BUILDING FLOOD RESILIENCE

WHITEPAPER

OTT HydroMet

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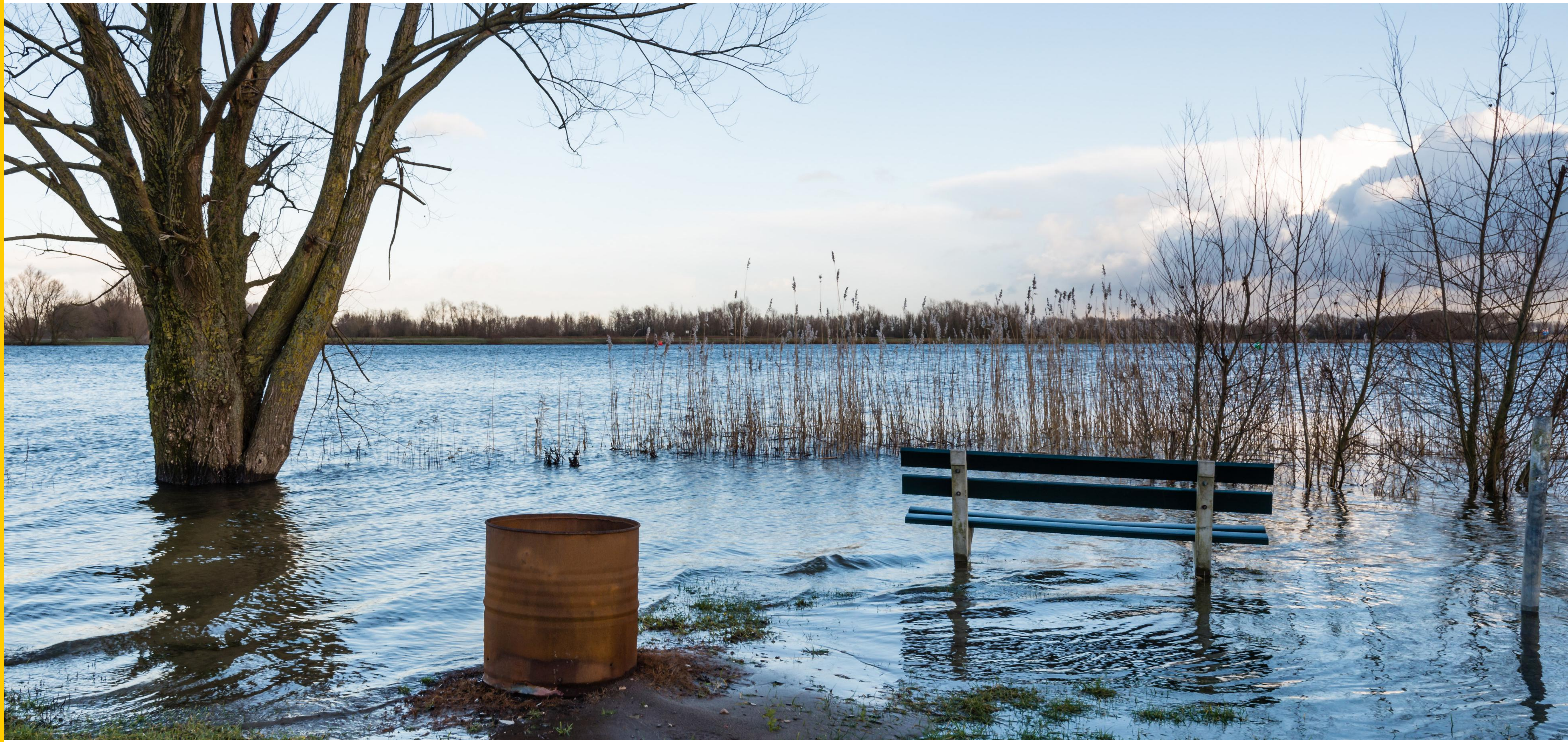
Flooding events have been increasing in both frequency and intensity. Combined with population growth and urbanization, there is a greater urgency for developing effective flood resilience through sustainable development and adaptation to climate change. This whitepaper aims to offer guidance on the development of flood resilience with particular focus on the latest technologies in monitoring and alarm networks.



Background

A report by the National Climate Assessment, which summarizes the impacts of climate change on the United States, says: in many areas, heavy rainfall events have already, and will continue to become more frequent and severe as climate continues to change. It also says: Residents of some coastal cities see their streets flood more regularly during storms and high tides. Inland cities near large rivers also experience more flooding, especially in the Midwest and Northeast. Insurance rates are rising in some vulnerable locations, and insurance is no longer available in others.

Similarly, the European Environment Agency says: experiences and predictions of more floods, droughts, rising sea levels and other extreme weather are driving public bodies across the EU increasingly to take action to adapt to the new climate realities.
Put simply, rising levels of greenhouse gases result in warmer air, which is able to hold more water vapour, thereby causing heavier rainfall events and more frequent instances of flooding. Of course, many other factors affect flood frequency and intensity, but it is clear that as societies become increasingly urbanized, the requirement for effective urban flood resilience is imperative, because this often results in an increase in impervious areas, along with larger populations being exposed to flood risk.

In the UK, a recent report conducted by Risk Management Solutions showed that around £1.1 billion a year of flood damage is being prevented by the current network of river barriers and flood defenses. The report compared simulations of weather events with and without flood defenses, and showed that inland flooding would, on average, cost almost three times more on an annual basis without the defenses – £1.8bn rather than £0.7bn.

According to the United States National Weather Service, property damage from flooding averaged $7.9bn per year in the US, with more than 80 flood fatalities annually, based on a 30-year average. Most of these fatalities result from people driving vehicles into floods or wading in flooded areas. Consequently, most of these deaths are preventable through a combination of earlier and better warnings, and outreach campaigns to make the public more aware of flood risks. Recent developments in communications technologies mean that improved flood warning capability is now possible.

Historically, it was often expensive to build networks to transmit remote hydrometeological data from the field due to upfront set-up costs combined with operation and maintenance costs. Networks had to be restricted to the highest risk areas that were most prone to flooding.

Flooding events were most damaging when there was little or no flood warning, and even when flood conditions arose, the technology may have been unable to monitor in all of the most appropriate locations, and to get that information to where it was needed most.

Introduction

The development of an urban flood resilience strategy demands a holistic approach, based on a number of key issues. These include a thorough assessment of the risks, stakeholder engagement, a risk mitigation plan, the implementation of effective monitoring and alarms, and the establishment of widely accepted and properly resourced flood response procedures and countermeasures.

The key objective is to empower communities with the right data and enable the mitigation of flood risk. **Monitoring data is required to provide timely alarms, but also to enable the identification of flood hotspots and the assessment of mitigation measures.** To achieve this, a network approach is essential; the entire catchment must be monitored at critical locations and data must be collected without or with as few gaps as possible.

The tactical elements of an urban stormwater and flood risk management plan involve a variety of interrelated engineering, environmental and socio-political challenges. The plan should accommodate the future uncertainties associated with extreme weather events and increasingly rapid urbanization. Flexible mitigation measures will be necessary, accommodating traditional grey infrastructure such as pipes, tanks and drainage channels, as well as blue-green solutions such as swales, rain gardens, wetlands, green roofs and restored urban streams. These techniques can provide infiltration, attenuation, and storage mechanisms that mimic the pre-development hydrology of an area.

Developments in monitoring technology will play a vital role; helping to assess existing and future infrastructure, establishing baseline data, and providing a comprehensive monitoring and alarm resource with the ability to disseminate warnings to all stakeholders so that timely and appropriate flood response measures can be implemented.

Monitoring is obviously an essential component of a flood warning system, but it is also important because flood protection measures can be costly, so investment plans should be based on accurate, reliable data. In addition, the availability of data enthuses and empowers communities; helping them to understand the problem and to understand and agree to the costs associated with flood resilience.

A flood monitoring network consists of sensors that can collect data on certain parameters to understand current problem areas and future flood risks. Such parameters can include:

- **Water level/depth**
- **Water flow/discharge**
- **Precipitation/rainfall**
- **Soil moisture**

“...grey infrastructure such as pipes, tanks and drainage channels, as well as blue-green solutions such as swales, rain gardens, wetlands, green roofs and restored urban streams can provide infiltration, attenuation, and storage mechanisms that mimic the pre-development hydrology of an area.”

Risk Assessment

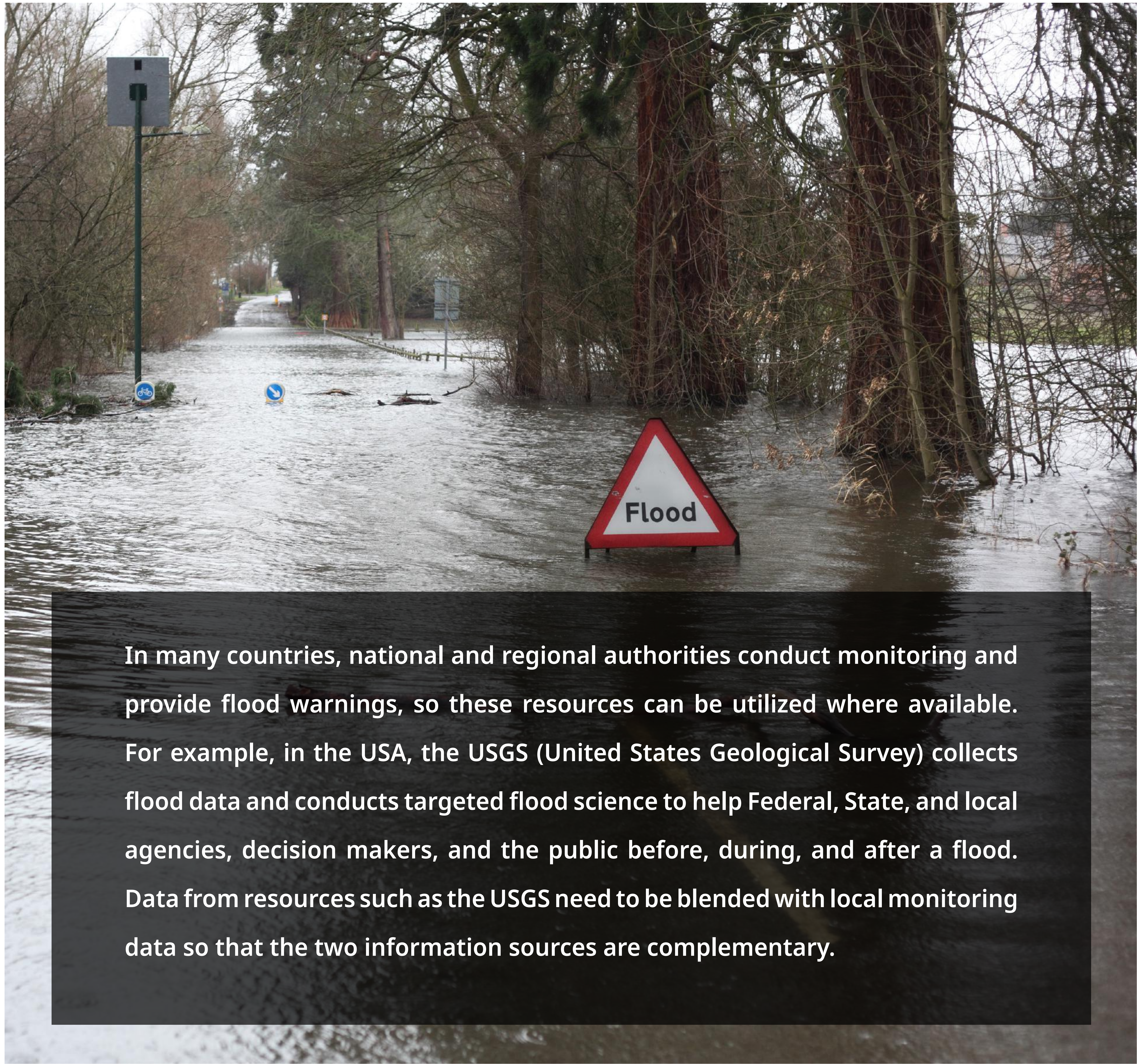
Pre-existing flood risk data and maps are available from a wide variety of sources including federal government, local authorities, the insurance industry, etc. However, in line with the holistic approach mentioned above, any gaps in the spatial and temporal data should be filled in addition to the assessment of any uncertainties. This will facilitate the identification of flood sensitive locations where mitigation measures may be required and where monitoring is most needed. However, the future effects of climate change on severe weather and sea levels, for example, should be taken into consideration. This is because intense rainfall may occur anywhere, so existing maps that identify locations that are sensitive to riverine flooding, for example, may need to be adapted to accommodate new threats.

In addition to drainage and water storage infrastructure, all water resources will need to be assessed including rivers, streams, lakes, canals, reservoirs, etc. A catchment-based approach is generally recommended because this provides a clearer understanding of the factors affecting flooding. It can also help to build a more effective early warning system by installing raingauges with low power telemetry in the catchment that can operate unattended for longer periods in remote locations.

Existing flood related assets will need to be reviewed, including flood relief channels, flood barriers, spillways, weirs, sluices, culverts, outfalls, trash screens, etc. Drainage maps are useful, but are sometimes incomplete and drains need to be regularly checked and maintained.

Towns and cities often represent higher financial risk from flooding due to the density of population and the high value of specific assets. However, the assessment should also include sensitive locations such as major traffic routes, residential areas, schools and hospitals.

Any existing monitoring data will help to establish 'normal' conditions as well as the severity of extreme conditions. This data is extremely useful in assessing the effectiveness of existing assets and in making sure that investments are targeted and appropriate. Any spatial or temporal gaps in the data will undermine the quality of the plan. Going forward, this highlights the importance of establishing a comprehensive network of continuous monitors.

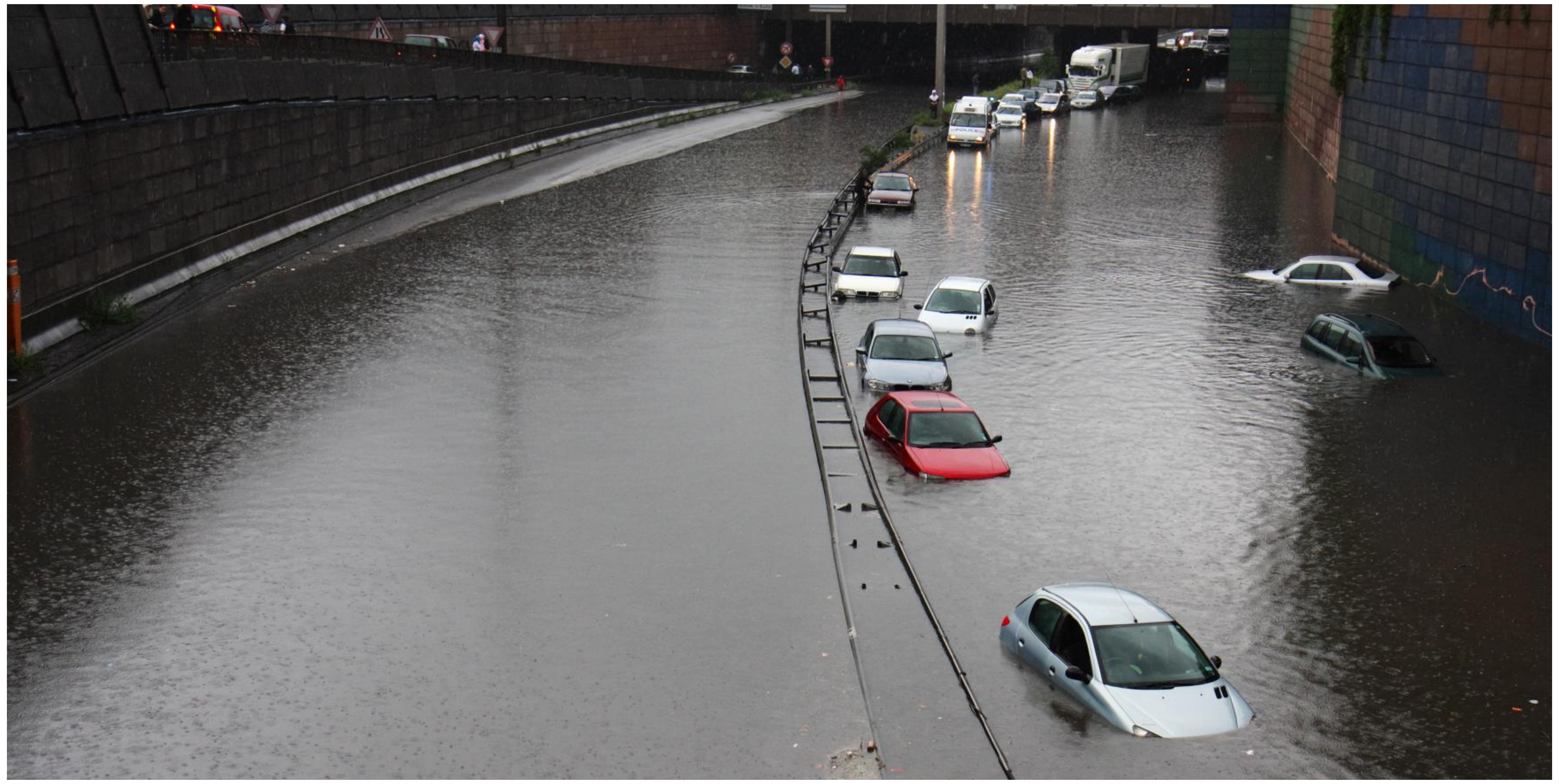


In many countries, national and regional authorities conduct monitoring and provide flood warnings, so these resources can be utilized where available. For example, in the USA, the USGS (United States Geological Survey) collects flood data and conducts targeted flood science to help Federal, State, and local agencies, decision makers, and the public before, during, and after a flood. Data from resources such as the USGS need to be blended with local monitoring data so that the two information sources are complementary.

Planning Flood Resilient Infrastructure

Once the risks have been evaluated and the threats have been categorized according to their severity, it will be necessary to factor in future changes in the climate and in urban development plans – will building take place in flood plains for example, and will developers be obliged to implement flood mitigation measures? Significant uncertainty exists in relation to urban development and climate change, which complicates flood management decisions. Consequently, flexibility is vitally important – developing monitoring systems, measures and flood defenses that can evolve over time.

In the past, cities have chosen structural measures to either safeguard development from an estimated flood risk (through flood defenses such as levees and flood walls) or to direct flood waters away from developed areas (by increasing drainage capacity with pipes, canals, and storage basins). However, structural measures are expensive and are based on finite predictions of risk. They are also usually based on a historical perception of flood risk, and do not accommodate the changing risks from climate change, for example. Additionally, they may result in the transfer of the flood threat downstream.



This grey infrastructure is generally designed to remove water from the point of deposition, often transferring it into watercourses or via sewers to a water treatment facility.

Flood resilience plans therefore also seek to employ non-structural measures such as blue green infrastructure. Blue assets include features such as ponds, swales, wetlands and detention basins. Green infrastructure includes land and plant based ecological treatment systems such as green open space, parks, woodlands, and domestic gardens. Synergies can be created when flood management is integrated within urban design. For example, the greening of cities has amenity value, enhances biodiversity, protects against urban heat islands, and can provide fire breaks.

Both blue and green infrastructure are designed to slow the flow of water, providing water harvesting opportunities and increasing ground infiltration, whilst reducing sediment and contamination in surface water runoff. These blue green assets are examples of sustainable urban drainage systems (SUDS), and are sometimes known as low-impact development or best management practice (BMP).

There are a number of problems associated with grey infrastructure. Firstly, watercourses may not be able to accommodate the flows resulting from extreme weather, which can cause flooding. The overloading of combined sewer overflows, for example, can result in the transfer of raw sewage into rivers. Secondly, the diversion of water away from urban areas reduces the amount of water infiltrating the ground, which lowers groundwater levels and reduces dry weather flows in watercourses. Thirdly, surface water runoff can also contain contaminants such as oil, dissolved salts and metals.

Planning Flood Response

The level of response should be defined by the level of risk, and all stakeholders should be involved in the development of appropriate response procedures for each level. Stakeholder empowerment and mutual ownership of the flood problem are key to the development of an integrated flood management plan. This ensures that monitoring takes place in the right locations; that alarm levels are appropriate; that the right people have access to the data at the right time, and that flood response measures are timely and appropriate.

Waterways obstructed by debris or ice, heavy rain, rising groundwater, snow melt, hurricanes and typhoons can all lead to flash flooding, surface water overflow, riverine flooding, tidal flooding and coastal storm surge. Where there is a potential threat to property or life, communities need to establish emergency response procedures that can be implemented immediately when alarm conditions have been met. However, monitoring and alarm systems should be capable of characterizing the level of risk so that response procedures are appropriate.

A risk based approach will be required to ensure that the emergency response plan protects the most vulnerable people and assets. Importantly, the plan should clearly indicate the procedures that will be implemented at every level of risk.

When there is a low level of risk, and monitoring indicates just the possibility of road overtopping, for example, the local highway authority may be the only organization that requires notification. If the risk is higher and there is potential for some properties to be flooded, a broader group of organisations will require notification to implement flood protection measures and possibly help with evacuation. In extreme cases, when severe flooding is expected and there is imminent danger to life, property, roads and infrastructure, a wider group of organizations and communities will need to be alerted. Important decisions will have to be made as flood risk escalates, and the right alarms can also help determine how quickly these critical stakeholder reactions and responses need to take place. It is therefore vital that those making the decisions are basing them on sound data.

Communication plays a vital role in flood response; not just in the continuous availability of real-time hydrometeorological data, but also in the transfer of important information to response teams and to communities. Communication channels will therefore need to be defined, and will include the provision of monitoring data on websites, direct notifications to response teams and alerts to the public via websites, email, cellphone messaging, the media, social media and general media such as local TV and radio.

Hydrometeorological expertise will be necessary to define an effective monitoring capability that will provide accurate and reliable warnings of flood threat. This will involve a catchment-based approach in which appropriate monitoring locations are identified for the continuous measurement of precipitation, water level and flow. In addition, it will be necessary to log the data and to apply appropriate telemetry so that alarms can be raised and live data can be accessed remotely. Cameras are becoming very popular with both flood authorities and the public - facilitating visual verification of site conditions when the monitoring system raises alarms.

Key steps to follow when developing a flood monitoring plan

1

ASSESS

Determine which purposes the flood monitoring network needs to fulfill. Possible uses are to:

- Assess risk of frequency, duration, and amount of heavy rain or high water.
- Raise alarms for water levels above a certain threshold.
- Track long-term trends for frequency and duration of flooding, overtopping, and ponding.
- Measure the effectiveness of flood mitigation measures.
- Monitor flood sensitive locations and problem areas.
- Provide accurate water resource statuses and heavy rain alerts.

2

(to steps 3-5)

DEFINE NETWORK

Develop an understanding of where sites will be placed to measure water data:

- Critical areas/risk hot spots.
- Problem areas on flood risk maps.
- Where there is flood inundation potential (water ponding potential).
- Where water may overtop roads, culverts, etc. or flash floods.
- 'Sensitive areas' > upstream/downstream of neighborhoods, buildings, and schools.

Determine which parameters (rainfall and intensity, water level, water flow, etc.) will be most helpful to identify flood events and how frequently the data needs to be collected.

Key steps to follow when developing a flood monitoring plan

3 (to steps 4-5)

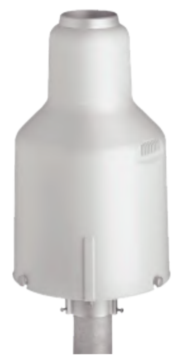
SELECT TECHNOLOGIES

The next step is to choose the technology for each site, which will be dictated by the individual site's needs.

PRECIPITATION SENSOR

OTT PLUVIO²

- Need high levels of accuracy with the ability to measure rainfall intensity.
- Suited for remote locations where low maintenance is required due to the cost of site visits.
- Suited for extreme weather conditions.



SUTRON STAINLESS STEEL TIPPING BUCKET

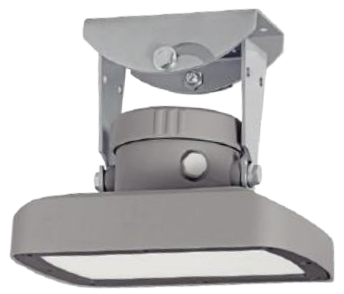
- Measures rainfall accumulation and/or rate.
- Contains an internal tipping bucket, designed for years of accurate and trouble-free operation.
- Standard precision instrument, ideal as a standard US compliant solution for accurate rainfall measurements.

TO MEASURE RAIN FALL AND INTENSITY

WATER LEVEL SENSOR

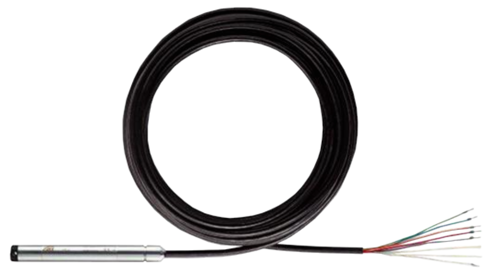
OTT RADAR LEVEL SENSOR (RLS)

- Non-contact sensor can be mounted safely above the water flow to avoid debris and high sediment concentrations in the water, to prevent damage during flood conditions.
- Provides very accurate and continuous water level data.
- Measurement values are drift-free and unaffected by air temperature, humidity, flood events; this reduces the likelihood of missing data.



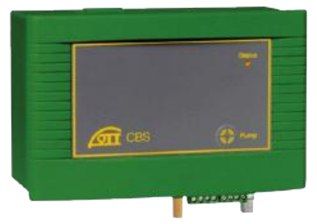
OTT PRESSURE LEVEL SENSOR (PLS)

- A rugged pressure sensor designed for operating at significant depths year-round.
- Deployable in stilling wells or pipes for surface water applications to measure water level, depth to water, or pressure.
- Measures using an integrated ceramic pressure-measuring cell, which is highly reliable.



OTT COMPACT BUBBLER SENSOR (CBS)

- Monitor river levels with the sensor and electronics located out of the water *(bubbler tube still needs to be submerged).*
- Accurate, reliable, and drift-free measurements even during flood conditions.
- Suited for lightning-prone areas.



FOR RISING WATER LEVELS

Key steps to follow when developing a flood monitoring plan

4

DEFINE ALARM CONDITIONS

Within your monitoring stations, you can set thresholds to trigger alarm notifications when exceeded. Detailed investigations should be conducted to define the procedure for alarm conditions:

- How these alarms will be raised
- Who will be contacted and how
- What measures should then be undertaken

5

ADAPT AND IMPROVE

With the benefit of a comprehensive monitoring network, flood events can help network managers to better understand the conditions that cause flooding and increase confidence in warning system effectiveness. Continue refining and improving your:

- Data reliability and speed of data availability
- Alarm conditions
- Flood prediction models
- Technology/gages and where to locate them

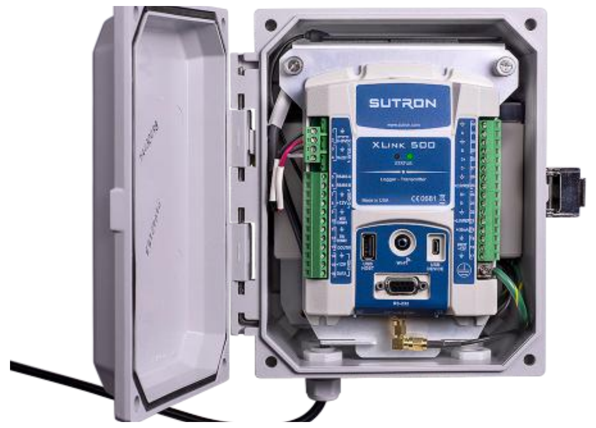
CRITICAL RAIN AND WATER LEVEL DATA AVAILABLE AND ACCESSIBLE WHEN YOU NEED IT THE MOST

Data Transmission and Software

Intelligent, battery powered dataloggers are necessary to collect data from the sensors, and in the case of level sensors, they are able to translate level measurements to flow where the level/flow relationship has been characterized.

Hydrometeorological instrumentation needs to run with a very low power requirement because mains power is often unavailable in the key measurement locations, so solar power is the main alternative. OTT, Lufft and SUTRON instruments are therefore carefully developed to operate on extremely low power. This includes sensors, dataloggers and telemetry equipment such as radio, mobile (such as LTE/ 4G) and satellite. Some loggers can operate over Wi-Fi and Ethernet. Increasingly, the internet is being included in communications networks, which helps to increase flexibility and lower costs. As a result of these developments, OTT HydroMet's customers are able to access their monitors securely nearly anytime and anywhere with TCP/IP connections and routers.

The Internet of Things (IoT) and the ability to manage huge volumes of data (Big Data) mean that the advantages of smart monitoring networks can be fully exploited. For example, a single sensor reporting, say, extreme rainfall might be correct or it might be an indication of vandalism or some other problem. However, if that sensor is part of a network with a data management platform such as Hydromet Cloud, users would be able to view the movement of heavy rain across the network through a web-based interface. As the number of sources for data sets increases, overlapping data can provide cross computation and added insight.



Hydromet Cloud can be accessed with a PC or via a mobile app. It enables users to create their own dashboard to quickly collate frequently viewed data that can be displayed as plots, tables or values, and exported in a variety of formats, which enables easy analysis of trends. Features include:

- map view with colour-coded map pins (for alarm status).
- alarm status using user-defined values, rate of change, etc.
- alarm messages issued automatically by email, text or push notification on a mobile phone.
- Separate limits can be set for different levels of risk and users can create alarm distribution groups for notifications.

Remote Communication & Redundancy

When designing monitoring networks, it's important to cover the whole catchment; any gaps would represent an opportunity for a flood risk factor to be missed, thereby nullifying the effectiveness of the entire flood response system. It's also imperative that telemetry operates quickly and effectively during an emergency, as communications are often affected by severe weather. Redundancy can be built in so, for example, if communications via GOES satellite are too slow during alarm situations, the network should have the capability to switch to Iridium® or cellular communications once a pre-set threshold has been reached.

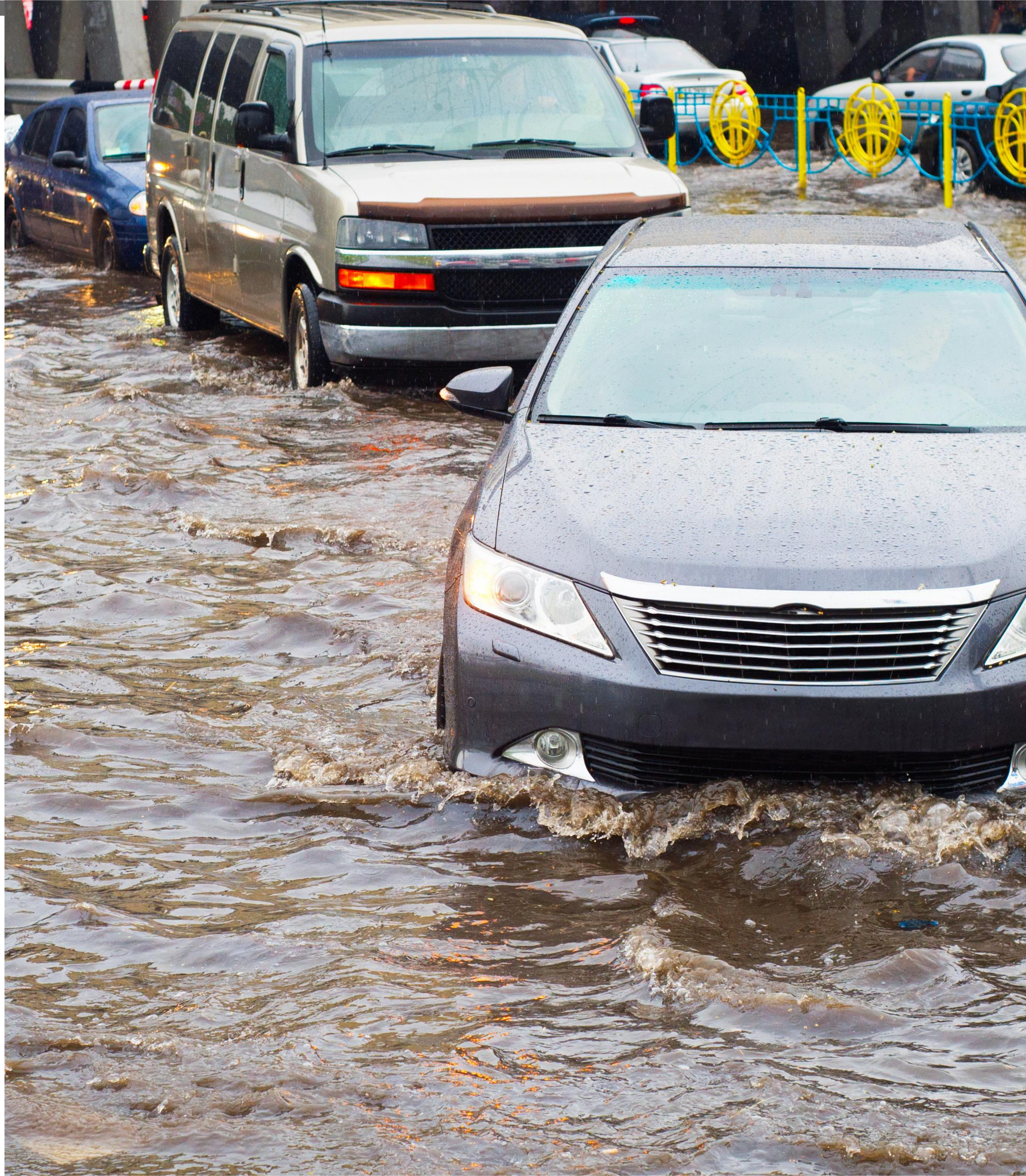
Iridum and cellular communications also allow for remote configuration of critical monitoring stations. Two-way communication can reduce the number of site visits conducted by directly accessing the site from your office, which can also reduce maintenance and field costs. Data capture can also be improved by catching data gaps and quickly configuring new data settings.

Driving Continuous Improvement

Integrated urban flood risk management is a continuous process in which effectiveness depends on how stakeholders are able to raise awareness about flood risk and improve the implementation of urban flood risk management. Monitoring data is therefore critical in the post-event evaluation of a flood; helping to determine which mitigation and response measures worked well and which did not. This helps to improve the qualification and timing of alerts and to define future tactics. Such data is also essential for the continuous improvement of the models that underpin future investments and flood plans.

Monitoring data is required to characterize a flood – a 100 year flood has a 1% chance of occurring in a given year, and a 20 year flood has a 5% chance. Even this 100-year model may become unreliable over time as flood frequency and severity increases: Hurricane Harvey in southern Texas in 2017, for example, would be categorized as greater than a 1,000 year event. It was soon followed by a storm in Texas in 2019 which is categorized as a 200-year event, meaning a 1,000 year event and 200-year event occurred within a few years of each other.

In a changing world, where infrastructure development and climate change are constantly affecting the behaviour of water, monitoring helps to identify the changing vulnerability of different locations, and thereby informs flood projections and future flooding investments. For example, flood frequency and severity is breaking new ground, so comprehensive monitoring networks are necessary to characterize the new flooding paradigm.



Conclusion

Recent developments in smart sensors, communications technology, IoT and the management of Big Data, have combined to dramatically improve the ease with which flood managers can implement integrated flood management plans incorporating comprehensive catchment modelling. These technologies already exist and cities around the world are already benefitting from the flood resilience that OTT HydroMet's monitoring networks are able to deliver. Key features of these systems include reliable, easy-to-deploy rain, water level and flow monitoring sensors; information integration and modeling software; and an automated smartphone-based, geo-targeted alert system.

Climate change and urbanization represent significant challenges, but with the benefit of comprehensive monitoring networks, flooding and urban planners are better able to design sustainable cities, assess effective measures and provide flood alarm infrastructure that protects life and property.

With simple access to reliable data, towns and cities will be able to continuously adapt and improve both their flood infrastructure and their flood response plans; and thereby achieve urban flood resilience.

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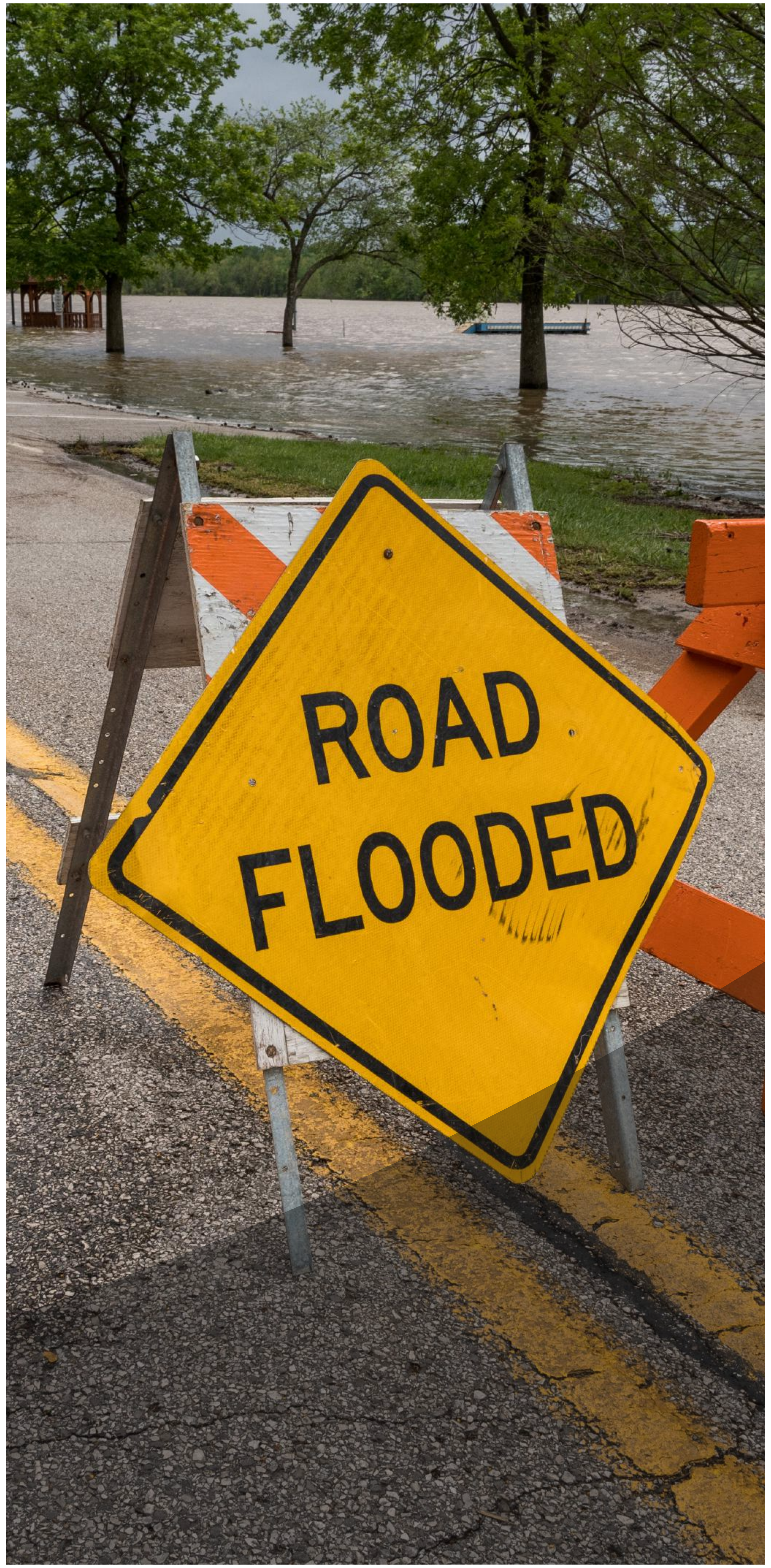

Insights for Experts

For more information, please contact

OTT HydroMet USA
5600 Lindbergh Drive
Loveland, CO 80538 | U.S.A.
Phone +1 (970) 669-3050
sales@otthydromet.com
www.otthydromet.com