants. However, low levels of contamination may be missed when utilizing these methods for biological contamination due to the very small path capable of being monitored and the fact that only a small sample is being analysed.

A.4.1.7 Tests for microbial indicators of contamination

Many relevant authorities require the monitoring of indicators of microbial contamination. These tests can include tests for faecal indicators such as total coliforms, *E. coli*, Coliphage, hydrogen-sulfide-producing bacteria; total bacteria counts via heterotrophic plate counts and other methods; as well as tests for specific pathogens such as cryptosporidium and giardia. The methodologies to be used for these tests are often specified by the relevant authority, as are the actions required when such a test gives positive results. Tests for microbial contamination can either result in a simple presence/absence outcome or in an enumeration through a "most probable number" or "direct count" methodology. Many microbial tests, from a regulatory standpoint, are commonly evaluated on a presence/absence basis and require little statistical manipulation to recognize when a problem occurs and action is required. These tests can be a good indicator of a breakdown in the treatment train. It should be noted that most of these tests take some time to perform (up to several days) depending upon the method used and, as such, they are a lagging indicator of any potential problems.

A.4.1.8 Tests for specific chemicals or pathogens

There are a number of individual analytical methods and techniques available for measuring specific contaminants. These methods are often available either in online versions or as field or laboratory methods. Tests for individual contaminants are restricted to detecting the analyte being measured and would miss other contaminants. However, they are useful when the chances of the water being contaminated with a specific compound are high. For example, it can make sense to measure for petroleum hydrocarbons if there is an oil refinery near a water intake.

A.4.1.9 Syndromic surveillance

Syndromic surveillance is a concept that comes originally from the medical profession. In the medical case, the term refers to surveillance using health-related data that precede diagnosis and signal a sufficient probability of a case or an outbreak to warrant further public health response. Though historically syndromic surveillance has been utilized to target investigation of potential cases in a disease outbreak, its utility for detecting outbreaks associated with contamination is beginning to be utilized. As it pertains to water, syndromic surveillance is the concept of using data analysis to monitor a number of non-specific indicators of a possible event. These include such data as hospital admissions, emergency calls, pharmacy sales and complaints to the utility. These data streams are directed to a centralized repository or computing system that correlates all of the factors and extrapolates the probability of an event.

While much useful information could theoretically be extrapolated from such a monitoring programme, there are some caveats:

- Syndromic surveillance, by its very nature, is directed towards thwarting naturally occurring outbreaks of disease. The results of an intentional contamination event using water as a vector may spread quickly enough to make detection by such a mode redundant and unnecessary.
- The reliance on such a mode of detection delays the reporting of the hypothetical event until actual exposures have occurred. This may be adequate in cases of a bacterial contaminant that may have a fairly long incubation period and can be treated with antibiotics. It may be inadequate in the case of a chemical or biotoxin contamination event. By the time such an event is detected via syndromic surveillance it may be too late for an effective response.

Syndromic surveillance does have merit as a supplement to, and a check on, other kinds of monitoring.

A.4.2 Examples primarily for wastewater

A.4.2.1 General

There are a number of instruments and measurement methods that can be especially useful in the monitoring of wastewater for potential events. The following examples of such measurements are not exhaustive and others could be used. Some of these methods can also find use in the monitoring of drinking water.

A.4.2.2 Flow

There are a number of methods available for measuring flow. Due to the corrosive and fouling nature of wastewater, methods that do not require direct contact with the wastewater can have advantages for this type of application. The measurement of flow in the collection system can be important in predicting loading and operation of the treatment plant. Unusual flows can cause problems in the treatment train and require that adjustments be made to prevent damage to the treatment system and the environment.

A.4.2.3 Toxicity

For a general description of toxicity testing see [A.4.1.2](#). As it pertains to wastewater, toxicity testing is not designed to indicate toxicity to the human population but rather to the biomass responsible for breaking down the wastewater's constituents before it is discharged. This being the case, toxicity testing methods that make use of the actual indigenous biomass that is found in a given wastewater treatment facility are the most useful. Other methods that utilize standard organisms may be of some value but are not likely to give the same response as those methods that use the facility's actual biomass. Toxicity testing in wastewater can also be of value in determining the effectiveness of treatment in rendering the final effluent non-toxic before discharge. In this case, methods other than those that use indigenous biomass can be a better choice as the goal is to determine toxicity to the environment.

A.4.2.4 Dissolved oxygen (DO)

Dissolved oxygen (DO) levels are important in maintaining the optimum conditions for the biological treatment of wastewater. There are a variety of methods that can be used to measure this parameter, including spectrophotometric, titrimetric, galvanic probe, polarographic sensor and luminescent probe methods. All have their individual advantages and disadvantages.

A.4.2.5 Respirometry

Respirometry is the measurement of bacterial respiration in an enclosed sample. It basically measures the kinetics of oxygen utilization in the wastewater treatment process and can be useful in process control and detecting abnormal events. Both online grab sample methods and laboratory procedures are available. A subset of respirometry is the oxygen uptake rate (OUR) test.

OUR is an important wastewater control parameter for the activated sludge process carried out using a DO analyser that measures the amount of oxygen used up by the microorganisms — expressed in unit time of mg/l (ppm) per hour. Basically, knowing the OUR should provide information that reflects how active the microbes are in the aeration tank and whether they are consuming the oxygen provided for them to biodegrade the organic matter in the influent. OUR is usually converted to specific oxygen uptake rate (SOUR) so that this will give a more accurate representation based on the concentration of microorganisms in the sludge culture. SOUR can be obtained by simply dividing OUR with mixed liquor suspended solids (MLSS).

A.4.2.6 Oxidizable material: biological oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC)

The removal of oxidizable materials is one of the major functions of wastewater treatment. Monitoring of both the incoming and outgoing oxidizable material can be an important process control and event detection input in wastewater systems. Traditionally, the biological oxygen demand (BOD) test has been performed to monitor this parameter. Many effluent discharge permits are based around the BOD test. The major drawback for this parameter is that the test relies upon the action of bacteria over a number of days (traditionally 5 days, but it can be up to 30 days to run the test). This time delay makes the use of this parameter problematic in process control and event detection. To help with this time offset, a number of quicker technologies to help estimate oxidizable material are available. The most widely used of these is chemical oxygen demand (COD).

In COD testing, a chemical oxidation that results in a colour change is performed rather than the depletion of oxygen via bacterial action. The test is fairly rapid (about 2 h) and can be fairly easily performed. Another alternative, TOC testing, relies upon the chemical oxidation of all of the organic material present in a sample to CO₂ and the subsequent measurement of the resulting CO₂. In some versions this chemical oxidation is enhanced with exposure to UV light or high temperature. This process is readily available in both online and laboratory versions.

Other methods such as scanning UV fluorescence and adsorption have been developed to estimate the oxidizable materials in a waste stream. These instruments do require some calibration for the individual deployment to get them to correlate well with the other methods of measuring oxidizable material. They are most effective in waste streams that are consistent in nature without any wide variability in the types of organic material that may be present.

A.4.2.7 Nutrients

The control of nutrients in wastewater effluent is quickly increasing in importance. Parameters such as ammonia, total Kjeldahl nitrogen, phosphate and nitrate are being required to be controlled with the goal of preventing environmental damage through eutrophication of receiving water bodies. Online and laboratory methods are available for all of these parameters and can be useful inputs to an event detection system whose task is to keep the system in conformity.

A.4.2.8 Bulk parameter monitoring

There are a wide variety of other parameters that can give valuable information regarding the status of wastewater in wastewater treatment plants and wastewater conveyance systems. These include, but are not limited to, pH, conductivity, temperature, oxidation reduction potential (ORP), hydrogen sulphide and hydrocarbons. These are useful not only for event detection but also for asset protection and process monitoring.

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Annex B (informative)

Influence matrix table (IMT)

B.1 General

An IMT contains suspected connections between event indicators and performance measurements based on scientific knowledge and water industry experience. Continual improvement can refine the content to reflect any unusual, possibly unique, circumstances to which the water utility is exposed.

B.2 IMT structure

There is no preferred format for an IMT.

The IMT should be structured as a list of rules from the most severe at the top to less severe at the bottom. Each rule should be structured as a Boolean rule with several items as the cause and having a result.

NOTE A Boolean rule is mathematical syntax that uses “If... then...” statements in the following (example) form:

If (pH > 9 and free chlorine <0,2 and chlorination state = ON) **then** event type “organic contamination from non-human source” is likely to occur with 90 % confidence.

The formal definition for a Boolean rule is as follows: a list of variables where each variable has several states or values, each of which is examined against a predefined value, returning with a true or false answer.

The Boolean rule is a combination of one or more of these variables in an IF/THEN statement with multiple variables connected by OR/AND/NOT logical relationships.

[Table B.1](#) shows an example of part of an IMT that supports the four example relationships described in [B.3](#).

Table B.1 — Example Boolean rules for an IMT

‘If’ rule	‘Then’ effect
Flood report = ON and algae observed = ON	Turbidity would increase
Odour report = ON and taste report = ON and chemical spill in the vicinity = ON	TOC change from normal ¹
Disinfection process problem = ON and disinfection process not functioning properly = ON and low chlorine alarm = ON	Free chlorine level in water declines to a low level ²
NOTE ‘ON’ indicates sensor alarm; ‘OFF’ indicates no sensor alarm.	
¹ Taste and odour problems are usually caused by organic materials and an increase in TOC would be expected in this case.	
² An indication of a problem in the disinfection process system combined with an indication of a problem in the level of free chlorine in the water implies the latter could be due to a malfunctioning of the dosing system and not due to an intrusion of organic contamination.	

Table B.1 (continued)

'If' rule	'Then' effect
pH low = ON and conductivity high = ON and toxicity high = ON	Heavy metal contamination of the waste stream
If a wastewater system is cross-connected to a drinking water system by mistake	Water temperature could rise Turbidity could increase
If a pipe break occurs in a wastewater system	Sewage level at downstream collection area should decrease relative to the level in similar days.
<p>NOTE 'ON' indicates sensor alarm; 'OFF' indicates no sensor alarm.</p> <p>1 Taste and odour problems are usually caused by organic materials and an increase in TOC would be expected in this case.</p> <p>2 An indication of a problem in the disinfection process system combined with an indication of a problem in the level of free chlorine in the water implies the latter could be due to a malfunctioning of the dosing system and not due to an intrusion of organic contamination.</p>	

B.3 Examples for drinking water and wastewater

B.3.1 Simulation system to predict a water source pollutant's arrival time at an intake

B.3.1.1 General

For the purpose of decision support, a simulation system calculating the pollutant's arrival time at an intake can be used when a water quality event happens in the upper reaches of a catchment, river or aqueduct system. An IMT can be included in the simulation system or can be used by intake facility's operators. [Figure B.1](#) shows an example of such a system.

B.3.1.2 Simulation system principle

When a water quality event occurs significantly upstream of a water supply intake then reports and/or measurements may be obtained. For example, the date, time, place, kind of pollutant, flow and amount of surface water involved. Simulation based on equations for the continuity of an incompressible fluid; flow rate distribution analysis; and pollutant diffusion analysis can be carried out using those reports, measurements, river basin characteristics and the pollutant's diffusion properties.

An IMT that is structured with those reports and/or measurements can be included in the simulation system as part of software. If not included, the IMT can be prepared and used manually by intake facility's operators. As a result, the time to flow down to, and concentration of the pollutant upon arrival at, a downstream intake can be predicted.

B.3.1.3 Simulation system practical use

In the Tokyo Metropolitan Waterworks Bureau, a decision support system (simulator) for a surface water source quality event has been introduced.

The simulator is used to support the decision-making processes leading to outcomes such as the decision to install temporary stop-boards across the drinking water system intakes.

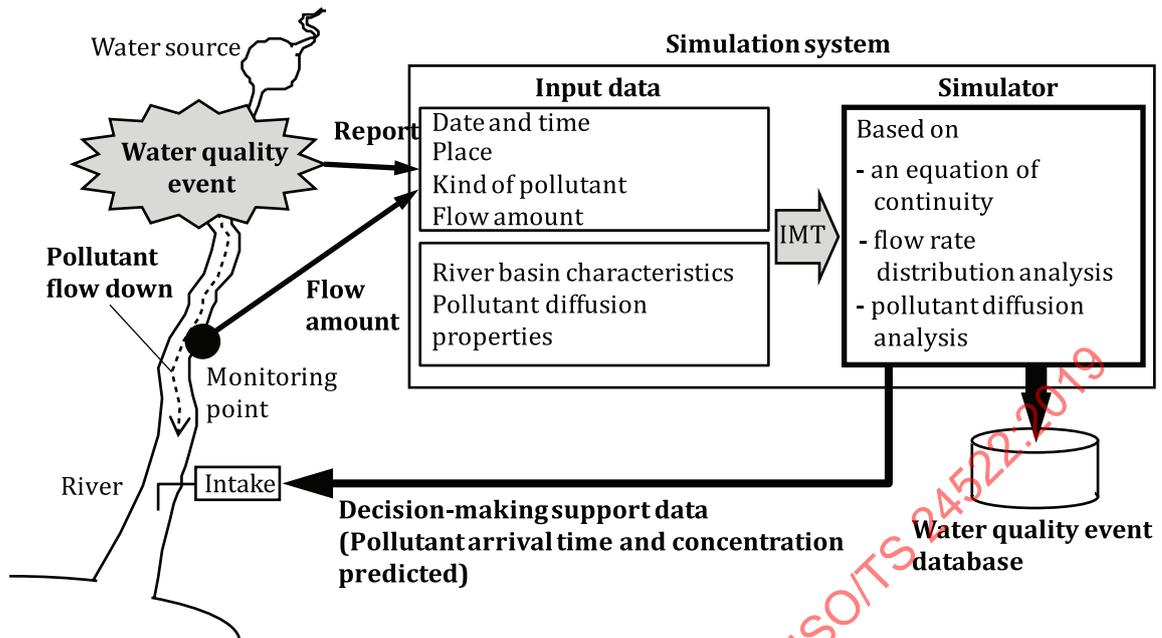


Figure B.1 — Structure of a simulation system to predict a water source pollutant's arrival time at an intake

B.3.2 Simulation system to predict the rainwater inflow amount to a wastewater system

B.3.2.1 General

For the purpose of decision support, a simulation system calculating the inflow amount of rainwater to a wastewater system can be used when an intense rainfall event happens in the catchment. An IMT can be included in the simulation system or can be used by the wastewater system's operators. [Figure B.2](#) shows an example of such a system.

B.3.2.2 Simulation system principle

When an intense rainfall event occurs on the catchment then reports and/or measurements can be obtained. For example, the time, area and amount of rainfall; water levels and flows in the wastewater system. Simulation based on dynamic analysis; hydraulic model; tank modelling; and multiple regression analysis can be carried out using those reports, measurements, catchment data and wastewater system characteristics.

An IMT that is structured with those reports and/or measurements can be included in the simulation system as part of software. If not included, the IMT can be prepared and used manually by the wastewater system's operators. As a result, inflow amount and time of the rainwater's arrival at points within the wastewater system can be predicted.

B.3.2.3 Simulation system practical use

In the Tokyo Metropolitan Government Bureau of Sewerage, a decision support system (simulator) for an intense rainfall event on the catchment has been introduced.

The simulator predicts a sudden inflow of the stormwater to the wastewater system and is used to support the decision-making processes leading to outcomes such as the decision to divert drainage facilities to avoid a flood.

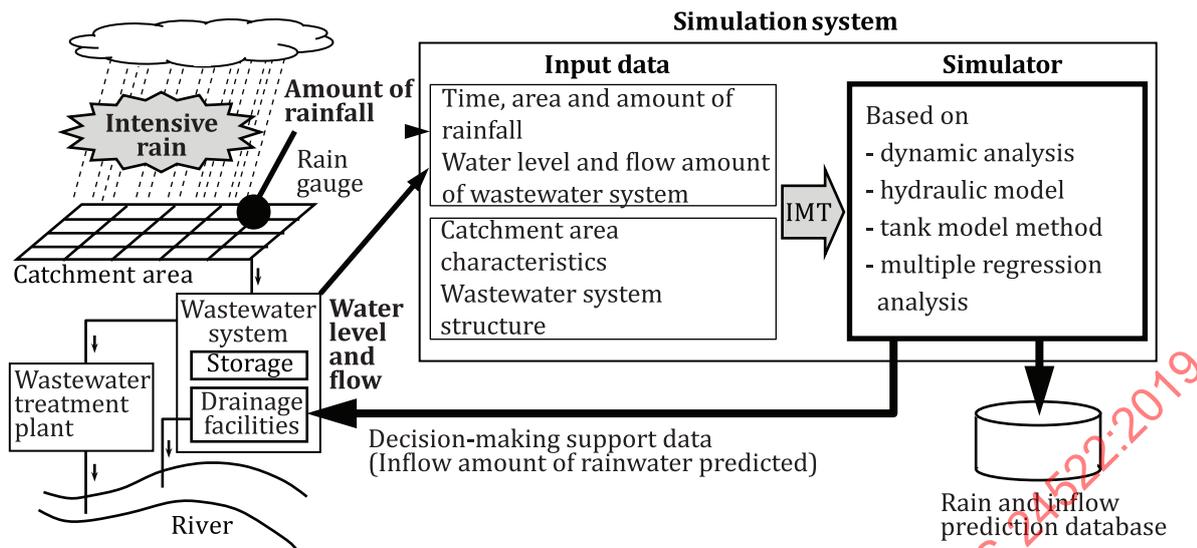


Figure B.2 — Structure of a simulation system to predict the inflow amount of rainwater to a wastewater system

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Annex C (informative)

Event identification table (EIT)

C.1 General

An EIT contains examples of connections between changes in measures resulting from an event's effects that are potentially reflective of actual events in the drinking water or wastewater system. Continual improvement can refine the content to reflect any unusual, possibly unique, circumstances to which the organization is exposed.

Development and use of the EIT can permit both simple and complex calculations. Simple calculations can be performed manually or with an off-line computer. Complex calculations, especially when short-time-intervals monitoring is required, could require an automatic control system.

C.2 EIT structure

There is no preferred format for an EIT.

The EIT should be structured as a list of rules from the most severe at the top to the least severe at the bottom. Each rule should be structured as a Boolean rule with one or more variables as the cause and having a result. Each rule in the EIT can have statistics to indicate how many TP, FP, FN outcomes (see [D.2](#)) have originated from applying the rule in the past.

NOTE True negative (TN) is not listed here as it is the common situation.

[Table C.1](#) shows an example of part of an EIT that supports the preliminary conclusions described in [C.3](#).

Table C.1 — Example for an EIT

‘If’ measurement(s)	‘Then’ event(s)
Turbidity change positive and chlorine change negative and pressure change negative	Pipe break
Turbidity increase and free chlorine decrease and pressure decrease	Cross connection
pH decrease and free chlorine decrease and DO increase and increase in total dissolved solids (TDS)	Pipe corrosion — DO decrease
Unexpected pressure drop and Complaints from customers about low flow	Pipe break
Water consumption in unusual hours	Leakage in pipes
High level of wastewater in collection terminal and complains about odour	Wastewater pipes are blocked

Table C.1 (continued)

'If' measurement(s)	'Then' event(s)
Extreme values of conductivity or pH	Intrusion of industrial wastewater to domestic wastewater system
High level of BOD in water	Intrusion of domestic wastewater system
High level of total suspended solids (TSS)	Failure of the wastewater treatment process
Increased pH and conductivity	Metal contamination
Increased level of oil and TSS	Contamination from food industry
Increased level of soil salinity	Contamination from electronics industry

C.3 Examples of preliminary conclusions drawn

C.3.1 General

The following three examples of preliminary conclusions utilize the knowledge contained in [Table C.1](#) to evaluate relationships between a suspected event's consequences and the potential causative event type.

C.3.2 Example 1

Increase in turbidity; decrease in free chlorine; and decrease in pressure.

Event type: pipe break.

Following a pipe break the water pressure drops as water can flow through the break. Material from outside the pipe can enter the drinking water system. This can cause an increase in turbidity and as a result a decrease in free chlorine which reacts with the organic material that has entered the drinking water system. A decrease in drinking water pressure can also result in back siphoning from pipes connected to the drinking water system, if not protected by a back flow prevention device, leading to contamination of the drinking water system.

C.3.3 Example 2

Decrease in pH; decrease in free chlorine; increase in DO; and increase in TDS.

Event type: pipe corrosion.

An oxidation reaction leads to the formation of rust. This causes a decrease in DO, and a drop in pH, and an increase in solids suspended in the water that remains in the pipeline, with consequent protection of waterborne pathogens and production of discoloured water.

C.3.4 Example 3

Increase in turbidity; decrease in free chlorine; decrease in pressure; and change in temperature.

Event type: cross connection.

Inappropriate cross-connection between drinking water network pipes and other pipes (e.g. gas distribution, wastewater, process water, cooling water) can result in increased turbidity, a decrease in free chlorine and changes in temperature due to the interaction with non-drinking water.

C.4 Measurements of change

C.4.1 General

Measurement(s) of a possible event's effects provides an entry point to consider the EIT's content and consideration of the possible cause of the measurement changes.

While online monitoring provides a real-time continuous data stream to aid in event detection, in most cases, the primary input for event detection will be grab sampling and field or laboratory testing. In cases where the ability to maintain an online programme is limited by environmental, financial, technological or human resource constraints, a programme of manual sampling and testing can represent the only viable source of performance data input for event detection.

C.4.2 Manual sampling versus automatic sampling

An analysis programme can rely on samples that have been taken either manually or via the utilization of automatic samplers.

Automatic samplers can be programmed to take either single samples or composite samples. There are advantages to each.

In composite samples, the number of analyses that need to be conducted is decreased, but the samples offer no insights as to the timing of an event. Discrete single samples can determine the timing of events but require more testing resources. Samplers can be programmed to take samples at preset intervals or when they are triggered by events such as water quality changes or remote signalling.

As manual sampling is often the only recourse due to various constraints, it is advisable to conduct it in a consistent manner, whether that sampling is routine or initiated by conditions.

C.4.3 Site selection

The selection of sampling sites that give an adequate picture of the monitored system is crucial to the success of a programme of analysis used for event detection.

It is advisable to choose sampling sites based on knowledge of the system being monitored. Computer programmes that utilize a model of the connections and flows found in a system are available to help facilitate site selection.

If no such models are available, knowledge as to the location of key nodes (e.g. major pipes, water storage units, pumping points), critical infrastructure (e.g. hospitals, police stations) and high-value potential targets (e.g. schools, densely populated areas, government buildings, military installations) can be used to guide site selection.

Other important factors include access at all times and under all environmental conditions to the sampling sites; coverage and representativeness of a wide area from a single sampling point; and balancing of the number of sites being monitored based on budgetary and perceived risk concerns.

C.4.4 Frequency of monitoring

As a general rule, the more frequently a system can be monitored the better. As the purpose of event detection is to reveal rare transient events, continuous monitoring is the ideal scenario.

Where continuous online monitoring is impractical, reliance on grab sampling and testing will necessarily make it more difficult to detect such events.

The more often a system can be sampled, the more likely it is for a given event to be detected. However, for efficiency, the goal should be to sample only as often as is practical to detect the change, given resource constraints and the nature of the parameter being measured.

C.4.5 Importance of baseline

Water conditions in most systems are not static. When monitoring water quality parameters for change, it is imperative that a baseline be established from which to judge the magnitude and importance of any changes that can occur.

In baseline development, it is advisable to take into account changes that are normal for a given system and include an adequate database to encompass changes that occur on an hourly, daily, weekly or seasonal basis.

It is advisable to establish baseline development on the same sampling protocols and analysis techniques as the envisioned monitoring programme. This way, the water utility will understand the variability found under normal operating conditions for the parameters being monitored. This will eliminate undue concern when variability of a similar nature is detected during routine or triggered monitoring.

The effort involved in developing a baseline from grab sample data can be substantial, but it is critical for a successful programme of event detection based on a grab sampling programme.

The more extensive the baseline development, the more confidence a water utility can have in evaluating deviations from the baseline encountered during a monitoring programme and in its determination of whether or not an event has occurred.

C.4.6 Recommended parameters for drinking water

The monitoring programme needs to be based on assessment of likely risk using a detailed understanding of the drinking water system.

There are a number of water quality measures that can be quickly and easily performed to give an indication of potential contamination. Note that these are all inferential measurements that do not directly measure the levels of a specific toxicant in the water but rather attempt to detect changes in water quality parameters that would occur if a toxicant was present.

Not all measures are applicable to all situations. A knowledge as to which parameters are the most important to monitor should be based upon a knowledge of the normal levels of these parameters in the drinking water system and how potential contaminants could affect them. Even simple visual inspection can be a valuable indicator.

Many organizations including the United States Environmental Protection Agency (USEPA) have done extensive research into how various threat agents affect water chemistry. This research has led to a suggested hierarchy of parameter importance.

Chlorine: The simplest and most useful measure of chlorine residual, in drinking water supplies that add chlorine, can react with many types of potential contaminants.

Organic, inorganic and biological compounds can alter chlorine residual levels, while both free and total chlorine levels have been shown to react.

NOTE For many contaminants, total chlorine (monochloramine) reacts more slowly and to a lesser extent than free chlorine, although both measures can have value. Counterintuitively, not all contaminants cause a decrease in chlorine residual. Some can, in fact, make the levels appear to rise unexpectedly.

TOC: According to numerous studies, the second most useful measure is TOC or surrogate measurements such as scanning UV that can indicate TOC levels. These measures can be very useful in detecting organic and biological contaminants.

Various methods of detecting TOC are available. These different methods respond to different compounds in different ways. The user should be aware of these differences.

pH: pH analysis is simple to perform and is useful information on the acid base relationships present in a drinking water system. Many potential contaminants can have a dramatic effect on pH.

Conductivity: Conductivity is a measure of a water sample's ability to conduct a current. It can be correlated to measurements such as salinity and total dissolved solids.

Conductivity is often the only bulk water quality parameter to exhibit a significant change when inorganic salts are the contaminant in question.

Turbidity: Turbidity is a measure of the non-dissolved particulate matter in a water sample. Some metal and organic compounds can increase turbidity when introduced to a drinking water system. Biological materials can also cause turbidity levels to rise.

Toxicity: Toxicity is the ability of a chemical or mixture of chemicals to cause a living organism to undergo adverse effects upon exposure. These effects can include negative impacts on, for example, survival, growth and reproduction.

Toxicity tests are analytical experiments that attempt to detect or quantify toxicity in a sample by measuring the results exposure produces on standard test organisms. These tests use living organisms or enzyme-based systems to determine the toxicity level of a water sample.

There is a wide variety of test organisms in use and they all respond differently to different toxins. Note that baseline development is crucial to understanding changes in the drinking water system when using toxicity measurements.

Other measures: There are a number of other measures that can find use in detecting events. These can include, but are not limited to, indicator bacterial monitoring, ORP, DO, nitrate/nitrite, ammonia, cyanide, acetyl cholinesterase inhibitors, refractive index, colour, temperature, pressure and tests for other specific compounds or pathogens.

Flow and pressure: Flow and pressure are indications of the physical regime of the drinking water system. Normally, unless operational changes are made to the drinking water system, flow and pressure measurements would be steady over a short period. Fluctuation of flow or pressure or a sudden drop of one of them can be indicative of pipe break.

During the night (02:00 am to 05:00 am), flow is supposed to be low. The minimum flow for these hours can be learned over time. Deviation from the minimum value can be indicative of a leakage.

Temperature: This value is fixed on the short run. It fluctuates over day and night and between winter and summer. Sudden change of temperature can be indicative of an intrusion of water from another source, such as wastewater.

C.4.7 Recommended parameters for wastewater

pH: pH is a simple-to-perform analysis that gives useful information on the acid base relationships present in wastewater. Many potential contaminants can have a dramatic effect on pH. Sudden changes in pH can be indicators of industrial or other unusual discharges.

Flow: Flow is easily measured and can give indications of potential problems if flows are either too high or too low for the proper functioning of the treatment process.

Dissolved oxygen (DO): The measurement of DO during the treatment process can indicate problems with nutrient loading or biomass health in the treatment process. Sudden increases in DO can indicate a failure in the biomass, whereas sudden decreases in DO can be indicative of an overloading of the treatment system's capacity.

SOUR: SOUR is an important wastewater control parameter for the activated sludge process and is carried out using a DO analyser that measures the amount of oxygen used up by the microorganisms, expressed in unit time of mg/l (ppm) per hour. Knowing the OUR can indicate how active the microbes are in the aeration tank and whether they are consuming the oxygen provided for them to biodegrade the organic matter in the influent.

Toxicity: Toxicity measurements measure the ability of a substance to adversely affect living organisms. Toxicity measurements of the influent can be valuable in indicating the presence of substances that could disrupt the biological aspects of the treatment process. There are a variety of different organisms that can be used when measuring toxicity, but methods that use the actual biomass from the treatment process being monitored should be used in wastewater applications where this is possible.

Oxygen demand measurements (BOD or COD): BOD is the amount of DO needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at a certain temperature over a specific time period. The term also refers to a chemical procedure for determining this amount. This is not a precise quantitative test, although it is widely used as an indication of the organic quality of water. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C, and is often used as a robust

surrogate of the degree of organic pollution of water. BOD can be used as a gauge of the effectiveness of wastewater treatment plants. BOD is a long test (commonly 5 days) and, as such, is not an ideal early indicator of problems. BOD is similar in function to COD, in that both measure the amount of organic compounds in water. COD is a much more rapid test (2 h) and can be a better input for early warning than BOD. However, COD is less specific, since it measures everything that can be chemically oxidized, rather than just levels of biologically active organic matter.

Other measures: Other parameters can be useful and provide additional information. These include measurement of nutrients such as phosphate, ammonia and nitrogen. Fat, oil and grease can also be valuable to indicate potential clogging, especially in wastewater conveyance systems and wastewater treatment plants.

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Annex D (informative)

Examples of statistical methods for the evaluation of event classification within the EDP

D.1 General

Most events are unrelated to water quality. For example, the measurements associated with the following are not indicative of water quality related events: unreported operational changes; erroneous measurements due to malfunctioning of instruments or calibration defects.

D.2 Types of event

Each event can be classified into one of four different types, as follows:

- **'TRUE POSITIVE' (TP)** — both classifications agree that an alert was justified;
- **'TRUE NEGATIVE' (TN)** — both classifications agree that an alert was not justified;
- **'FALSE POSITIVE' (FP)** — the process-based classification generated a 'SHOULD ALERT' result but the actual classification generated a 'SHOULD NOT ALERT' result;
- **'FALSE NEGATIVE' (FN)** — the process-based classification generated a 'SHOULD NOT ALERT' result but the actual classification generated a 'SHOULD ALERT' result.

D.3 Event identification

D.3.1 General

An event identification method can be described by different levels of sophistication. The following illustrate three levels:

- simple: can be performed manually;
- intermediate: can be done with simple customized available software (e.g. Excel);
- sophisticated: requires dedicated software.

An event would be declared based on a consecutive group of samples if one of the conditions described in [D.3.2](#), [D.3.3](#) and [D.3.4](#) exists. An event would be declared when one of these conditions exists and end when none of them exists.

Each event can be given an event ID regardless of its time span.

D.3.2 Simple level

One or more of the single measurements are either:

- out of regulation limit requiring a comparison of actual field value with predefined limit;
- fixed; or

- violating safety rules defined by the water utility, based on previous knowledge regarding water quality measurements.

D.3.3 Intermediate level

One or more of the measurements are either:

- out of their statistical limits (e.g. average $\pm 3 \times$ standard deviations);

NOTE Required to calculate the average of a list of known values and the standard deviation of the same list, and compare if the actual field value exceeds the limit of average $\pm 3 \times$ standard deviations.

- within 1 % of upper or lower quintiles;

NOTE Requires sorting known historical values and seeking the location of actual field value within this list.

- a rate of change that is abnormal considering its physical or chemical limits, or compared with the average change.

D.3.4 Sophisticated level

One or more of the multiple parameters' measurement combinations are either:

- rare considering their normal frequency in the occurrence of combinations; or
- unusual considering the sequence in which the combinations occur.

D.4 Event classification by similarity

Each drinking water/wastewater event can be classified based on similarity to past events. Classification can be described as one of the following:

- event is similar to past known actual hazardous event;
- event is similar to past known actual non-hazardous event;
- event is not similar to any past event.

Similarity can be defined by the following statistical method.

Assuming all measurements are continuous values, each measurement can only be normalized by the following calculation:

$$\hat{X}_i^t = \frac{X_i^t - X_{\min}}{X_{\max} - X_{\min}}$$

where

\hat{X}_i^t is the normalized value of parameter X , sample i at time t ;

X_i^t is the actual measurement;

X_{\min} is the valid minimum of X ;

X_{\max} is the valid maximum for X .

Once the values of X have been normalized, the similarity between two samples can be calculated by Euclidean distance.

For example:

$$d_E(i, j) = \sqrt[k]{(X_k^i - X_k^j)^2}$$

where

d_E is Euclidean distance;

k is the number of dimensions for each sample;

i and j are indexes of selected samples.

In the case of drinking water, the dimensions can be, for example, pH, free chlorine, conductivity or turbidity. The maximum value of normalized ED is subject to the number of dimensions according to the following rule:

$$\text{Max } ED(k) = \sqrt{k}$$

Thus, given the distribution of Euclidean distance between samples, an abnormal sample can be identified, as demonstrated by the numerical example in [D.5](#).

D.5 Numerical example for similarity calculations

The following numerical example is considered as a sophisticated level of event identification ([D.3](#)).

For raw numerical samples for similarity calculations and raw samples after normalization, see [Table D.1](#) and [Table D.2](#), respectively. The bottom line of [Table D.2](#) shows the centre of gravity of all samples. For the calculation of the Euclidean distance between each sample and between each sample and the centre of gravity, see [Table D.3](#) and [Table D.4](#), respectively. Based on this distance it can be seen that sample 2 and sample 10 are close to the centre of gravity and thus are similar.

Table D.1 — Raw samples

Sample ID	pH	Cl	Conductivity	Turbidity
1	7,21	0,21	201	0,43
2	7,14	0,34	234	0,55
3	7,08	0,32	324	0,34
4	6,98	0,54	265	0,66
5	7,32	0,22	345	0,54
6	7,13	0,18	534	0,34
7	6,99	0,56	190	0,78
8	6,86	0,42	167	0,45
9	6,87	0,33	187	0,34
10	7,01	0,28	256	0,54
min	6,86	0,18	167	0,34
max	7,32	0,56	534	0,78

Table D.2 — Raw samples after normalization

Sample ID	pH	Cl	Conductivity	Turbidity
1	0,76	0,08	0,09	0,20
2	0,61	0,42	0,18	0,48
3	0,48	0,37	0,43	0,00

Table D.2 (continued)

Sample ID	pH	Cl	Conductivity	Turbidity
4	0,26	0,95	0,27	0,73
5	1,00	0,11	0,49	0,45
6	0,59	0,00	1,00	0,00
7	0,28	1,00	0,06	1,00
8	0,00	0,63	0,00	0,25
9	0,02	0,39	0,05	0,00
10	0,33	0,26	0,24	0,45
Min	0,00	0,00	0,00	0,00
Max	1,00	1,00	1,00	1,00
Average	0,43	0,42	0,28	0,36

Table D.3 — Euclidean distance

Sample ID	pH	Cl	Conductivity	Turbidity
1	0,107 8	0,117 0	0,035 7	0,023 2
2	0,031 0	0,000 0	0,009 8	0,014 5
3	0,002 1	0,002 8	0,021 4	0,127 3
4	0,029 5	0,277 0	0,000 2	0,137 2
5	0,321 9	0,099 7	0,041 4	0,009 6
6	0,023 8	0,177 3	0,516 3	0,127 3
7	0,022 5	0,335 2	0,047 9	0,413 7
8	0,187 2	0,044 3	0,079 2	0,011 4
9	0,168 8	0,000 7	0,051 5	0,127 3
10	0,011 3	0,024 9	0,001 5	0,009 6

Table D.4 — Distance of samples from centre of gravity (absolute and relative to max distance)

	Absolute	Relative
Sample ID	0,532 573	0,266 287
1	0,235 158	0,117 579
2	0,391 897	0,195 949
3	0,666 294	0,333 147
4	0,687 485	0,343 743
5	0,919 082	0,459 541
6	0,905 117	0,452 559
7	0,567 545	0,283 773
8	0,590 206	0,295 103
9	0,217 592	0,108 796
10	0	0

NOTE The maximum normalized distance for four dimensions is the square root of 4, i.e. 2.

D.6 Human classification and quality of detection

Based on the Euclidean distance, each new sample is assigned a classification according to the nearest past sample. For example, if sample 7 is similar to a previously classified event which was itself classified

as a true positive, then sample 7 will also be classified as positive. Sample 7 will be classified as a true positive only when authorized personnel have also judged that this is a positive event.

On the other hand, in this instance, a sample at a distance larger than 0,5 from any known sample can be classified as unknown.

The sample classification according to similarity should be approved by a human expert. The expert would tag each classification as true or false. This will yield the four types of events as depicted in [D.2](#).

Given the count of each group, a Kappa statistic should be calculated. The Kappa calculation is given by the following process:

Table D.5 — Event counts by event type

	Expert positive	Expert negative	Total
Model positive	TP	FP	A
Model negative	FN	TN	B
Total	C	D	T

B = Total cases where the model's classification was negative.

D = Total cases where the expert's classification was negative.

$$T = TP + FP + FN + TN$$

where T is the total number of cases.

TP + TN = Total number of cases where model and actual values are the same.

$$M = (TP + TN)/T$$

where M is the observed probability for agreement between model and actual event classification.

A = Number of cases where the model's prediction was positive.

A/T = Probability of a positive prediction by the model.

C = Number of positive events.

C/T = Probability of all positive events.

C/T * A/T = Probability of a random agreement on positive events between prediction and an actual event's classification.

B/T = Probability of a negative prediction by the model.

D/T = Probability of all negative events.

B/T * D/T = Probability of a random agreement on negative events between prediction and an actual event's classification.

$$L = (C/T \times A/T) + (B/T \times D/T)$$

$$\text{Kappa} = M - L/(1 - L)$$

Value of Kappa is between -1 and 1.

Value of 1 means perfect detection.

A value which is closer to 0 means the classification procedure has no relation to the human expert.

In some cases, related to [Table D.5](#), we may value the different “situation” through FP to FN with different weights, for example an FN is 10 times more significant than an FP.

NOTE A value which is closer to 1 means agreement between the classification procedure and the human expert. A value which is close to -1 means that the classification procedure systematically opposes the human expert. In reality Kappa values above 0,75 are considered good detection/prediction.

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Annex E (informative)

Signal measurements' grouping

E.1 General

Signal grouping can be used in order to gather several signals into a single measurement which describes changes in the process being monitored.

The group signal can be used to find out one of the following abnormal measurements:

- Point anomaly: a point value which is rare or violates any engineering rule.
- Contextual anomaly: a point whose value is normal but which is abnormal in the context in which it is introduced.
- Collective anomalies: a set of consecutive measurements which are not likely in the current location.

For further details of the above three types, see Reference [8].

The following are three examples of signal grouping:

- nearest neighbour (E.2);
- local density (E.3);
- numerical prediction (E.4).

E.2 Nearest neighbour

The nearest neighbour (NN) detection algorithm is a method in which at each time frame the average distance to the nearest group of K samples (specifying the group size beforehand) is measured. Normally, changes in water quality occur slowly. Thus, the above average distance changes occur slowly. When contamination occurs, samples within the same time frame can vary from one another. Thus the nearest neighbour samples can differ and the average distance to the current location of the (same sized) group can be drastically different.

An example for such calculation can be based on the samples given in [Annex D, Table D.1](#). Assuming that samples are taken in the same time frame from which sample 1 was taken, all other samples will be similar to sample 1 and thus have a very small Euclidean distance from one another.

If some contamination pollutes the water, the samples within the same time frame will be different and the Euclidean distance between samples will be larger than normal.

The single grouping measurement in this case is the average Euclidean distance between samples.

An example of such grouping could be an algorithm such as that shown in Reference [2].

E.3 Local density

A local density (LD) detection algorithm is an algorithm that counts the number of historical samples located in a given cell. A cell is a logical region of data that conforms with a Boolean rule, an example of which is as follows:

If:

- pH > 6,5 and pH < 7,0; and
- conductivity > 200 and conductivity < 250; and
- turbidity > 0,5 and turbidity < 0,8;

then:

- the current record is similar to a known event.

Similar cells are defined in order to cover all the working space. For each cell the average number of historical samples is recorded. Then a density profile (i.e. the distribution of counts that can be found in samples from the drinking water system over time) is defined. Statistically, in most cases, this profile includes medium to high density. Cells with low density or zero density are rare. If the measurements reveal a situation where the local measurements of a sample from a drinking water or wastewater system normally display cell densities that are low or none, but are now displaying higher cell densities, most of the time this can indicate an abnormal situation.

The single grouping measurement in this case is the number of historical points in a given cell.

An example of such grouping could be an algorithm such as that shown in References [3] and [4].

E.4 Numerical prediction

A numerical prediction (NP) detection algorithm is a method in which one measurement of water quality is predicted using other water quality measurements. The mathematical relationship between the inputs and the output (TOC in this case) is learned with a standard statistical model. Once a significant statistical model is estimated, this model can be used for event detection.

The statistical model is the output from the NP algorithm. The model is constructed using either a statistical linear or nonlinear least square model. For this purpose, several hundreds of records are taken. Each group of records will contain a number of variables (each with individual time stamps). One of these variables will be dependent upon the remaining variables within the group. Numerical modelling is used to establish the relationship between the non-dependent variables and the dependent variable. Then the values of the current non-dependent variables are used to predict the value of the dependent variable. If the difference between this predicted value and the actual value of the dependent variable is greater than normal it implies that the current situation is an event.

For example, TOC is predicted using other measurements such as pH, free chlorine, conductivity and temperature (referred to as inputs).

In a linear or nonlinear regression, the TOC value is predicted using pH, free chlorine, conductivity and temperature values. The difference between the actual TOC value and the predicted value is compared. If the difference for a specific record related to a specific time stamp is more than two standard deviations away from the actual TOC measurements, this record is assumed as a rare record.

The event detection is performed by real-time TOC prediction, using the actual inputs measured. This prediction is compared with the actual measurement of TOC. The difference between these two measurements is expected to be between the borders of the root mean square error of the prediction model. If not, then some other input (which was not included in the original model) is affecting the actual measurement of the TOC.

If different types of model outputs (e.g. TOC, DOC, free chlorine) are used, different types of contamination can be detected.

The single grouping measurement in this case is the difference between the actual and predicted value of a numerical model.

An example of a linear prediction model for such an algorithm can be found in Reference [5].

Annex F (informative)

Verifying the EDP's response to potential types of events

F.1 The importance of verification testing

After implementing an EDP it is important to verify that it is functioning properly. The verification should include the integrity of all data streams being utilized by the EDP as well as verification of the system's functionality in processing the data and responding in an appropriate manner. This should be done during commissioning and periodically afterwards. Verification should also occur when any major changes are made to the system, or to the data streams being utilized as inputs to the system, to ensure that the system continues to function as designed and its ability to respond to events has not been compromised. This is true of EDPs that use advanced algorithms as well as simple statistics-based/manual systems.

There are two main methods of verification, and each water utility can choose which verification method best suits its own operation.

- Verification through the analysis of artificial data streams is used primarily to determine if the EDP's internal algorithms and/or functions are performing properly.
- Verification through the introduction of surrogate chemical compounds to the system's sensors is used to verify that the entire system is functioning as designed.

F.2 Verifying the integrity of data streams

F.2.1 General

It is important to verify that the data being provided to the EDP accurately reflects the conditions at the site being measured. How verification of this is handled depends upon whether or not the data stream in question is being provided by traditional online water quality physical and chemical sensors; if it is the result of field or laboratory routine or emergency testing; or if it is more nebulous in nature — such as records of hospital admissions, emergency service calls or customer complaints.

F.2.2 Verifying the integrity of data streams for traditional online water quality physical and chemical sensors

To ensure that the data being received from online instruments is accurate, manufacturers' suggestions for calibration and maintenance should be followed. This usually involves the use of standard calibration solutions.

The actual measurements can also be periodically verified on the sample matrix with independent instrumentation. This is especially true of instrumentation such as ORP sensors that can appear to be calibrated but don't respond to actual water quality changes due to fouling or sensor degradation.

A small subset of the data generated by the sensors should be verified against the data that is fed into the EDP to ensure integrity and proper synchronization of time stamps.

F.2.3 Verifying the integrity of data streams from laboratory or field analysis

Data streams produced via laboratory or field analysis should be generated via standard practices that help to ensure good-quality data generation.