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Drinking water, wastewater and storm water systems and services — Adaptation of water services to climate change impacts —

Part 1: Assessment principles

Services et systèmes d'alimentation en eau potable, d'assainissement et de gestion des eaux pluviales — Adaptation des services d'eau aux impacts du changement climatique —

Partie 1: Principes d'évaluation

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Foreword

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This document was prepared by Technical Committee ISO/TC224, Drinking water, wastewater and stormwater systems and service.

A list of all parts in the ISO 24566 series can be found on the ISO website.

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Introduction

The fact that climate change is occurring is recognized globally. Programmes have been introduced internationally through a number of agreements, commencing in 1992 when the "Earth Summit" produced the United Nations Framework Convention on Climate Change (UNFCCC)[1] as a first step in addressing the climate change problem. Additional agreements have since been reached regarding the responses needed to combat climate change, notably from the 2008 Kyoto Accord[2] to the 2015 Paris Accord of Climate Change.[3] Climate change is the defining issue of the age.

Scientific investigation and confirmation of climate change has been led by the Intergovernmental Panel on Climate Change (IPCC), established by the World Meteorological Organization (WMO) and United Nations Environment Programme to provide an objective source of scientific information. In 2013 the IPCC provided more clarity about the role of human activities in climate change when it released its Fifth Assessment Report.[3] It is categorical in its conclusion that climate change is real and human activities are the main cause.

From shifting weather patterns that threaten food production to rising sea levels that increase the risk of catastrophic flooding, the impacts of climate change are global in scope and unprecedented in scale. Adapting to these impacts will be more difficult and more costly in future. Climate change is generally described as changes in long-run weather patterns, triggered generally by global warming. These changes result in severe and often unpredictable weather events (e.g. powerful storms, droughts, ice storms, floods) which may be short or long term in their occurrence and local or regional in nature. Their severity deepens: droughts are longer, rainfalls and snowfalls become heavier. These events impact the infrastructures and the operations of water utilities, whether drinking water, wastewater or stormwater systems.

All water system services rely on both natural resources and infrastructure, and regardless of their specific purpose (supply of drinking water, collection and management of wastewater or stormwater) they can be similarly affected by the manifestations of climate change, e.g. sea-level rise, flooding, high winds, excessive snow or rainfalls, droughts.

For example, the need for rapid reaction to flooding due to extreme precipitation (flash floods) has been exacerbated by a large increase in the number of extreme precipitation events, coupled with compaction or degradation of soils, deforestation, loss of ground cover or poor agricultural practices in the watershed. These events have resulted in pluvial flooding in many major cities during the last 10 years. Between now and 2100, flood risk (in terms of expected annual damage) is likely to increase strongly when no adaptive or mitigative measures are taken. The projected increase can be two times for storm surge and almost four to eight times for pluvial flooding.[4] These events can and have affected all types of water utilities.

Other IPCC research reports[3] give warning that many global risks of climate change are concentrated in urban areas. The reports summarized indicate that risks are amplified for those lacking essential infrastructure and services or living in poor-quality housing and exposed areas. The key risks, all of which are identified with high confidence, include severe ill-health and disrupted livelihoods for urban and regional populations due to flooding from a range of sources, including pluvial, fluvial, storm surges and coastal flooding or other consequences of climate change, such as forest or bushfires.

Therefore, climate change adaptation is essential in order to make the service areas more robust for future climate developments and to reduce the risk impacts in this respect. Climate adaptive strategies will influence the development of the urban or regional layout. For flooding issues, these can include either storing higher water volumes or managing water flows. Flow-management techniques include returning stormwater channels to more natural, living streams which slow the flow, increase habitat, provide visual amenity and provide cool spaces. Other strategies the water utility can consider include implementing source control measures or encouraging infiltration or evapotranspiration measures. All of these should be undertaken without endangering other critical functions of the city, notably ease of access for people with disabilities and flow of traffic. In selecting the strategies and adaptations to be implemented, the water service should consider the liveability and public health needs of the community or region. Water is able to be used in smarter and better ways to achieve water utility objectives at the same time as helping the community to adapt to climate change. Also relevant to the management of water utilities is the treatment of water drawn from environmental sources for drinking water purposes, for example runoff into surface water sources or intrusion of salt water into coastal aquifers. Water utilities also need to consider the treatment of stormwater and wastewater prior to discharge into receiving bodies of water to preserve or improve aquatic ecological systems or their potential reuse.

Many adaptive strategies are long-term and potentially very costly initiatives, taking several decades to implement even under the most optimistic circumstances. This requires significant investment and water utilities to work carefully with their stakeholders, customers and communities to determine who pays. It means that water utilities also face critical planning and implementation options. Issues are related to timing as well as speed of delivery and process, leading into decision-making.

There is a need for guidance on the evaluation principles that should be used to assess possible adaptive responses to climate changes that are affecting the effectiveness of the provision of water services. Principle-based guidance can be used to help find the optimum response to the application of scarce investment capital and operating expenditures while meeting social, economic and environmental objectives, as well as other objectives such as shareholder, regulator and customer objectives.

NOTE 1 This was identified by ISO/TC 224 in the development of ISO 24536.

NOTE 2 The subject of climate change has also been considered by CEN in respect to both services and products. See CEN-CENELEC Guide 32.[36]

Since these responses involve public investment funds and operating costs, the applied funds should be well-managed and accountable to the public. Investments in private systems should equally be well-managed and accountable to the investors. In either situation, the careful and consistent assessment of the impacts and effects of climate change should be identified, discussed and set out in a way that enables them to be standardized for common application in all aspects of response planning and implementation

The World Bank has estimated that, globally, almost USD 3 trillion is needed just to meet Sustainable Development Goal (SDG) 6 – Ensure availability and sustainable management of water and sanitation for all.[5] This does not account for adapting existing infrastructure to climate change.

Evaluation principles for assessing possible adaptation responses can and should be identified, discussed and set out. Standardization of these principles will enable them to become commonly available for application in all circumstances.

Standardization of these principles will also facilitate the achievement of sound investments in a transparent manner by decision-makers and provide confidence to stakeholders, whether of public or private water systems.

Drinking water, wastewater and storm water systems and services — Adaptation of water services to climate change impacts —

Part 1: Assessment principles

1 Scope

This document identifies and sets out principles for integrating climate change impacts into the planning and design activities of water utilities for the provision of water services. It also includes methodologies to assess the principles in the context of climate change and to provide examples of adaptations made.

NOTE Discussion of impacts and strategies for responses for stormwater, drinking water and wastewater utilities are intended to be set out in ISO 24566-2:—[1], ISO 24566-3:—[2] and ISO 24566-4:—[3], respectively, with examples of adaptations that have been made.

2 Normative references

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

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

3 Terms and definitions

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

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

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

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

3.1
acute
immediate or short-term consequences

Note 1 to entry: Adapted from ISO 19869:2019, 3.5.1, "acute hazard".

1) Under preparation. Stage at the time of publication: ISO/DIS 24566-2:2023.

2) Under preparation. Stage at the time of publication: ISO/CD 24566-3:2023.

3) Under preparation. Stage at the time of publication: ISO/CD 24566-4:2023.

3.2
adaptation to climate change
DEPRECATED: climate change adaptation
process of adjustment to actual or expected *climate* (3.4) and its effects

Note 1 to entry: In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.

Note 2 to entry: In some natural systems, human intervention can facilitate adjustment to expected climate and its effects.

Note 3 to entry: Adaptations to *climate change* (3.5) can be of a temporary or short-term nature, intended to respond only to the event in question. Such limitations can be repeated should that event reoccur.

[SOURCE: ISO 14090:2019, 3.1, modified — Note 3 to entry has been added.]

3.3
chronic
continuing over a long time period or recurring at low levels frequently

[SOURCE: ISO 26367-2:2017, 3.2, modified — "generally used in reference to human health effects" removed from the definition.]

3.4
climate
statistical description of weather in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years

Note 1 to entry: The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization.

Note 2 to entry: The relevant quantities are most often near-surface variables such as temperature, precipitation and wind.

[SOURCE: ISO 14090:2019, 3.4]

3.5
climate change
change in *climate* (3.4) that persists for an extended period, typically decades or longer

Note 1 to entry: Change in climate can be identified, for example by using statistical tests, by changes in the mean and/or the variability of its properties.

Note 2 to entry: Climate change might be due to natural processes, internal to the climate system, or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

[SOURCE: ISO 14090:2019, 3.5, modified — Note 1 to entry has been revised.]

3.6
governance
system of directing and controlling

[SOURCE: ISO/IEC 38500:2015, 2.8]

3.7
hazard
potential source of harm

Note 1 to entry: The potential for harm can be in terms of loss of life, injury or other health *impacts* (3.8), as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Note 2 to entry: In this document, the term usually refers to *climate*-related (3.4) physical events or trends or their physical impacts.

Note 3 to entry: Hazard comprises slow-onset developments (e.g. rising temperatures over the long term) as well as rapidly developing climatic extremes (e.g. a heatwave or landslide) or increased variability.

[SOURCE: ISO 14090:2019, 3.7]

3.8
impact
effect on natural and human systems

Note 1 to entry: In the context of *climate change* (3.5), the term "impact" is used primarily to refer to the effects on natural and human systems of extreme weather and *climate* (3.4) events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructures due to the interaction of climate change or hazardous climate events occurring within a specific time period and the *vulnerability* (3.14) of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts and sea level rise, are a subset of impacts called "physical impacts".

Note 2 to entry: Impacts on services and infrastructures (see Note 1 to entry) can include effects on operations.

[SOURCE: ISO 14090:2019, 3.8, modified — Note 2 to entry has been added.]

3.9
mitigation
human intervention to reduce Green House Gas (GHG) emissions or enhance GHG removals

[SOURCE: ISO Guide 84:2020, 3.1.4]

3.10
risk
combination of the probability of occurrence of harm and the severity of that harm

[SOURCE: ISO/IEC Guide 51:2014, 3.9, modified — Note 1 to entry has been removed.]

3.11
service area
local geographic area where an organization has the legal or contractual responsibility to provide a service

Note 1 to entry: The service area can be established, for example, by political boundaries (e.g. citywide utility); by legislative action (e.g. formation of a utility district); or by interjurisdictional agreements (e.g. intercity agreements to provide wastewater services)

[SOURCE: ISO 24513:2019, 3.3.9]

3.12
strategy
organization's approach to achieving its objectives

[SOURCE: ISO 30400:2022, 3.1.6, modified — "organization's" has been added at the start of the definition.]

3.13
sustainability
state of the global system, including environmental, social and economic aspects, in which the needs of the present are met without compromising the ability of future generations to meet their own needs

Note 1 to entry: The environmental, social and economic aspects interact, are interdependent and are often referred to as the three dimensions of sustainability.

Note 2 to entry: To achieve sustainability, the economy needs to comply with social and environmental needs.

Note 3 to entry: Sustainability is the goal of sustainable development.

[SOURCE: ISO Guide 82:2019, 3.1, modified — New Note 2 to entry has been added, the previous Note 2 to entry has been relabelled as Note 3 to entry.]

3.14
vulnerability
propensity or predisposition to be adversely affected

Note 1 to entry: Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of a capacity to cope and adapt.

[SOURCE: ISO 14090:2019, 3.15]

4 Objectives

The careful and consistent consideration of climate change is essential for water services, whether it is for infrastructure rehabilitation, construction or operational practices. The selection of a response to the impacts of climate change should follow the assessment of the likely efficacy of the response alternatives and their potential impacts on the socio-economic objectives of the utility.

The primary objective of this document is to set out the principles for making such assessments, which should lead to selecting the optimal response approach to the climate change in question. The process should follow the principles set out in ISO 14090. An additional objective of this document is to help to guide water utilities to develop appropriate and timely climate change adaptation responses that suit their context. Examples of such responses include:

— ensuring the delivery of best practices for water system infrastructure management through planning, development, innovation and operation;

— integrating urban drainage systems into landscape design as part of the initial design phase;

— implementing water system operating systems and management that are economically and environmentally viable in the long term, including monitoring and early-warning systems;

— enhancing resilience to global warming through adaptive measures, such as creating functional, energy- and water-efficient, low-carbon, climate-resilient water services;

— increasing potential for sustainable land development and management by working with water basin managers and organizations to promote or provide appropriate water services and by-products or infrastructure for flood management for landowners;

— providing treatment of water and wastewater flows for potential reuse to reduce demand and increase reliability of long-term water supplies or to reduce impacts on receiving aquatic ecosystems;

— supporting healthy aquatic ecological systems.

5 Principles for response approaches

The response approach to climate change adaptation should follow the principles set out in ISO 14090, which include:

— change-orientated perspective (preparing, supporting and facilitating organizational changes as necessary at all levels);

— flexibility (continually reviewing, responding and adapting to new conditions, information methods and responses as they emerge);

— mainstreaming and embedding (integrating changes into organizational processes, policies, strategies, plans and procedures, and implementing changes);

— robustness (using appropriate methodological approaches and information sources that are relevant to decisions and actions);

- subsidiarity (empowering delivery of adaptation at the level, scale and degree of competence that will have the greatest effectiveness);
- sustainability (taking into account economic, social and environmental issues equitably and balancing the needs of present and future generations);
- synergy between adaptation and mitigation (undertaking climate change adaptations with a view to minimizing climate change);
- systems thinking (understanding cross-cutting issues by examining internal and external interdependencies and linkages);
- transparency (reports and communications are based on an open, understandable and appropriate presentation of information for all interested parties);
- accountability (acknowledging and assuming responsibility while accepting the need for scrutiny and the need to respond to this scrutiny).

In addition, the response approach should take the following aspects into consideration:

- integrated water management;
- interdisciplinary approach;
- multi-objective approach;
- value engineering to reduce costs and increase effectiveness and benefits.

Following these principles will enable the following functional recommendations to be taken into account.

- The capacity of water systems should allow for foreseeable qualitative and quantitative changes in inflows, source water and demand over the design working life of the water system, including the influence of climate change projections.
- Design criteria for system capacity, reliability and stability should include consideration of climate uncertainty, based on future climate projections. It is recommended that the results of ensemble models be used, forecasting seasonal temperature and precipitation variations into the future (e.g. 50-year projections) and covering the relevant watershed.

Design criteria should be based on local climate data, projections and scenarios based on an ensemble of different climate system models. These should be developed and used to inform climate impact modelling for water services. The data and projections should be based on an agreed, recognized data source, for example the World Meteorological Organization,[6] as modified by locally relevant authorities such as national or regional government agencies. Climate services provide local climate projections online.

These principles are reflected in the decision-making framework set out in Reference [7], which resembles the plan-do-check-act process promoted in ISO 9001 and reflected in all ISO management systems documents.

6 The nature and impacts of climate change

6.1 Nature

6.1.1 General

Classifying the essential characteristics of climate change for the purposes of preparing and implementing responses of either an infrastructural or operational nature for water utilities is complex. This clause sets out a structure that can be useful for water utilities in conducting reviews and formulating plans for responding to climate change impacts. The Intergovernmental Panel on Climate Change has published a number of documents that would be useful adjuncts to this document. Reference [8] is particularly useful. A complicating factor is to determine whether or not the observed changes are the result of slow but continuing trends (i.e. chronic changes and impacts) or occasional but extreme events within the climate patterns (i.e. acute changes and impacts). The changes are often interrelated because climate changes are themselves also interrelated. For example, global warming has the impact of increasing environmental water temperatures and allowing an increasing presence of exotic toxins; equally, it can result in the loss of glaciers and an increase or decrease in water flows, resulting in sea level rises and coastal flooding.

The impacts of climate change (whether chronic or acute) can be structured in the following general pattern of layering under the categories environmental, institutional and social.

6.1.2 Environmental

Examples include changing temperature patterns, changing precipitation patterns resulting in floods and droughts, increasing wind speeds and frequency of severe storm events, and an increasing severity and frequency of bush or forest fires. There are a number of major concerns for water utilities. For drinking water utilities, the major concern is the potential for reduced water inflows to storage facilities or retention areas arising from droughts or the potential excessive inflows affecting the water quality in the facilities or retention areas. For wastewater utilities, especially those with combined sewer systems, the major concern is excessive inflows impacting on the biological treatment systems. For all water utilities, other concerns include the potential for inundation of infrastructure and facilities and damage to pipelines through soil and water movements.

6.1.3 Institutional

Examples include regulatory and policy changes, increased energy costs or disruptions, changing insurance costs and regulations and volatile financial markets. The speed and intensity of adaptation responses can present transition risks to water utilities.

6.1.4 Social

6.1.4.1 Population factors

Key among the social category impact issues are changes to migration patterns and demographics and related water-use patterns. This category also covers the question of interdependencies.

6.1.4.2 Interdependencies

The provision of water services is part of a set of critical infrastructures in every country.[7] It maintains cities, industries and economies. It is intimately and critically linked to the energy grid, to all social services, commerce and food supply. For example:

- The chemical sector provides treatment chemicals for water treatment, but is also dependent on water for the production of chemicals.
- The energy sector supplies energy for water treatment and distribution, but also requires water for some energy production processes.
- Telecommunications rely on water for equipment cooling and facility operations, while the water sector relies on telecommunications for control systems, monitoring systems, internal communications and communications with the general public and emergency responders.
- Transportation is essential for the delivery of chemicals by truck and rail and enables employees in the sector to get to and from work.

6.2 Chronic impacts of climate change

6.2.1 General

There are four chronic impacts of climate change which can be independent of each other or which can contribute to each other. These are:

— rising temperatures, generally considered to be the impact of global warming;

— changing water levels (which can sometimes lead to flooding);

— flooding;

— changing precipitation patterns.

6.2.2 Rising temperatures

Rising temperatures are the principal chronic impact of climate change and are generally considered to result from the continuing impact of global warming. The average temperature of the globe is slowly increasing and will continue to increase over the coming decades.

There are regional variations in the rate of increase in temperature, notably in the Arctic and Antarctic and high mountain ranges with glaciers, where the loss of snow and ice coverage is reducing the amount of reflected solar radiation and exacerbating this loss of snow or ice coverage. The impact of this on Arctic communities is loss of permafrost and soil instability, and in high mountain areas, a reduction in glacial water reserves, increased or decreased potential for water flow, and the creation of glacial lakes, which are considered unstable and can impact on river basin flows. The loss of glaciers in the Antarctic and the loss of sea ice in both regions is resulting in ocean level rise.

Other regions affected by air temperature rises are suffering from increased droughts or changes in precipitation patterns.

Other sub-global impacts of temperature rise include:

— increasing desertification in already stressed areas on all continents;

— changes in ocean currents and temperatures, with consequential impacts on weather patterns;

— changes in precipitation patterns, notably more frequent or extended droughts or rainy seasons;

— changes in atmospheric wind speeds and flows, leading to extreme storm events.

Impacts of rising temperatures on water utilities include the following:[9]

a) Reduced source water quality and quantity due to:

1) reduced oxygen concentrations, release of phosphorus from sediments and altered mixing;

2) increased evaporation;

3) increased occurrence of eutrophication and algae blooms in water bodies;

4) snow and ice cover changes, leading to reduced or earlier peak streamflow and/or extension of low flow periods.

b) Increased water and wastewater treatment challenges, including:

1) increased microbiological activity and risk from new species with changing water temperatures, leading to an increase in disinfection by-product levels;

   2) impact on temperature-related wastewater treatment processes (e.g. reduction of oxygen levels and transfer rates).

c) Increased asset challenges, including:

   1) corrosion of sewers and stormwater pipes;

   2) reduced oxygen content in wastewater effluent receiving waters, leading to additional wastewater treatment requirements.

d) Energy challenges, including:

   1) increased risk of electrical power blackouts or brownouts resulting from competition for available energy supplies;

   2) rationing of electrical energy supplies due to increased use of air conditioning and associated costs and emissions impact;

   3) supply chain supply problems for hydrocarbon energy sources.

e) Health and well-being challenges, such as:

   1) risks to water industry workers' health and lives during heatwave events.

f) Customer challenges, including:

   1) complaints to service providers;

   2) increased demand due to outdoor use during heatwaves;

   3) increased recreation on water reservoirs.

Rising temperatures can be the principal contributor to the following additional chronic impacts.

— competition for power supply between residential demand (air conditioning), industrial demand (keeping factories running) and loss of hydroelectric power generation due to, for example, lower water levels behind dams.

6.2.3 Rising water levels

A significant chronic impact of global warming is the predicted rising of ocean levels, in part from the melting of the Arctic and Antarctic ice formations and in part from the warming of the oceans themselves.

Impacts of rising water levels will be felt by many coastal communities and cities. For coastal communities, an issue that can potentially arise is salt water intrusion in groundwater sources, affecting the use of the source. Similar increases in water levels can be observed on large lakes with impacts on adjacent towns and cities.

Such water level increases are likely to result in chronic flooding problems in low-lying areas of towns and cities or adjacent agricultural areas in the watershed.

6.2.4 Flooding

Where flooding is expected to take place with some frequency (e.g. seasonally or annually), regardless of the level of flooding or if it takes place slowly over long periods which can be projected (e.g. due to rising water levels), the impact should be expected over a given number of years, providing opportunities for long-term adaptation planning. A commonly used measure of chronic flooding is the average recurrence interval (ARI), which is a way of explaining how rare an event is by comparing how often, on average, the particular event of interest has occurred in the past. For example: once a year (ARI: 1:1 year), once a decade (ARI: 1:10 years) or once in 30 years (ARI: 1:30 years).

Flooding events (whether slow water rises or by excessive run-off) merit recognition as a prominent consequence of climate change.

Water service infrastructures (plants and networks) are frequently vulnerable to flooding events; for sewerage works, flooding can lead to contamination of flood water through sewage leaks. Many of the responses are similar, although implementation decisions and timeframes can vary depending on the assessment of needs and benefits. Operational impacts can include the need to disinfect water distribution systems or re-establish biological processes in the wastewater or stormwater treatment facilities.

6.2.5 Changing precipitation

As air temperatures rise, precipitation patterns and levels of precipitation are changing seasonally and regionally and can result in variations in water levels in natural water bodies (either increases or decreases) and in potential losses of infrastructure.

6.3 Impacts on water services

6.3.1 General

Impacts on water services can be both operational and infrastructural. Operational impacts can include changes in treatment processes to respond to changes in water quality, such as increased sedimentation or quantity. Increased precipitation can cause washouts of infrastructure and decreased precipitation can result in stranded infrastructure assets no longer meeting their intended purpose. For water utilities, the three most critical acute climate change impacts are:

— extreme temperatures events;

— extreme precipitation events;

— extreme atmospheric turbulence events.

The duration of these phenomena can be short (from several hours to several days) or long (from several months to several years). The impacts of these events often require immediate short-term responses, while also requiring long-term measures to be planned and implemented.

The response measures required can be operational or infrastructural. Operational impacts can include changes in treatment to deal with variations in water quality, such as increased sedimentation or quantity. An increase in precipitation can lead to washouts of infrastructure, while a decrease in precipitation leads to inefficiency in infrastructure that no longer fulfils its function.

These acute events can lead to flooding, drought and storms of both an extreme and non-extreme nature, which can affect water service infrastructure and operations. Drought can also lead to acute events such as fires, especially in catchments which are heavily forested or otherwise rich in vegetation. These can be local and short-term in nature but are often widespread over larger regions (such as river basins) and longer lasting.

6.3.2 Extreme temperatures

High or extreme temperatures have four likely consequences: fires, droughts, impacts on infrastructure and impacts on worker health and safety. If prolonged, extreme temperatures dry the vegetation in the surrounding watersheds and can lead to forest, bush or grass fires.

A direct consequence of severe fires and impact on the water service is that they can also damage above-ground assets and impact long-term yield through the changes in water consumption associated with developing forests rather than mature forest. Another consequence is that the soil in the burnt areas becomes friable and mixed with ash and will likely be washed off the terrain in the first rains, whether extreme or normal levels of precipitation, thereby potentially contaminating water sources and necessitating mitigative or adaptive measures either operationally or infrastructurally.

The occurrence of extreme temperatures (either heat or cold), which can also shift the continuing temperature ranges experienced, has an impact on infrastructure design, operation, maintenance and repair. Underground infrastructures can be impacted by deepening frost levels or by more frequent freeze-thaw cycles. Crews can suffer heat or cold exhaustion while undertaking repairs or maintenance activities. Changes in the temperature ranges can impact supply or receiving body water quality. Additional treatment of water sources for drinking water supply or of collected waters can be necessary to protect the ability of receiving waters or lands to absorb discharges or to receive treated wastewater or stormwater for irrigation.

6.3.3 Extreme precipitation

Extreme precipitation can refer either to increased precipitation (rainfall, snow storms, ice storms, hail storms) or decreased precipitation (droughts, decreased water flows, lower water levels, less groundwater replenishment, lower water tables).

Impacts on water utilities are likely to include changes in water quality or quantity, potential flooding of infrastructure or loss of access to water sources (lowering of groundwater sources or changes in surface water levels).

While some operational changes can handle the impacts, it is likely that infrastructural changes will be needed for water extraction and supply systems for wastewater collection networks, including in-system storage areas and treatment plants, and for stormwater and flood protection systems. The planning and design of new infrastructure also needs to consider the impact of extreme precipitation.

6.3.4 Extreme turbulence

This condition results in tornados, hurricanes, cyclones and typhoons, and rapid changes in wind direction, which can cause infrastructure destruction and reduced levels of service, either directly or by toppling trees or towers. When coupled with extreme precipitation, this can affect the operations of water system services.

The more frequent and severe occurrences of extreme storm events (hurricanes and typhoons) with impacts on coastal and land communities should be considered. These are often associated with storm surges that can penetrate long distances inland and cover very wide areas, whether seaborne or lake borne.

Both operational and infrastructural changes are likely to be required to address the impact on water utilities. The infrastructure has to be strengthened to resist physical damage from turbulence, including protection from storm surges, perhaps by diking or by relocation. Operational changes can be useful (along with the installation of remote-control systems so that staff are not endangered while still being able to operate the facilities and onsite backup power supplies).

6.3.5 Floods

Flooding events, whether or not caused by the rapid rise in adjacent water levels, merit recognition as a prominent consequence of climate change. The nature of the adaptive responses (short- or long-term) is similar, although implementation timeframes vary depending on the assessment of needs and benefits.

Flooding events can result from extreme precipitation, increased snow melts or extreme coastal storms and storm surges. The reactions to acute flooding events are considered in terms of average recurrence interval (ARI), for example ARI 1:100 years, ARI 1:1 000 years or ARI 1:5 000 years, depending on the degree of risk or hazard.

Impacts on water service infrastructures (plants and networks) are frequent as they are vulnerable to high peak flows requiring more flood space in retention areas or reservoirs, to generalized flooding events, and for sewerage works, flooding events can lead to contamination of flood waters through sewage leaks.

Flooding of upstream agricultural lands can lead to contamination of water sources through the spread of animal manure, which affects drinking water supply services.

6.3.6 Droughts

By their nature, drought events tend to be associated with broad geographical regions; while some can be relatively short-lived (i.e. seasonal), some endure for several years or decades and even lead to desertification of large geographical areas. Dry warm winds can exacerbate the lack of precipitation by increasing the loss of any surface moisture.

The greatest concern to water services from drought is the diminishing inflows to water retention facilities or areas, resulting in decreased water availability, higher use of non-climate-dependent sources and higher costs, lower groundwater reserves from reduced recharge and reduction in water quality from seawater intrusion.

6.3.7 Fires

Forest, bush and grassland fires (whether caused by human intervention or natural causes such as lightning) are associated with droughts. Those occurring in areas surrounding water services are considered acute events. They have severe consequences for the water services as they can affect the service infrastructure, the health and safety of employees, water quality and the capacity of the service to assist other emergency responders (as well as local residents, livestock and wildlife populations). The possibility of limiting access to water service infrastructure during or immediately after fire is important.

The possible consequences of these fires taking place in forests, bushlands and grasslands and the impacts on water utilities occurring from water runoff following rains, include:

— soil and ash sediments entering nearby watercourses, thereby affecting water quality and treatment systems;

— loss of soil in the burnt areas (along with the natural seeds remaining in the soil areas) needed for the natural regrowth of the vegetative cover, thus affecting long-term water retention in the watershed.[9]

6.4 Examples of consequences for water utilities

Depending on the nature of climate change and notwithstanding specific impacts set out in 6.3, the nature of the impact on water utilities can include:

— infrastructural capacity, reliability and stability problems (flow management and storage);

— operational problems arising from changing water source qualities, meeting demands for the provision of treated water for irrigation purposes, managing untreated overflows, achieving process efficacity given changing flows, managing odours and preventing pollution of receiving bodies;

— infrastructure, equipment and property damage;

— droughts (soil moisture deficits resulting in slower catchment response to runoff and therefore lower inflows, and subsoil subsidence and supply or collection system damages) and water scarcity issues resulting in water supply problems (including the need for deeper wells or accessing alternative supply sources);

— freeze or thaw cycles impacting on subsoil conditions and supply or collection system damages;

— building and other above-ground asset damage and losses;

— fires leading to loss of access to infrastructure, run-offs causing water quality issues and health risks to staff;

— water quality issues related to cyanobacteria and algae;

— human thermal conflicts with heat and cold for staff and population.

6.5 Response implications

Some of the responses can involve operational changes during an extreme weather event. Other responses can require adaptive changes in anticipation of long-term climate change conditions, such as higher frequencies of events or longer durations of events beyond the capability to adjust through operational changes. Impacts on and examples of implemented adaptive responses for stormwater, drinking water and wastewater systems are intended to be set out in the other parts of the ISO 24566 series.

7 Adaptation approaches

7.1 General

Responses implemented by water utilities can be either adaptive (i.e. adapting services to the impacts of climate change) or, in some cases, mitigative (i.e. assisting in mitigating climate change, e.g. reducing GHG emissions and therefore the degree of global warming). Both types of change can be either short-term or long-term. Responses will vary depending on the climate change cause and the climate change impact.

7.2 Adaptive responses

7.2.1 Categories

Adaptive responses fall into one of three broad categories: preparatory, short- and long-term adaptive responses and can contribute to:

— responding to the types and impacts of climate change;

— the prevention of global warming (as the cause of climate changes), e.g. reductions in greenhouse gas emissions.

Individual responses for either purpose can fall into either or both categories (preparatory, short- or long-term adaptive categories).

NOTE This document relates mainly to the impacts of climate change on water system design and operations and responses related to the first task (responding to the impacts of climate change).

7.2.2 Preparatory responses

Since climate change is an accepted fact, water services should be preparing to adapt to climate change impacts. Preparatory responses should include:

— developing risk and safety culture within the organization and stakeholders;

— developing and monitoring early warning systems;

— developing risk modelling capability;

— identifying interdependencies with other sectors;

— building redundancy and diversifying supply sources, including backup power;

— undertaking asset adaptations and adaptive pathways planning for different climate scenarios;

— developing, testing and implementing crisis management plans and increasing preparedness for the range of possible actions of urban and regional actors (e.g. communities, public enterprises) before, during and after climate change events;

— protecting receiving bodies of water from pollution (e.g. from industrial areas, fuel tanks, landfill) in case of flooding;

— supporting healthy and resilient communities and ecosystems;

— continuing to support water efficiency and conservation measures;

— building organizational resilience;

— establishing permanent data backup systems outside the risk zones.

7.2.3 Short-term adaptive responses

Short-term adaptive responses tend to involve operational changes or temporary responses during the climate event, for example diverting stormwaters to pre-constructed retention areas such as wetlands or increasing the treatment dosages of chemicals to counter potential pollution issues.

Examples of short-term adaptive responses include:

— reducing water consumption through public information campaigns;

— water loss identification and reduction measures;

— inflow and infiltration identification and reduction in wastewater networks;

— reduction of stormwater flows, including promotion of soil percolation and rainwater reuse measures;

— reviewing and optimizing operations in light of climate change aspects;

— introducing procurement procedures and criteria that promote more efficient electrical and mechanical equipment for achieving greenhouse gas reduction and reduction of climate change impacts;

— converting equipment to alternative or renewable energy;

— reviewing resilience of data systems, including temporary backup systems.

7.2.4 Long-term adaptive responses

Adaptive responses tend to anticipate long-term climate change conditions, such as continuing higher frequencies of events or longer durations of events. These higher-frequency or longer-duration events may not necessarily be impossible to adjust through operational changes. In some cases, operational changes may be enough, but this decision needs to be based on a sound vulnerability assessment of the water system.

Other adaptive responses could require:

— changes to the water system design;

— developing new water sources;

— moving infrastructure to safe locations;

— introducing water efficiency and loss management programmes;

— changes to the infrastructure or treatment processes of a continuing nature.

7.3 Examples

Table 1 provides examples of how responses to a climate change impact can be either a short- or long-term adaptive response, depending on the impact's frequency or scope of consequence.

Table 1 — Examples of short- and long-term adaptive responses depending on the frequency or scope of the impact

Impact	**Short-term adaptive response** (Low frequency, low scope occurrences)	**Long-term adaptive response** (High frequency, high scope of occurrences)
Forest, bush or grassland fires in the watershed.	Conducting preliminary burns to minimize the amount of combustible material in the watershed.	Constructing fire lanes and changing vegetation or land use.
Forest, bush or grassland fires in the watershed leading to soil instability and runoff.	Placing temporary barriers in watershed channels, such as bales of hay to slow or prevent run-off.	Constructing permanent barriers to retain run-off.
Excessive storm water run-off from non-permeable surfaces during extreme precipitation events.	Allowing temporary stormwater bypass to receiving bodies of water and risking contamination of receiving bodies.	Constructing stormwater bio-retention ponds or larger retention infrastructures to allow for treatment before discharge.
Loss of water quality in drinking water sources due to excessive watershed run-off from extreme precipitation.	Stopping intake from water resources if there is backup from another source or there is sufficient water in the distribution reservoir. Increasing coagulants to reduce turbidity and chlorination unless there is a risk of trihalomethane (THM) generation. Issuing "do not use or boil water" orders or distributing bottled or other water meeting water quality standards (see ISO 24527).	Investing in enhanced drinking water treatment systems or opening non-surface-water sources that are protected.
Loss of external power sources due to power-line collapses.	Obtaining temporary power sources such as mobile generators.	Installing alternative backup power systems and using them regularly to ensure operability at any time.
Loss of water source capacity due to drought.	Implementing a water-rationing programme on consumers while providing supplies to essential services.	Installing expanded water purification capacity through such projects as desalination or wastewater recycling.

7.4 Mitigative responses

Water utilities, like all organizations, have a general and sometimes specific responsibility to reduce their contributions to global warming. This can be achieved coincidentally to some of the adaptation responses if those responses provide opportunities for:

— reducing their consumption of hydrocarbon products;

— converting where possible to non-carbon-based energy sources;

— retrofitting buildings;

— adjusting treatment processes;

— adjusting collection and distribution systems;

— introducing smart systems.

8 Adaptive response approaches

8.1 General

In order to facilitate the development, adaptation and sustainability of water utilities in the face of climate change challenges, a systematic evaluation should be undertaken of adaptations proposed based on a standardized set of principles. While the approaches are set out in this clause, further information regarding methodologies for conducting response assessments is set out in Annex A.

8.2 Risk-based approach

Although it is now unequivocal that climate change is occurring, there are various opinions as to its cause and uncertainty about the rate and geographical distribution of the change and the impacts it will have.

As a result, adaptation to climate change involves making decisions in the face of uncertainty. The uncertainty is in the rate and geographical distribution of changes and where modelling is used there are additional uncertainties.

Uncertainties arise from:[7]

— physical risks: impacts on the built environment (gradual onset and extreme);

— transition risks: impacts driven by policy, technology and social responses to the physical risks;

— liability risks: impacts driven by the failure to respond (mitigate or adapt).

The use of a risk-based approach to adaptation allows for uncertainties to be acknowledged and embraced in the decision-making process. Risk assessments should be iterative, as the circumstances of climate change can change and new information can become available, and should take into account the organization’s strategic planning cycle. Risk assessments require:

— consultation with stakeholders, including customers, emergency response agencies, community support agencies, local and regional governments;

— continuous improvement, because climate events can be inconsistent and warning thresholds can change over time depending on the responses made;

— risk context analysis, which requires analysis of time lags, uncertainty and cumulative impacts of events;

— risk analysis, which requires scenario setting and planning techniques;

— screening and evaluation, due to the complexity of cumulative and interdependent relationships.

Vulnerability assessment is an integral part of the risk management process. The assessment should cover present vulnerabilities to the water system (i.e. due to present climate events) and future vulnerabilities based on an assessment of expected future climate change conditions (i.e. rates of change or commencement of climate conditions outside present ranges). The assessments should be communicated with and form a part of financial planning for the service. This should include in particular a discussion on time horizons, as the impacts of climate change are likely to go beyond typical financial planning and investment scenarios for water systems. Vulnerability assessment is an integral part of the risk management process to inform and prioritize the required risk response. Vulnerability assessments can be enhanced by the practice of hazard mapping, for example flooding,[10] sea level rises, temperature changes and wind turbulence patterns.

8.3 Integrating with urban and regional planning activities

Planning, whether urban or regional, often involves many levels of government and organizations, each with their own set of priorities and objectives. The planning activity can include urban planners, land developers, state or local governments and agencies, environmental and conservation groups, as well as social infrastructure services such as telecom, power and gas distributors.

While planning adaptive responses to climate change, water utilities should seek and ensure cooperation to guarantee integration with urban and regional planning.

The planning system should aim to support sustainable outcomes for people and the environment into the future, and in particular:[11]

— to provide for the fair, orderly, economic and sustainable use and development of land, including watersheds;

— to provide for the protection of natural and human-made resources and the maintenance of ecological processes and genetic diversity;

— to secure a pleasant, efficient and safe working, living and recreational environment for all residents and visitors;

— to conserve and enhance those buildings, areas or other places which are of scientific, aesthetic, architectural or historical interest, or otherwise of special cultural value;

— to protect public utilities and other assets and enable the orderly provision and coordination of public utilities and other facilities for the benefit of the community;

— to facilitate development in accordance with the objectives set out in this subclause;

— to balance the present and future interests of all residents.

8.4 Adaptive response contributions to sustainability

Contributions to sustainability objectives typically include actions to:

— develop functional, energy-efficient, low-carbon, climate-resilient cities and regional areas;

— encourage natural resource protection, such as receiving water bodies, clean air and reforestation;

— protect biodiversity.

Blue and green infrastructure (B-GI)[12] can work better, cost less and often be more reliable and provide more benefits than conventional infrastructure. It is considered as an effective approach to countering climate change.[13] There are many benefits from using B-GI, which combines water-related (blue) infrastructure with green-related modifications. These include improved stormwater management and reuse, improved air quality and human thermal comfort, creation of social amenities such as green spaces and recreation, more biodiversity and ecology, carbon reduction or sequestration, cool runoff temperatures, cost reductions, groundwater recharge through increased infiltration and reduced runoff, insulation of buildings, natural evapotranspiration, new jobs and industry, increased property values and rainwater harvesting.

8.5 Response contributions to resilience

Resilience is contextual. Improving resilience in one area can reduce it in another: there are trade-offs and the need to improvise to be considered. For example, having a set of pre-established emergency response plans based on likely adaptation to climate change can fail to take into account climate change impacts that might actually occur, thus rendering the plans invalid. In particular, it requires consideration of the interdependencies between critical infrastructures and cascading impacts that can occur during an event. Resilience includes social and community resilience and requires effective leadership and strategy from a water utility, as well as empowered customers and stakeholders. It also requires the continued provision of core services at a reasonable cost. Resilience encompasses resistance (to a crisis), recovery from the crisis and transformation after a crisis to embrace new opportunities. Managing risks is a resilience challenge.

Resilience encompasses:[7]

- maintaining service delivery;
- ensuring network in a functioning state;
- maintaining interdependencies with critical service areas;
- having crisis teams in place and at the ready;
- managing data and information sources;
- monitoring and improving;
- having safety plans in place and operational;
- ensuring governance structures are effective;
- being aware of innovation;
- promoting internal creative problem-solving.

The adaptation should be resilient in the sense that it will survive and cope with the range of climate change impacts that are both foreseeable and unpredictable. The climate change impacts to be faced by water services will change over time either due to the failure of global warming (climate change) strategies to meet objectives or due to the success of these strategies.

Resilience is more than implementing the right technology or practice to assess and address risks of global warming and associated climate change events. It is an approach that should be part of a coherent and holistic strategy to ensure water system services can continue to meet customer needs. Resilience needs to be built and coordinated at the basin, city and utility levels (at both the leadership and staff levels) to ensure adaptive measures for water systems are effective and integrate with other urban services.[14]

8.6 Key elements of adaptive responses

8.6.1 Whole-business approach

Climate change is affecting the ability to predict future performance based on past performance. Infrastructure designs based on a 1:100 ARI (average recurrence interval) can now need to become 1:50 designs.

NOTE The average recurrence intervals the average time period between floods of a certain size. For example, a 100-year ARI flow will occur on average once every 100 years.

Adaptation to climate change has to become part of ongoing management of existing infrastructure, and improved decision-making has to be developed for new infrastructure. This requires a whole-business approach. Trade-offs need to be considered between developing smarter adaptive measures during the planning and construction stages or adapting progressively during refurbishment and renewal of infrastructure. Understanding the likelihoods of possible impacts is key to achieving the best economic value adaptation to performance and servicing standards.

A system and whole-business approach requires, in particular:

- embedding adaptation to climate change needs into asset management strategies and plans and other related strategies and plans (e.g. energy management plans as energy, water and waste management is interrelated with asset planning, and setting targets and metrics to be achieved);
- managing financial risks, including those identified in the Task Force on Climate-related Financial Disclosures (TCFD) report[15] and liability insurance;

— understanding customers and the community, including their willingness to pay for various adaptive options or measures, taking on equity considerations, adjusting service standards and developing communication or education around climate impacts;

— understanding and embedding regulatory obligations within the adaptation to climate change context;

— establishing redundancies for critical infrastructure to ensure business continuity;

— using consistent risk-assessment frameworks, methodologies and climate scenarios;

— considering network supply system changes and interdependencies, including identifying and pursuing advantageous cross-sectoral partnerships;

— considering communication needs and working to build internal capacity by gaining senior management buy-in and building the capability of staff and managing risks to staff from climate change;

— knowledge-brokering across organizations and with stakeholders, shareholders and customers, particularly around levels of service and trade-offs;

— understanding the role of emerging technology and digital innovation (e.g. smart meters, big data, forecasting and predictive models, remote sensing or monitoring technology).

Assets need to be overdesigned or redesigned to account for future climate conditions.

8.6.2 Management of assets

8.6.2.1 Existing assets

While events resulting from climate change can be generally predictable (i.e. likely to occur), the timing can be uncertain and the magnitude of the change can fluctuate considerably. Rainfall events are predicted to become more severe; indeed, extreme rainfall events beyond expectations have already occurred. Predicting the frequency and magnitude of floods (e.g. 1:100 years or 1:1 000 years) is challenging, but predictions, including the elements of possibility and probability, are necessary. In addition to appropriate early warning capabilities, dedicated crisis management procedures and tools should be implemented to ensure a proper response in the case of such events.

For existing assets, adaptation to climate change is primarily a crisis management situation and, as such, responses can be ad hoc and pragmatic, for example constructing temporary berms around buildings in danger of flooding, acquiring portable generators to ensure key functions continue, and temporarily evacuating staff. In the face of climate change, water utilities should be undertaking vulnerability assessments of their infrastructure, developing risk profiles and registers and beginning to make adaptations. These responses can not necessarily be consistent with long-term responses that might be considered for planned or future assets. Planning and carrying out effective communications with customers and other stakeholders is essential in these situations.

The impact of climate change on existing assets is also an early warning signal which should generate a planning process to modify these assets and make them more resilient.

Guidance for the management of existing assets can be found in the ISO 24516 series.

8.6.2.2 Planned assets

In addition to the system and whole-business approach already mentioned, there is the operational approach, which includes:

— designing using projected future design flows, for example by adjusting historic design flows, which can result in increased or decreased flows and changes to the level of service;

— designing infrastructure for shorter service lives and retrofitting or replacing these when conditions so necessitate;

— allocating land and easements to accommodate infrastructure and controlling the interaction between infrastructure and surrounding development;

— flexible planning and designing using a combination of approaches for different drainage, collection or supply components;

— planning and carrying out effective communications with customers and other stakeholders.

Guidance for the management of planned assets can be found in the ISO 24516 series.

8.7 Long-term economic viability assessment

Many adaptations will involve financial aspects, including avoided costs and avoided damages.

Economic viability assessments measure the likelihood of success (i.e. a positive benefit–cost ratio) of a particular action or set of actions. An assessment of economic viability is an evaluation of the various economic impacts that can result from the implementation of a particular project.

The total cost of the project (both capital and operational costs calculated on a long-term perspective), including societal or community costs, needs to be compared with the economic benefits (including societal or community benefits) achieved. Many societal benefits (e.g. enjoyment from increased access to green or protected habitats) are difficult to quantify in financial terms.

As an additional element of the economic viability assessment, a framework should be established to allocate the costs and the risks (including benefits) among the various stakeholders.

A final element of the assessment is the need to consider intergenerational equity.

8.8 Assessment and monitoring of adaptive responses

Assessment of the adaptive responses needs to be undertaken and monitored over time so that the responses can be adjusted as necessary against changing climate conditions and customer needs.

The comparison (pre-adaptation and post-adaptation) should be through performance indicators, which are the focus of ISO 24510, ISO 24511 and ISO 24512.

A fundamental assessment and monitoring process of the adaptation to climate change scenarios themselves should take place, i.e.:

— What climate change events have occurred and are they stable or changing?

— Are there new vulnerabilities (conduct risk assessments and determine priorities)?

— Have the adaptive measures been effective or should they be changed?

A base for assessment and monitoring of the measures and actions of the water utility should be the service standards established by the utility, as approved by the utility's governing body. The service standards should be the most recent standards established, which then form the baseline for monitoring future performance. They should be developed for any mitigative or adaptive response proposed. Such service standards can include:

— the annual frequency of stormwater flood events;

— the projected duration of a stormwater flood event;

— the maximum population evacuation caused by a stormwater flood event;

— the annual frequency of loss of service in water distribution caused by wind-related power outages;

— the duration of loss of service in water distribution caused by wind-related power outages;

— the maximum population suffering reduction of drinking water distribution due to drought;

— the degree (percentage) of water quality deterioration in water resources caused by rising temperatures;

— the degree (percentage) of water quality deterioration caused by increasing precipitation;

— frequency of insufficient water source and drought caused by decreasing precipitation and snowfall.

These assessment and monitoring activities should be undertaken within the general social and community framework of the health and safety of the affected populations.

Annex B provides a recommended assessment template in Table B.1.

The principle of plan-do-check-act discussed in ISO 9001 should be adhered to.

9 Recommended approach for responses

The future ISO 24566-2, ISO 24566-3 and ISO 24566-4 are intended to address adaptations of water systems to climate change, recommending that a five-step methodology be followed:

1) understand and assess the current situation, vulnerabilities and opportunities;

2) assess future situations and vulnerabilities including awareness and communication;

3) develop adaptative strategy(ies) including a target-setting process;

4) conduct a financial risk assessment; and

5) monitor, review and update.

The documents in the ISO 24566 series note that individual steps may be repeated as necessary in the methodological process.

These documents further recommend that within each of the methodological steps, the following key functions should be considered.

a) Governance: the governance function of the organization can change as a result of the climate change, either because there is an internally recognized need to adjust the governance mechanism or process or because external influences (e.g. senior levels of government) require governance changes.

b) Strategies: the strategies followed by the organization in developing responses can vary depending on the duration and nature of the change and the responses determined to be effective or possible.

c) Risk management: risk management is a function that should be carried out continuously to ensure that risks are managed to acceptable levels.

d) Operation and asset management: operations and asset management should be a continuing function of any organizations especially in the face of changes.

e) Metrics and targets: metrics and targets should always be determined (with levels of confidence around the metrics) in order to determine if responses are effective, and targets should be established for the relevant data in order to determine the success or failure of the response. In this area, performance indicators are very relevant.