Project Iceberg

National Underground Asset Register

Assessment of additional Use Cases – Resilience Planning

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Resilience planning - NUAR Use Case Summary

Working in partnership with the Geospatial Commission (GC), the Iceberg Industry Group delivered a workshop (Nov 2019) looking at additional applications and benefits, (over-and-above strike avoidance), that may be realised by the creation of an underground asset register and better subsurface data use. Twelve use cases were reviewed and prioritised by delegates during the workshop. Resilience Planning (including flood risk) was one of the top 5 use cases identified. This document, prepared by the British Geological Survey, forms a more detailed review of the Resilience Planning use case and provides information on the strategic case for change, economic case and feasibility, along with case studies and user applications.

Government Planner

I am a government planner in London. It's my job to identify critical and vulnerable infrastructure.

> I need to better understand criticality and risk to inform our emergency, security and disaster response planning. Flooding and terror incidents are a particular concern.

Summary Observations:

- Buried utility infrastructure must be resilient to shocks (notably floods and blasts/collapse) and stresses (notably corrosion and ground motion).
- The costs to the utility sector associated with these hazards are significant - corrosion (4-5% of GDP); ground movement (£300-500m/yr); flood impacts to water/energy infrastructure typically ~3-10% of the total flood event cost.
- Multi-hazard and multi-utility impact assessment is essential for resilience planning but requires collaboration and data sharing by a number of government and non- government organisations in addition to the utility sector.
- Combining NUAR data and other datasets would enable multi-factor scenario modelling or 'Digital Rehearsing' for many events. However key baseline data can be difficult to access, subject to licences or security restrictions or in some cases unavailable. **This results in valuable information for resilience modelling being excluded from the risk analysis.** NUAR itself needs to be embedded within the underground asset and construction sectors to reach a level of data maturity that provides sufficient data coverage to ensure its effectiveness.
- Improved collection and sharing of subsurface asset information via NUAR (e.g. asset condition/proximity to other assets/material type) offers the opportunity to formalise access to standardised data, in a structured format to greatly assist the future of resilience planning for critical infrastructure.
- Effective resilience planning requires robust processes, not just access to data. Recent resilience-based collaborative projects have focused on better 'process' i.e. Building understanding of e.g. 'Who holds the data?' 'Who do we need to talk to?' 'What software do we need?'
- There is a strong dependency with the *Asset Maintenance Planning* and *Emergency Response* NUAR use cases.

Resilience planning - NUAR Use Case Summary

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I need to better understand criticality and risk to inform our emergency, security and disaster response planning. Flooding and terror incidents are a particular concern.

"I need to consider both how **natural hazards** (e.g. Flood, landslides, collapsed ground) and **anthropogenic hazards** (e.g. Fire, explosion, security, terrorist attack) might affect assets located underground. I need to consider 'shocks' to the system as well as 'chronic' stresses."

" I am preparing myself and our community…. "

How can I best evaluate the hazards and risks I need to prepare for?
How can our community adapt and reduce the impacts of such an event?

Q. What data do I require in advance?
- ✓ Accessible
- ✓ Funding/ licence agreements
- ✓ How can I share this data effectively

Q. How reliable does the data need to be?
Q. How detailed does the data need to be?

Government planners need to identify critical and vulnerable infrastructure assets

- to better understand criticality and risk
- to better inform emergency response planning
- to better inform security decisions
- to better inform disaster response planning
- to better inform climate change adaptation and resilience planning

Linking all the above processes is a desire to create improved risk assessments. This is currently achieved through supported access to environmental data and relevant above ground info (land use etc.). Underpinning future development in resilience planning is **easily accessible** access to **quality and reliable subsurface** information such as the NUAR platform.

Resilience planning is different to Emergency response:

An Emergency Response is: " I am dealing with this now"

Emergency Response Questions:
What event am I dealing with now?
How can I get the data I need now?
How much do I trust my data to make an immediate decision?

Resilience planning: Ability to Plan – Ability to Adapt – Ability to Absorb

What is urban resilience?

"the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience."

100 Resilient Cities (2018). What is urban resilience? www.100resilientcities.org/resources/.

Stresses: chronic, slow-moving disasters that threaten the fabric of a city.

Shocks: acute events that threaten the city.

How does this apply to buried assets?

Stresses:

- Corrosion of assets
- Ground motion
- Temperature fluctuations
- Overloaded capacity
- Urban development
- Aging infrastructure

Interdependencies

Shocks:

- Hydrological hazards (floods, inundation).
- Geohazards (landslides, earthquakes)
- Extreme weather (storms, freeze)
- Explosions, blasts, attacks
- Collapse

Links with other NUAR use cases?

Asset maintenance:
Asset owners need to integrate underground infrastructure location with environmental data …To identify environmental risks to their assets and mitigate the effects.

Emergency response:
Emergency responders need to access up to date underground asset data live…
To better understand an emergency involving utility assets and can take immediate informed action.

What is a resilience plan?

A **resilience plan** provides a business, organisation or community with an understanding of policies, programs, or actions that can be taken to improve the community's resilience to a change in conditions.

Resilience planning can include:

- updating datasets
- updating contact information, making sure that the right people have access to the right information
- compiling maps (or understanding the collection that is already available)
- the development of standards
- creating incentive programs for collaboration
- Integration of data and systems to identify dependencies to understand cascading hazards and potential 'knock-ons'
- other plans or policies to better prepare for likely shocks and stresses to underground assets and infrastructure.

"How can I improve measures, access information sources that might allow for action in the face of uncertainty or unexpected events?"

"What can I learn from previous events or situations?"

"What can I change?"

"How will this improve resilience of the subsurface infrastructure and emergency response?".

What are the Dependencies with the other NUAR Use Cases?

Underground space usage

What other assets are nearby? What else could be at risk? Do we have the contacts for other asset owners?
Will any of the assets be damaged in the event of an incident?

Smart Cities

What technology is available or could be designed: Data portals? Apps for data collection? Alerts and thresholds (e.g. for warnings)? New materials

Resilience planning

Emergency Response

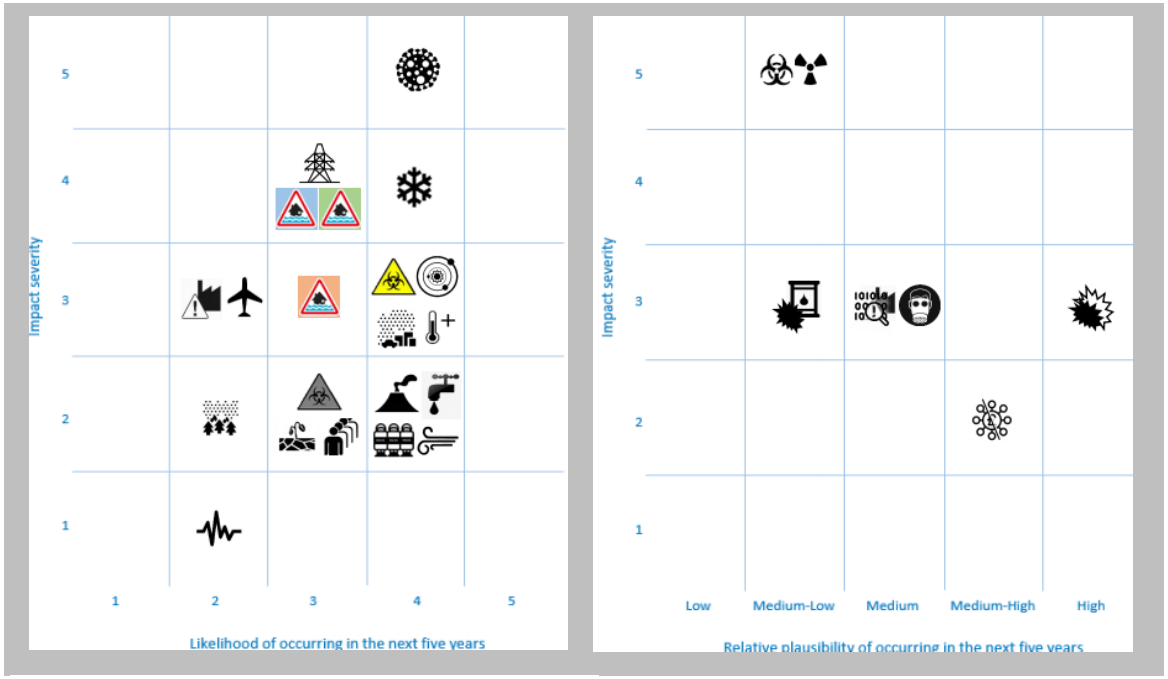
Asset maintenance planning

Have we considered deterioration of assets over longer term? Have we considered the combined impacts of Climate Change (long term) and population change and technology development on our assets?

Flood risk planning

Incident response planning. Could more have been done in advance to minimise impacts

UK National Risk Register. Inform, Plan and Prepare.



KEY

Natural hazards

- Coastal flooding
- River flooding
- Surface water flooding
- Storms and gales
- Cold and snow
- Heatwave
- Drought
- Space weather
- Volcanic eruptions
- Poor air quality
- Earthquakes
- Wildfires

Diseases

- Pandemic influenza
- Emerging infectious disease
- Animal disease

Major accidents

- Widespread electricity failure
- Transport accidents
- Industrial and urban accidents
- System failures

Societal risks

- Industrial action
- Public disorder

KEY

Malicious attacks

- Attacks on crowded places
- Attacks on transport
- Attacks on infrastructure
- Cyber attacks on infrastructure
- Cyber attacks on services
- Larger-scale chemical, biological, radiological or nuclear attacks
- Smaller-scale chemical, biological or radiological attacks

UK Cabinet Office

National Risk Register
Of Civil Emergencies
2017 edition

The UK government publishes the National Risk Register of Civil Emergencies to provide information on risks that could cause serious disruption to lives over the next five years. The National Risk Register is based on the National Risk Assessment, a classified assessment of risks to the UK.

Risks to buried assets

- Cold and snow
- Electricity failure
- Flooding
- Space weather
- Industrial and urban accidents
- Transport accidents and attacks
- Heatwaves
- Attacks on infrastructure
- System failures
- Storms and gales
- Earthquakes

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/644968/UK_National_Risk_Register_2017.pdf

Case Studies – Summary of key points

The case studies below are used to help demonstrate pinch points and problems in resilience planning with relation to surface and subsurface information and datasets. Whilst resilience planning had taken place enabling a quick emergency response, the examples also demonstrate a need to consider future stresses to subsurface assets such as population increase, development and climate change. In the short-medium term the NUAR platform is most likely to be useful for understanding 'stresses' on the buried assets.

Cast study Example	Key issue
Underground fire at Holborn	Unseen risks and further missing subsurface data information for decision making
Groundwater flooding	Subsurface pathways for flood waters accentuated by pipelines and permeable material
Superstorm Sandy	Subsurface flooding of infrastructure, coupled with damage to assets and cables, following breach of flood defences
Buncefield	Potential for pollution to key waterway increased as not all available data on subsurface draining pathways and channels included in local maps

Key learning points:

- There are differences between resilience planning for '*shock events*' and longer-term '*stresses*'.
- Buncefield Fire demonstrates an incomplete collation of available resources that could be rectified for a future shock.
- Superstorm Sandy and groundwater flooding display a requirement for detailed resilience planning to manage events of a similar nature or magnitude in the future; learning from previous issues that good defences can be breached or natural exposure can be exacerbated by asset infrastructure.
- There are continued issues with access to reliable data in a reliable format - not all data included in response if stored in different locations.
- The examples demonstrate that the pathways for movement of water, contaminants and gases underground are not fully considered.

All case studies demonstrate
- Gaps were exposed in data sources and transfer pathways
- Effect of buried infrastructure and presence of subsurface pathways are not fully considered

Case study 1 – Underground fire Holborn 01 April 2015

An electrical fault in the Victorian tunnels under Holborn, London, caused a fire and mass power outages in central London. The electrical fault ruptured a nearby gas main fuelled the fire which burned underneath the pavement for 36 hours.

"London fire commissioner Ron Dobson said: "This technically difficult fire shows just how complex London can be and how unseen risks underneath the capital can significantly affect businesses, residents and the day-to-day running of parts of the capital."

(https://www.bbc.co.uk/news/uk-england-london-32231725

What happened?

On the 1st April 2015 An electrical fault occurred in the Victorian tunnels under Holborn, London. The electrical fault ruptured a nearby gas main. This fuelled the fire which burned underneath the pavement for 36 hours.

The fire was running along a three-metre wide tunnel that runs for 400 metres between Great Queen Street and Aldwych in central London.

How is this related?

Statistics from the Health and Safety Executive (HSE) investigating the incident, showed there were 40 cases of pavements blowing up or catching fire in 2014 alone.

As the fire burned, London Fire Brigade were able to use the Metropolitan Police helicopter and infra-red images to locate where the main hot spots were.
Scotland Yard's explosives robot was used to go into the tunnel to provide information.

What were the impacts?

5 000 people were evacuated from nearby homes and business. The fire caused traffic restrictions, closed theatres and restaurants and a loss of telephone lines. Thousands of properties lost gas and electric supplies; 3,000 properties were affected, according to UK Power Networks.

Business leaders warned the Holborn fire could cost the capitals economy £40 million.

The service tunnels comprising >100 year old brick arches surrounded by concrete envelopes were damaged.

What else is important?

Response discussions included use of high-expansion foam however there was no compartmentation in the tunnels, there was no way of knowing where the foam would go and what structural damage it may have caused.

Who was involved?

London Fire Service	Local residents
Asset Owners	Local businesses
Scotland Yard and Met. Police	Transport for London
UK Power Networks	HSE

Case study 2 – Groundwater flooding – December 2000, January 2003 and July 2007

The Oxford floodplain is underlain by permeable shallow sands and gravels. In July 2007, during a severe flood event, 200 properties were affected by flooding from rising groundwater which was either the sole cause or the initial cause prior to inundation from fluvial waters.

The EU Floods Directive (2007/60/EC, which came into force in November 2007, includes provisions for: assessing the risk from groundwater flooding, producing groundwater 'flood hazard maps' and introducing measures to address any significant risk

What happened?

An estimated 1.6 million properties are at risk of groundwater flooding in England and Wales. Oxfordshire has experienced notable flood events in recent years. However, some properties suffered from groundwater flooding only in Dec 2000 and Jan 2003. Oxfordshire was further hit by severe flooding in July 2007 during the wettest summer on record. Groundwater levels in the area are very shallow and respond rapidly to both fluctuations in river level and rainfall. Groundwater flooding is often an early indication that more extensive flooding is likely to occur.

How is this related?

Where buildings have been constructed on the flood plain the removal of alluvium also provides preferential pathways for upward groundwater movement, as do man-made drainage channels. Where the water rises above its normal level, these can result in flooded gardens, cause drainage problems (e.g. inundation of sewerage systems) and create dampness beneath floorboards.

Groundwater can also flood properties in these low-lying areas where the ground floor or the inhabited basement is close to the level of the natural floodplain. Pre-war properties were usually constructed with basements and in time many residents have converted these into living areas. Groundwater levels are rising and infiltrating buried assets, making the asset part of a 'natural drainage system'.

What were the impacts?

In 2007, 1 600 properties were reported as being affected by flooding. 200 of these identified groundwater as the sole cause or the initial cause prior to inundation from fluvial waters. Subsurface pipework was reported as a key pathway for flow. The ballast fill surrounding underground pipes was noted to provide a high permeability pathway for groundwater.

What else is important?

Sewers are especially vulnerable to groundwater ingress through cracks in the access chambers or the pipes themselves. This can have a knock on effect on groundwater quality. Groundwater flooding in Patcham, Brighton 2000/2001 reportedly cost £800 000. In 2013/14, three water companies spent an additional £80 million responding to impacts of groundwater infiltration. Local Site and Monuments Records Data and National Schedule Monuments records have shown a wealth of historically significant archaeological remains where preservation is dependent on groundwater levels and flooding regimes.

Who was involved?

Environment Agency County/District Councils Utility owners	Local residents and businesses Flood Action Groups Blue lights

Case study 3 – Flooding of underground transport system: Superstorm Sandy NYC 29th Oct 2012

Hurricane Sandy's progression from the Caribbean to the U.S. East Coast caused deadly flooding, mudslides, and destructive winds. As it hit New York City, Superstorm Sandy created a storm surge.

National Geographic: *"Though Sandy is often described as an anomaly, for many it was a call to action. The disaster showed how vulnerable wider areas of the United States are to extreme weather events, particularly in a time when scientists warn that climate change is threatening sea-level rise and hotter temperatures. Since the storm, affected regions have rethought their disaster plans to try and increase their preparedness."*
https://www.nationalgeographic.com/environment/natural-disasters/reference/hurricane-sandy/

What happened?

On the 24th October 2012 Hurricane Sandy began it's rampage over the Caribbean and continued on a Northwards track for the next 7 days, causing devastation along it trail. The 'Superstorm' hit New York City on 29th October 2012. At a Consolidated Edison substation in Manhattan's East Village, a shut down plan was in action for the city, and based on previous experience and modelling, was protected by a structure for a surge of 12.5 feet. The surge experienced was was 14ft, and a gigantic wall of water defied the modelled planning design expectations. The water swamped underground electrical equipment, car parks and underground infrastructure.

How is this related?

Power shut down had been as part of the emergency response planned for underground equipment in some lower areas of city. National Grid had shut down sections of its gas distribution systems in flood-prone areas so the storm damage to infrastructure would not be amplified by leaking gas.

Underground wires can flood and be more difficult to repair, especially in low-lying areas. It can be harder for workers to get to the wires because manholes flood. When water recedes, it can be harder to find problems, pull out wires and equipment, dry them, fix them, and slide them back into place.

What were the impacts?

Different parts of the city had already been shutdown in phases as the storm passed. This was a precaution to try and protect underground equipment vulnerable to flooding from corrosive, destructive seawater.

The Surge left 250,000 lower Manhattan customers without power and pushed flood of seawater into the city, flooding basements, car parks and vehicle tunnels, railyards ferry terminals and subway lines. Subway stations and tunnels had to be pumped out. Electrical systems had to be cleaned, repaired and tested and in some places this took weeks.

What else is important?

National Grid estimated it will need to invest $200 million in infrastructure repairs and upgrades in the wake of Superstorm Sandy. The worst of the damage to the company's service area occurred in Rockaway Beach and Staten Island where 27 miles of mains had to be replaced.

Who was involved?

Local and Federal Government; Utility asset owners; Blue lights; American Red Cross	Hurricane Sandy Rebuilding Task Force Coastal managers

Case study 4 – Buncefield Fire 11th December 2005

The Buncefield explosion and fire that lasted 3 days. Further explosions resulting in 20 storage tanks being overwhelmed and 3 days to extinguish. The M1 was closed, and contaminants from the foam used to fight the fire, were subsequently found in the groundwater boreholes.

The Hertfordshire Oil Storage Terminal, had a capacity of about 60 million Imperial gallons (273 million litres) of fuel.

What happened?

The Hertfordshire Oil Storage Terminal is located in Hemel Hempstead, Hertfordshire, England, near the M1. On the 11th of December 2005 a broken gauge on a tank failed to alert staff the tank was over filling . Eventually large quantities of petrol overflowed from the top of the tank. A vapour cloud ignited causing a massive explosion and a fire. Further explosions resulting in 20 storage tanks being overwhelmed and 3 days to extinguish.

Air pollution, smoke, and disruption to businesses and personal life as a result of the fire were the biggest impacts at surface. Hundreds of homes were evacuated affecting about 2,000 people. Windows were smashed in the explosion. Public buildings were closed.

How is this related?

On this occasion, most of the fuel burned out – rather than spilling into the soil, so the impact on surrounding land and the water table was limited.

However, the adjacent area contained a number of drains and soakaways that the site operators had not identified and liquids were able to penetrate into the soil beneath them. The HOSL West site had drainage and a soakaway that were not featured on current plans but were shown on older company plans.

What were the impacts?

Subsurface issues arose from the quantity of water and foam used in fighting the fire. In May 2006, Three Valleys Water announced that it had detected a persistent, bioaccumulative, and toxic chemical called PFOS (fluorosurfactant perfluorooctane sulfonate) in a groundwater borehole close to the Buncefield site. This is a chemical used in fire fighting foam. No water from this well entered the public water supply and a nearby well and pumping station had been closed since the fire as a precautionary measure.

What else is important?

Post event reports concluded that added safety measures were needed for when fuel does escape, mainly to prevent it forming a flammable vapour and stop pollutants from poisoning the environment.

Reports highlighted that up-to-date drainage plans for areas on and off site should be readily available to emergency responders before and during an incident, to include topographical detail for surface flows and subsurface drainage features.

Who was involved?

Fire Service	Environment Agency
Health and Safety Executive	Highways Authority
UK Oil pipelines Ltd.	Several Engineering Companies

Case for Change and Potential Issues

Case for Change

Provide solutions that address problems across multiple sectors with subsurface assets creating maximum benefit
- ✓ Improved prediction methods (e.g. flood modelling, assessment of impacts on underground assets)
- ✓ Integrated risk assessment and 'live' risk modelling

Better coordination & emergency response, improving speed and effort
- ✓ Potential for better and quicker emergency response
- ✓ Golden Key Emergency access data

Integration with other models to evaluate subsurface critical and vulnerable infrastructure
- ✓ Devolution and regional planning response utilising local knowledge
- ✓ Better planning response to asset strike (e.g. accidental works or terrorist)
- ✓ Linking assets that can affect different hazards (e.g. pathways creating unnatural flow channels)

Make good financial investments that have the potential for economic benefit to the investor and the broader community
- ✓ Include flexible and adaptable measures that consider future unknowns of changing climate, economic, and social conditions
- ✓ Loss of local knowledge in ageing workforce needs collating costing time and money

Potential Issues

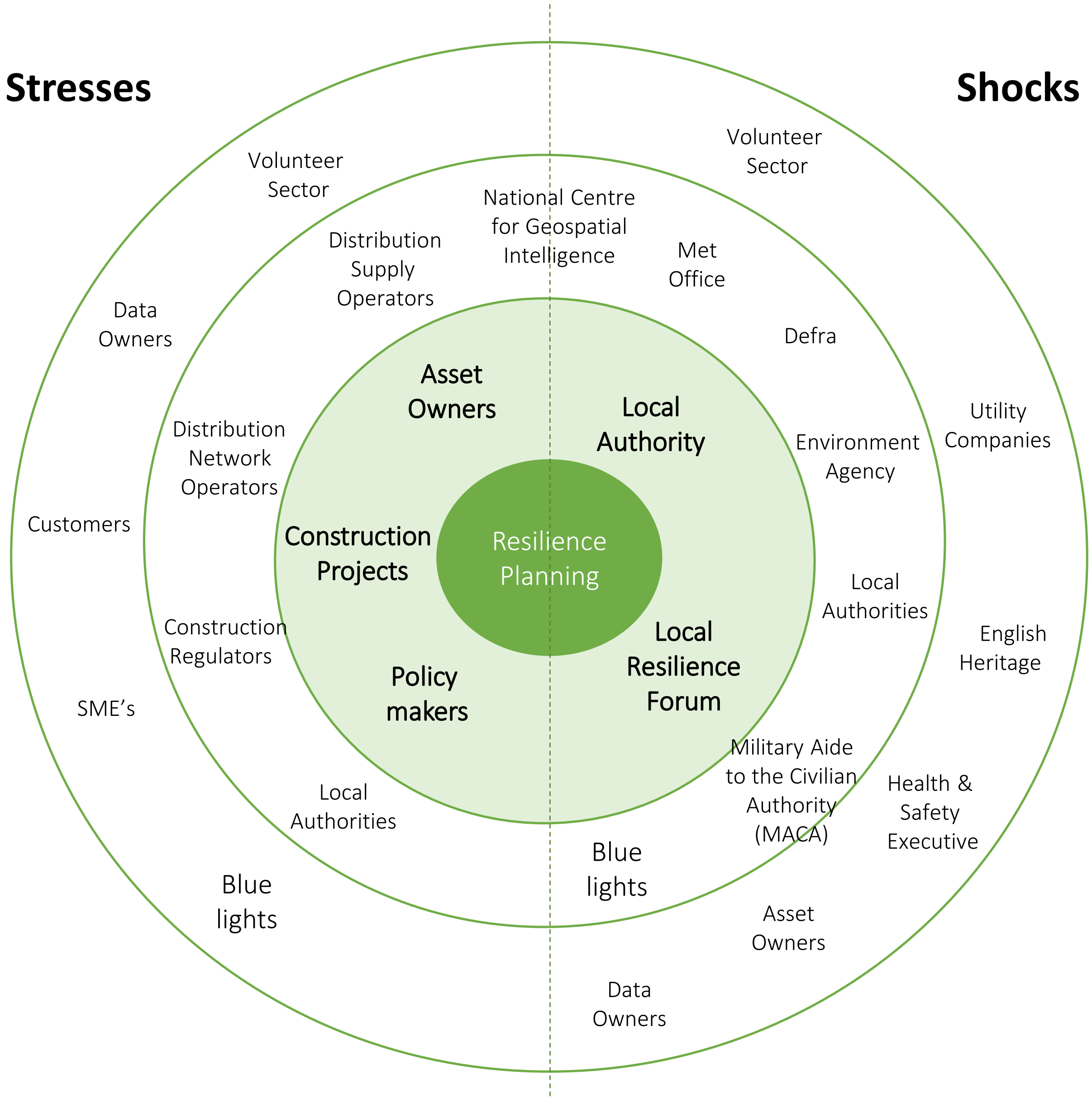
Accessibility of data
- * Licence agreements to useful information and data layers
- * Storage of sensitive data and inclusion in models
- * Ownership and maintained data management on underground assets

Hazard awareness and relationships with subsurface assets
- * Understanding of cascading hazards and contact with important stakeholders (e.g. pathways creating unnatural flow channels)
- * Natural resources, geological conditions and climate may move (e.g. landslide, salinity etc.) and/ or change

Over reliability on accuracy of data
- * Depth information of buried assets variable or none existent at present time
- * Accuracy of spatial information and age of data
- * Information on the condition of assets information, potential access to subsurface asset

Uptake of engagement with wider stakeholders and partners
- * Avoiding Heritage digs causing delays – localised records
- * Understanding wider geological/ natural conditions through collaboration with correct organizations.

Case for change – stakeholder mapping – resilience



- Data hard to access – different organisations to liaise with
- Data incomplete or out of date
- Data in different formats, requiring different software
- Wide consideration of response with different priorities: **Danger to life, Denial of access, Damage to infrastructure**
- No formal feedback loop

Water, Energy, Transport, Communications

Underpinning future development in critical infrastructure resilience planning is **ease of access** to **quality and reliable subsurface** information.

Resilience Planning for both current and emerging potential **shocks** and **stresses** have been identified as requiring improved data acquisition and with regard to critical infrastructure.

Local vs national Risk assessment require different levels of information. One data source could assist alignment.

User Journey - Key roles in '**shock**' resilience planning

Risk assessments enable **Local Resilience Forums** to highlight the biggest risks within the local resilience area and draw up appropriate resilience plans that are proportional to the risks faced.
The risk assessment process requires co-operation between organisations.

Consistent levels and methods of emergency planning for the United Kingdom are set out by the Civil Contingencies Act 2004

The Regulations that accompany the Civil Contingencies Act require that an Local Resilience Forum (LRF) is established in each police force area. This is known as a local resilience area.

A Local Resilience Forum (LRF) is not a legal entity, nor does a Forum have powers to direct its members. Nevertheless, the Civil Contingencies Act and the Regulations that accompany it provide that responders, through the Forum, have a collective responsibility to plan, prepare and communicate in a multiagency environment. Each Forum meets around twice a year.

E.g: A lead Agency is identified for the planning/ risk assessment, depending on the appropriateness and level of responsibility to that event:

Examples related to the waterways:

- A major flooding event → lead agency would be the Environment Agency
- A major water course pollution event → lead agency would be the Environment Agency
- Fire or explosion *which could pollute waterways* → lead agency would NOT be the Environment Agency as the risk to life should be managed before the risk to water course

How can we help support resilience planning with better subsurface data?
Can we assist and improve organisational links in resilience planning?
Can we assist access to subsurface information at earlier stage?

Civil Contingencies Act 2004 – Key roles in resilience planning

Category 1 Core Responders.
Responders are organisations at the core of the response to most emergencies (the emergency services, local authorities, NHS bodies). Category 1 responders are subject to a full set of civil protection duties including planning, arrangement and efficiency of response.

Category 2 Key co-operating responders that act in support of the Category 1 responders.
Category 2 organisations (the Health and Safety Executive, transport and utility companies) are 'co-operating bodies'. They are less likely to be involved in the heart of planning work, but will be heavily involved in incidents that affect their own sector. Category 2 responders have a lesser set of duties - co-operating and sharing relevant information with other Category 1 and 2 responders.

Category 1 responders:

- Local authorities (county, district, London borough etc.)
- The emergency services (police, fire & rescue, ambulance),
- NHS England, Wales, Scotland
- Public Health England, Wales,
- Port health authorities,
- Maritime and Coastguard Agency
- Environment Agency, Scottish Environment Protection Agency, Natural Resources Wales
- Armed Forces

Category 2 responders:

Utilities:
- Electricity distributors and transmitters
- Gas distributors
- Water and sewerage undertakers
- Telephone service providers

Transport:
- Network Rail
- Train operating companies
- London Underground
- Transport for London
- Highways England
- Airport operators
- Harbour authorities

Others:
- The Health and Safety Executive
- Voluntary aid societies (VAS)
  e.g. St John Ambulance
  British Red Cross

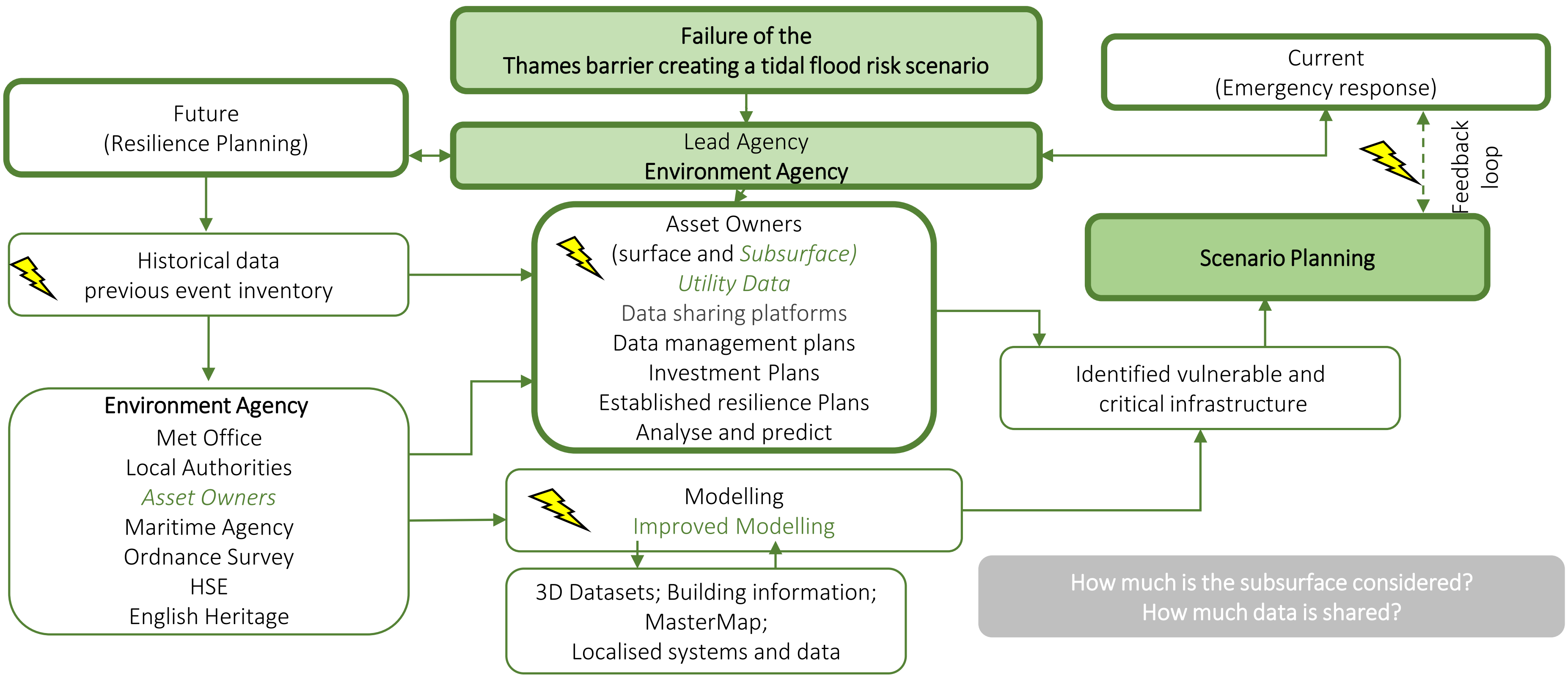
How much is subsurface information actually considered by the Category 1 and 2 responders in the current plans?

Stakeholder focus - 'Stress' Example: The Thames Barrier

- The Thames Barrier can be closed to reduce fluvial flood risk.
- Climate change will increase the number of closures required to protect against rising tides.
- With increased and more intense rainfall, fluvial flood risk will increase.

The Thames Barrier will be less and less available to assist with managing this fluvial flood risk as it will need to be conserved for tidal flood risk management – the purpose for which it was designed.

The particular constraint is the annual number of closures for the Barrier, as this must be limited to reduce the risk of failure and ensure readiness of the Thames Barrier for tidal surge flood conditions



Strategic case for change – Legislation and policy drivers

The UK has significant experience of resilience planning and handling of emergencies both natural and human induced. Several recent research and government-level investigations have highlighted potential gaps in capability, and have instigated policy change and strategic groups to address these.

The National Risk Register provides an over view of the key risks that are identified as potential to cause significant disruption to the UK (slide 6). Infrastructure is specifically mentioned in regard to severe weather response (Drought, flooding), space weather, wildfire, system failures , Transport, industrial accidents, public disorder malicious attack. Key in all cases is development of data and information sharing.

The independent review by Sir Michael Pitt of the summer 2007 floods recommended the development of plans to reduce the vulnerability of critical national infrastructure to **flooding and other natural hazards**. The review identified **no national standard for flood resilience for critical national infrastructure assets** and suggested that as a minimum, critical infrastructure assets should be protected to a 1-in-200 year standard against flooding. The Cabinet Office has set a benchmark that "as a minimum essential services provided by Critical National Infrastructure (CNI) in the UK should not be disrupted by a flood event with an annual likelihood of 1 in 200 (0.5%)". But the Committee on Climate Change have warned that "It is not clear how this benchmark has been interpreted by each sector and whether this minimum standard of flood resilience is now in place".

Under section 208 of the Water Industry Act 1991 ("WIA 91"), Defra's Secretary of State and the Welsh Ministers can issue general or specific directions to **water and sewerage** undertakers and to water supply and/or sewerage licensees in the interests of national security or to mitigate the effects of a civil emergency. The Security and Emergency Measures (Water and Sewerage Undertakers) Direction 1998 and Security and Emergency Measures (Scottish Water) Direction 2002– **commonly referred to as SEMD** – directs undertakers to maintain plans to provide a supply of water at all times.

The National Emergency Plan for **Downstream Gas & Electricity** (required under the terms of EU Gas Security of Supply Regulation (EU)994/2010) sets out arrangements between government, industry, regulator and other parties for **safe and effective management of downstream gas and electricity supply emergencies.**

In relation to emergency planning, response and recovery, the Civil Contingencies Act 2004 (CCA) **places statutory duties on utilities** as Category 2 responders (as defined by the Act). The duties placed on Category 2 responders include business continuity planning. Government will continue to encourage **critical infrastructure operators to have business continuity planning to international standards ISO 22301** - "Societal Security — Business continuity management systems — Requirements" and ISO 22313 - "Societal Security — Business continuity management systems — Guidance"

https://www.theccc.org.uk/publication/reducing-emissions-and-preparing-for-climate-change-2015-progress-report-to-parliament/)

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/644968/UK_National_Risk_Register_2017.pdf

Case for change - Example of the Pitt Review 2008

Widespread flooding took place in England in June and July 2007; 55,000 properties flooded, 7,000 rescued and 13 people died. Nearly 500,000 people were left without water or electricity and the insurance bill reported to be about £3 billion. Sir Michael Pitt was asked to carry out an independent review focussing on; flood risk management, the resilience and vulnerability of critical infrastructure, the emergency response, emergency planning and the recovery phase. The Pitt Review: Lessons learned from the 2007 floods, was published on 25 June 2008.
https://webarchive.nationalarchives.gov.uk/20100702215619/http://archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html

Increased collaboration between wider organisation network allows a greater potential and provision of useful data sets that infrastructure owners may have previously been unaware of/ not considered applicable to the underground assets of utilities and foundations.

The **Natural Hazards Partnership,** was established in 2011. The consortium provides authoritative and consistent information, research and analysis on natural hazards for the development of more effective policies, communications and services for civil contingencies, governments and the responder community across the UK.
They provide a timely, common and consistent source of advice to government and emergency responders for civil contingencies and disaster response. The partnership agreement creates an environment for the development of new services to assist in disaster response.

http://www.naturalhazardspartnership.org.uk/

The **Flood Forecasting Centre/ Scottish Flood Forecasting Service** are jointly staffed by **Met Office** and **Environment Agency/ Scottish Environment Protection Agency** employees. They are fully operational 24/7 supporting the Category 1 and 2 emergency response community, with Environment Agency or Natural Resources Wales, SEPA, flood warnings, and Met Office weather warning services.
This earlier and better communication of flood risk enables national and local responders and asset owners to support local communities at risk of flooding. This provides people more time to take action to protect themselves and their homes and businesses from flooding.

http://www.ffc-environment-agency.metoffice.gov.uk/
https://www.sepa.org.uk/environment/water/flooding/forecasting-flooding/

"The availability of required information"

- Improved data sharing for resilience planning will support the Government drive for better practice and cooperation between operators.
- Include directives on Water, Energy, Transport and Communications – all including subsurface assets and comments.
- However, there is no single authority for national infrastructure

Who has the responsibility for gathering the information where it is **not readily available**, as this can be resource-intensive;
"Also a need to establish standard methods of data-gathering and to ensure consistency in using these methods".

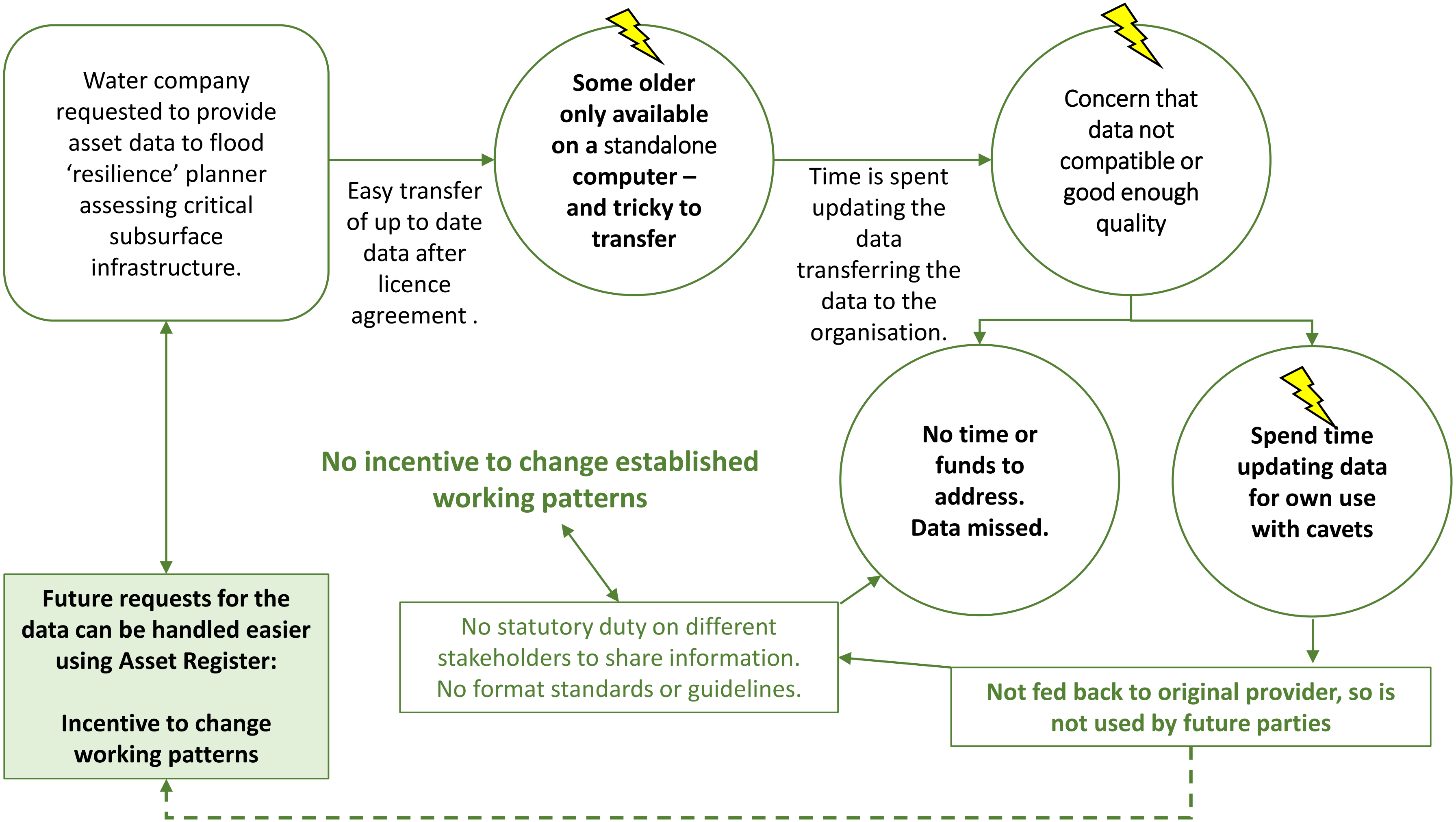
Data on the **public sewerage system** is held by Water companies, there are still **many privately owned sewers**.
"This situation may be improved if the proposal for water companies to adopt private sewers that feed into the public sewerage system goes ahead".

Who will **own the data** if we share it and how will users ensure it is the most up to date / will it be updated? IPR – Asset owners will need reassurance.

The **Critical Infrastructure Resilience Programme (CIRP)** within Cabinet Office will be working with relevant Lead Government Departments to put in place procedures for assessing the vulnerability of critical infrastructure to natural hazards, and to measure the levels of resilience in the sector.

Case for change – pinch points to achieve collaborative resilience plan

Example: An asset owner is in discussion with local resilience planner reviewing flood assessment models for a new housing estate. Critical infrastructure in the local area, is recorded by the asset owner and the developer but they don't match. Some of the Asset owners data is regarding inactive pipeline subsurface structures that could affect flow pathways, however it is older and buried on a standalone machine in the office.



NERC Environmental Risks to Infrastructure Programme (2014 – 2019)

Programme Coordinator: CIRIA

Programme members:
Arup • Atkins • EDF Energy • Environment Agency • High Speed 2 • HR Wallingford • London Underground • National Grid • Network Rail • Scottish and Southern Energy (SSE) • Scottish Water • Temple Group • Translink NI • Transport Scotland • UKWIR • WSP

https://nerc.ukri.org/innovation/activities/infrastructure/envrisks/eriip-overview/

The Environmental Risks to Infrastructure Innovation Programme (ERIIP) aimed to provide sound evidence for the identification and assessment of environmental risks and their impacts on infrastructure, translating the latest research into industry-relevant outputs.

'There is a wealth of data, knowledge and expertise in the UK research base which could address this challenge but this valuable resource is often difficult to access and requires translating to be more readily used.'

Funded projects of relevance:

Dr Dina D'Ayala University College London	Groundwater and Flood Risk in the London Rail Infrastructure Network: Building Resilience into Existing Masonry Infrastructure Assets	Arup (Ove Arup and Partners Ltd) (UK), London Underground
Dr Ana Mijic Imperial College London	Improved techno-economic evaluation of Blue Green Solutions for managing flood risk to infrastructure UK AECOM, Environment Agency	AECOM, Environment Agency
Dr Christopher Jackson British Geological Survey	Assessing the risk of groundwater induced sewer flooding to inform water and sewerage company investment planning	Thames Water Utilities Limited
Dr Simon Jude Cranfield University	Vulnerability of proximal infrastructure to sand washout from burst water pipes and leaking sewers	Anglian Water Services, BT, Lincolnshire County Council
Dr Rachel Dearden British Geological Survey	Modelling the geological factors in pipe failure for better infrastructure management	Yorkshire Water Services Ltd
Dr Christian Wagner University of Nottingham	Towards managing risk from climate change through comprehensive, inclusive and resilient UK infrastructure planning	Thames Estuary Partnership, Gov of Western Australia, Horizon Digital Economy Research
Professor Richard Dawson Newcastle University	Storm Risk Assessment of Interdependent Infrastructure Networks	Arup (UK), Atkins UK, Northern Powergrid, Scottish Water
Professor Jim Hall University of Oxford	Multi-Hazard Resilience Estimation and Planning for Interdependent National Infrastructure Networks	Arup (UK), Department for Transport, HR Wallingford Ltd, HS2 Ltd, JBA, Scottish Water
Richard Williams University of Glasgow	Decision support framework to incorporate river bank stability in pipeline crossing risk assessment	Scottish Water
Simon Tett University of Edinburgh	Playing Games to Understand Multiple Hazards and Risk from Climate Change on Interdependent Infrastructure.	Transport Scotland, Scottish Water, SGN, SEPA, Inverclyde Council, National Centre for Resilience, Climate Ready Clyde, Adaptation Scotland
Stephen Krause University of Birmingham	Innovative monitoring for contamination of water supply systems	Affinity Water, UKWIR, Thames Water, Portsmouth Water, EA

Ground conditions

Economic case for change

KEY REFERENCE: Pritchard et al., 2013. Soils corrosivity in the UK – impact on critical infrastructure. Infrastructure Transitions Research Consortium Working paper. www.itrc.org.uk/wp-content/PDFs/Soil-corrosivity-impacts-UK-infrastructure-report.pdf

£

Economic cost of corrosion within the UK the cost of corrosion has been estimated to be approx. 4-5% of Gross National Product (GNP) (Uhlig, 1985).

Ground movement causing damage to assets has direct and indirect costs of £300-500 million each year (Pritchard et al, 2013).

Insurers have estimated that **shrink–swell related subsidence impacts** on buildings and infrastructure cost the insurance industry over £400 million a year (Jones and Terrington, 2011).

Aging utility networks:

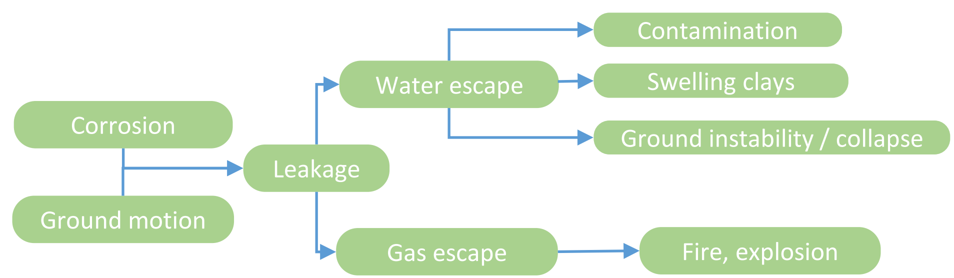
- Leakage from the **water supply network** is significant due to aging infrastructure. → For Thames Water this is equivalent to ~25% of daily supply (641ML/d) since more than half of the mains are >100 yrs old and prone to corrosion due to long exposure times. (Likhari et al. 2017)
- **Water/Wastewater**: Ashton et al. (2009) in their report outlining leakage targets in London highlight the serious potential impact that leakage could have on the underground transport network and traffic congestion →The latter was witnessed at the Brent Cross Flyover when a water main burst flooding and closing the North Circular road, a main commuter road into Central London (BBC, 2012).
- Aging **gas main infrastructure** has led the fracture rate to rise from 13 per 100km in 1977 to approximately 14,5 per 100km in 1999 → The HSE (2001) identified 91,000 km of iron gas mains within 30m of buildings at risk of failure, leading to the Iron Mains Replacement Program (IMRP) (HSE, 2011). Approx. 23,000 fractures and corrosion failures which had led to 600 'gas in building' events resulting in the fatalities of 1-2 people/yr had occurred up to 2001 with most iron pipes being 40-100 years old.

Underlying factors

- The gas and water utilities sectors are more greatly affected by corrosion issues. Electricity and telecommunication utilities are less affected by corrosion.
- Ground motion, in particular vertical movement is an underlying factor causing damage to buried utilities. In parts of London vertical motions can reach up to 50mm/yr (Boyle et al., 2000).
- Oliff et al. (2001) regard the settlement of soil as both inducing failure in older pipelines but also the most common cause of failure in modern (plastic) pipelines.

Leakages and burst from water pipes as a result of corrosion, can lead to cascading impacts including:

- contamination of underlying soil and groundwater,
- swelling of clay soils e.g. if a water pipe were to develop a leak in a clay soil the subsequent wetting could result in the swelling of the soil, of up to 10% of original soil volume (Nelson and Miller, 1992),
- Loss of support or ground collapse due to washing away of fine soil materials or dissolution of soluble rock.



Flooding

Economic case for change

£

2007 Summer floods: 55,000 properties flooded; £3 Bn paid out by the insurance sector.

- Flooding of the Mythe water treatment works in Gloucestershire led to loss of water supplies for 350,000 people for up to 17 days.
- Repair costs of local and trunk roads were estimated at £40-60m.
- Damage to electricity distribution assets cut off 40,000 people in Gloucestershire for 24 hours.
- In Yorkshire and Humberside 9000 customers were placed on rota disconnection (rolling blackouts) for several days.

(Pitt Review, Final Report 2010).

- Utility costs contributed to just over 10% of the total costs (Ciurean et al., 2018)

Water supply network: In 2013/14, three water companies spent an additional £80 million responding to impacts of groundwater infiltration. (Likhari et al 2017. nora.nerc.ac.uk/id/eprint/519019/)

Funding for flooding: In the price review for the period 2010-2014, Ofgem, permitted electricity companies to collect an extra £112 million from customers for flooding resilience.

Winter 2015/16: Total economic damage ~£1.6 Bn**.** The utilities (energy and water) sector reported damages at around 7% of the total costs of the floods. The costs include: physical damages to infrastructure, additional operational costs and welfare damages to consumers suffering disruption. (Ciurean et al., 2018).
61,000 people lost power in Lancaster. (National Risk Register of Civil Emergencies, 2017).

2000/01 Groundwater flooding in Patcham, Brighton cost a reported £800 000

Underlying factors

- The National Flood Risk Assessment shows that a sizeable part of our important infrastructure and public services are in flood risk areas. This is especially so for water-related infrastructure that needs to be near rivers.
- Predicting shallow groundwater levels is difficult. Underground structures such as buried pipes act as preferential pathways and drainage routes for shallow groundwater flow. Impermeable land cover and sustainable drainage systems complicate infiltration processes.
- Utility and transport infrastructure provides a route for flood water from surface to underground environments. E.g. During hurricane Sandy the subways were flooded with seawater and all subway tunnels beneath rivers flooded.
- Utility and infrastructure flood impact assessments need to take account of climate change, mobilisation of contaminants, and the impacts on flooding on underground construction costs.

Impact category	2007 (summer floods)	2013/14 (winter floods)	2015/16 (winter floods)
Utilities (water and energy)	£398	£30	£104
Total costs	**£3,900**	**£1,300**	**£1,600**

Comparison of economic costs by flood event by impact category (2015 prices) (£million) (Ciurean et al., 2018. http://nora.nerc.ac.uk/id/eprint/524399/)

Major incidents

Economic case for change

£

Holburn underground fire:

HSE investigating the incident, showed there were 40 cases of pavements blowing up or catching fire in 2014 alone.

5,000 people were evacuated from nearby homes and business. The fire caused traffic restrictions, closed theatres and restaurants and a loss of telephone lines. Thousands of properties lost gas and electric supplies; 3,000 properties were affected, according to UK Power Networks.

Business leaders warned the Holborn fire could cost the capitals economy £40 million.

Buncefield: (Dec 2005) Europe's largest peacetime fire occurred at Buncefield Oil Storage Terminal, resulting in injuries to >40 people. The incident, caused by overflowing petrol storage, resulted in a vapour cloud which ignited causing a massive explosion and a fire that lasted five days.

→ A system of drains and soakaways (tertiary containment) to ensure that liquids could not be released to the environment were inadequately designed and maintained and failed as a result.
→ The effluent treatment plant included soakaways that were not identified in the safety reports or emergency plans
→ Pollutants from fuel and firefighting liquids leaked from the bund, flowed off site and entered groundwater in the Chalk principal aquifer.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/644968/UK_National_Risk_Register_2017.pdf

https://www.hse.gov.uk/comah/buncefield/index.htm

A **gas explosion** at Buckstone Road, Edinburgh in 2005 was caused by interacting ground conditions.
→The four inch diameter cast iron gas main had suffered fissure corrosion at its base.
→ Ground instability had played a major role in the failure of the pipe (HSE, 2006).
→The resultant pipe leak allowed gas to migrate through the permeable soil where it collected within the basement of one of the properties in Buckstone Road, which finally resulted in an explosion.

An **gas explosion** at Bridge Street, Shrewsbury 2010 (Figure 13) prompted an investigation by the HSE (2010). It resulted in the destruction of six commercial properties in the town centre, luckily with no fatalities.

→ The sandy-gravel soil type which was identified within the excavated trench was deemed to be very aggressive to moderately corrosive.
→ The sandy-gravel soil type allowed the leaking gas to migrate to the nearby commercial properties that probably provided a source of ignition, there was no domestic gas supply to any of the affected buildings.

Mancunian way 'sinkhole' collapse: Torrential rain caused a sinkhole to develop which lead to serious damage to a 100-yr old sewer beneath the Mancunian Way, central Manchester. The road was closed for 10 months. Temporary sewer pipes were installed whilst a full replacement underground sewer pipe was installed by United Utilities at a cost of £6.5m
https://www.unitedutilities.com/corporate/newsroom/2016-news-archive/light-at-the-end-of-the-tunnel-for-mancunian-way/

Feasibility - SWOT - Natural Hazard Resilience

SWOT – Resilience to Natural Hazard

Strengths:
- Capability in localised risk analysis
- Clear operational criteria
- Improved cross-industry collaboration via Natural Hazards Partnership and Resilience Direct
- Highly skilled modelling sectors (e.g. flood)
- Strong regulation and licence conditions for resilience measures
- Momentum of collaboration

Opportunities:
- A market for resilience data/models exists
- 'Digital rehearsing' Digital Twins, scenarios and predictions for multi-hazards
- Access to high quality, curated and structured data
- A standard 'model'/'process' with a common operating agreement
- Re-insurance sector as potential hazard increase
- Ability to promote subsurface information to future resilience

Weaknesses:
- Modelling skills/data not always accessible/used
- Siloed approaches (e.g. geographical/ administrative boundaries to data sharing)
- Quality and level of detail of data
- Isolated communications
- Reactionary asset maintenance
- Not all data is free – a licence is needed, have to pay upfront but value isn't realised until later.
- Value of subsurface information not fully researched

Threats:
- Different resilience organisations use different ontologies and standards
- Increased hazards under climate change
- IP and security concerns means lack of sharing
- Potential disruption to existing markets for resilience assessments

Similar SWOT scenarios for both long term **Stresses** and Short term **Shocks** . UKCP18 predicts hotter direr summers and wetter winters, with extreme weather increases such as heat waves, stress , drought, storms and flooding. Better access to subsurface data will be required for critical asset assessments and more united data approach is a key aspect.

Feasibility - SWOT - Human Hazard Resilience

SWOT – Resilience to Human Hazards

Strengths:
- Identification of potential strains on infrastructure as a result of development (e.g. Urban Expansion, change in usage) or shock incident (e.g. Explosion, blast) Localised risk analysis by asset owners
- Clear operations criteria
- Cross-industry collaboration now encouraged
- Increase of awareness

Opportunities:
- Urban development leads to potential for subsurface data and information to be in demand.
- Wide communications and energy critical infrastructure focus
- Improved modelling and data sharing platforms
- Improved collaboration requested by Government
- Requirement for systems based approach (e.g. resilience and consequence of event on different local assets)

Weaknesses:
- Siloed approaches (e.g. geographical boundaries to data sharing)
- Localised risk analysis by asset owners
- Quality and level of detail of data
- Isolated communications between different operators
- Complexity in modelling of single point vs cascade failure

Threats:
- Different resilience organisations use different ontologies and standards
- Formats of data
- IP and security concerns means lack of sharing
- Potential disruption to existing markets for resilience assessments

Improved access to Subsurface information will assist response and planning for shocks and stresses as a result of human events. Uncertainty about expenses of adaptation and preparedness to event also register. Shared access to subsurface information could support financial side of resilience through removal of repetitive sourcing of common information. Whilst some site specific data may be too nuanced for a national register, wider information could have helped background information and event planning.