Adaptive asset management for flood protection

FAIR end report

BEGIN

Interreg
North Sea Region
FAIR
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Contents

Foreword

I am very proud to present you the End Report of the FAIR project (Flood defence infrastructure Asset management & Investment in Renovation, adaptation, optimisation and maintenance). This report is the completion of a successful project of the EU North Sea Region Program. It took place from 2016 until 2020. In this report you can find the results of the FAIR project.

As chair of the FAIR Policy Learning Group (PLG) I experienced up close the good collaboration between the FAIR beneficiaries developing the project, tackling its challenges and the reflection of the PLG-members on its developments and results.

I witnessed that a transnational approach plays a vital role in accelerating learning, as there is no budget or time for 'trial and error'. FAIR gathered together the major asset owners in the NSR in the first international collaboration of its kind.

The overall aim of the FAIR project is to reduce the flood risk across the North Sea Region (NSR) by demonstrating climate change adaptation solutions that will improve the performance of flood protection infrastructure.

Flooding poses a major risk of loss of life and economic damage in the NSR. Flood protection is the cornerstone of our strategy for reducing these risks. The infrastructure assets that protect us from flooding in the NSR, such as dikes, sluices and dams, are ageing: many are 70-100 years old and often fail to perform to the desired level. The flood protection infrastructure needs to be renovated, adapted and maintained right across the NSR.

FAIR demonstrates improved approaches for cost-effective upgrading and maintenance, optimising investments across national system asset levels, as well as applying adaptive, innovative technical designs. FAIR guides the full-scale implementation of reinforcement, upgrade and maintenance programmes for dikes, sluices, dams, flood gates and pumping stations at target sites in Belgium, the United Kingdom, Germany, Denmark, Sweden, Norway and the Netherlands.

The FAIR project has enhanced climate change adaptation methods and techniques by demonstrating improved approaches for adaptive investment planning and adaptive techniques for upgrading existing flood protection infrastructure. The demonstration and subsequent widespread implementation of the improved approaches and techniques will reduce the probability of flooding and minimise the impact of floods across the NSR, thus improving climate resilience at target sites covering most of the NSR.

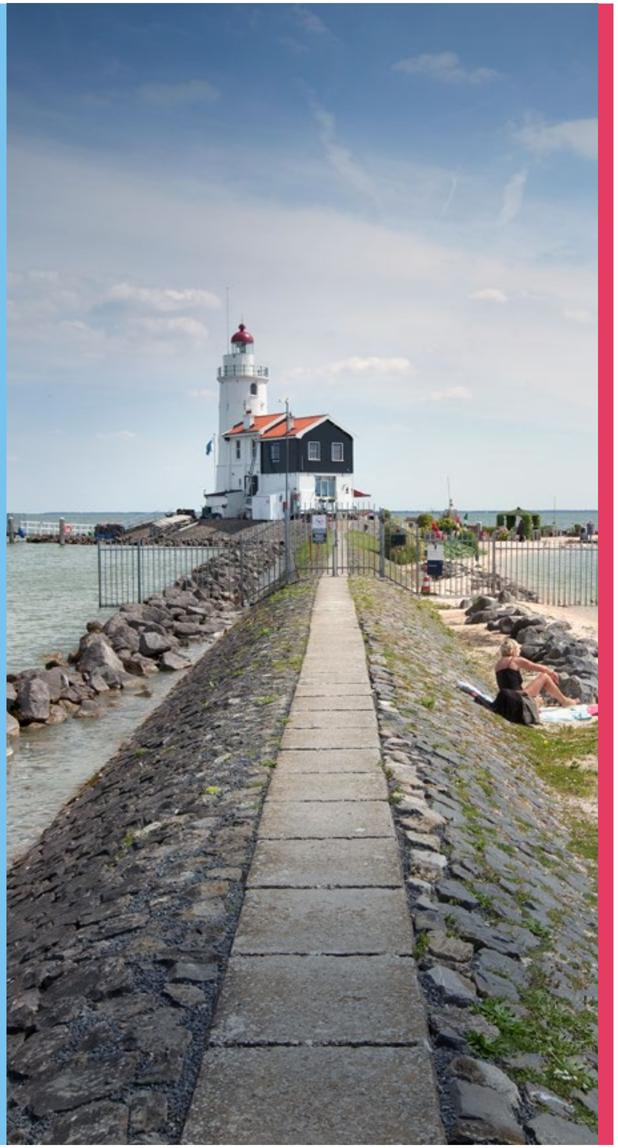
I would like to thank all the organizations for their work and cooperation in the FAIR project: Regional Water Authority of Schieland en de Krimpenerwaard (HHSK; NL), Agency for Maritime and Coastal Services, Coastal Division (MDK; B), The County Administration Board of Skane (SE), Helsingborg Municipality (SE), Danish Coastal Authority (DCA; DE), Esbjerg Municipality (DK), Sayers and Partners LLP (UK), IHE Delft (NL), Deltares (NL), Norwegian Water Resources and Energy Directorate (NOR), Hamburg Agency of Roads, Bridges and Water (LSBG; D), Hamburg University of Technology, Institute of River and Coastal Engineering (TUHH; D) , HAN University of Applied Sciences, Faculty of Technology (NL), Environment Agency (UK), Artlenburger Deich Verband Geschaftsstelle und Betriebshof (D), Dutch Flood Protection Programme (NL), ResilienServices (NL), Ecofutures ltd (UK) Rijkswaterstaat (RWS; NL) and the Joint Secretariat Interreg VB NSR Programme(DE).

“I wish all people who in any position have a role in flood protection asset management, take the TIME to read, learn and be inspired by the experiences of others”.

Willy Dekker

4 JUNE 2020 (MIDDELBURG, NETHERLANDS)

Summary and reading guide



This report is an output from the INTERREG NSR FAIR project[1] which aims to provide flood protection and flood risk management asset owners and operators, policy makers and fund holders, with guidance to help to address the various challenges facing those with responsibilities for managing the assets vital for protection from flooding in the NSR. The report draws on the experiences of the FAIR beneficiaries in shared working and brings together all of the various outputs from the project; intended to demonstrate good practice in asset management in the flooding domain, based on the pilot projects and experiences from the project.

The beneficiaries who have worked together on FAIR (from Belgium, Denmark, Germany, Netherlands, Norway, Sweden and UK) collectively represent the range of challenges and approaches being used for asset management for flood protection for countries in the NSR.

1. https://northsearegion.eu/fair/

Who this report is for

This report is relevant for policy makers, fund holders, planners, designers, operators and owners with an interest in asset management for flood protection. The report is not aimed at lay people, members of the general public and most citizens, unless they are especially well informed about flood risk management and the function and place of the assets used for this.

The various Chapters have particular relevance to the interested parties above. Policy makers should read this summary or the extended summary and if possible, Chapter 9 on the Way Forward. Funders may benefit from a clearer understanding of the issues and the new ideas about turning the flood 'problem' into one of seizing opportunities, as explained in Chapters 1 and 2, with inspiration from Chapter 7, where examples are given. Also the review of Challenges in Chapter 8 and Way Forward in Chapter 9.

Those responsible for planning, flood protection strategy, integrating with wider systems and services, many of whom are already familiar with the challenges and issues, will be interested in what FAIR is about in Chapter 2, the novel framework in Chapter 3 that the project has delivered, as a means of ensuring asset management is effective and above all adaptable in the face of change. Importantly, this will draw attention to the importance of the interface with the operational contexts of asset management, highlighted by the framework; and maintained by the tactical handshake. Following this, planners and others can follow the details of the framework, provided in Chapters 4, 5 and 6, with supporting examples from the FAIR pilots in Chapter 7.

Constraints to effective asset management are overviewed in Chapter 8 and a Way Forward in Chapter 9. Designers of flood risk management (FRM) or flood protection systems and assets will benefit from utilisation of the framework in Chapter 3, together with the details in Chapters 4 - 7. Operators need to be sure that they understand how the interaction with the strategic context of FRM asset management planning is essential, via the tactical handshake in the FAIR framework in Chapter 3. Chapter 5 provides more details of the operational context, and Chapter 6, of how the tactical handshake should function, with examples in Chapter 7. Asset owners may or may not be operators, but in any case need to be 'intelligent clients' who can be sure that any delegated operator, or consultant, is providing the required service. Therefore, owners need to be familiar with the approach used in FAIR, the framework in Chapter 3, together with the functioning of the framework components, ideally via Chapters 4 - 6. Owners also need to be familiar with the challenges in Chapter 8 and Way Forward in Chapter 9.

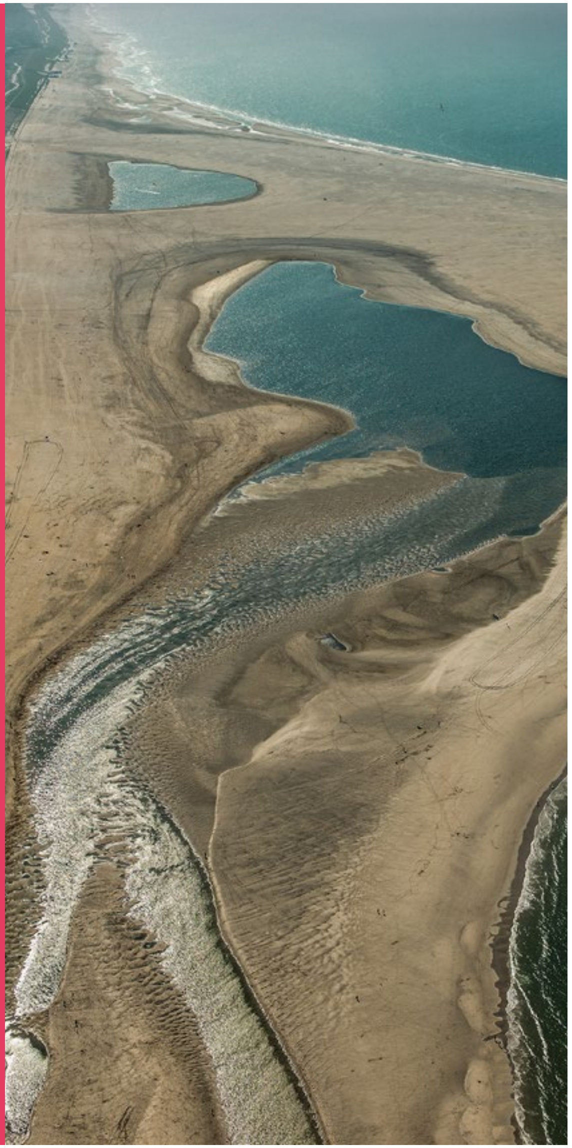
Context for the FAIR project

In the low-lying North Sea Region (NSR) flood defence assets are necessary to provide protection against flooding in many areas. This includes dikes, sluices, dams, floodgates, pipe or channel systems, pumping stations and increasingly, nature-based measures. Owners/operators of the flood defence assets have a great responsibility to keep these in such a condition that they will perform as required. As most of these assets are in public spaces, there is also the need to ensure that they are safe when the public interact with them.

Existing flood defence assets require recurrent replacement, renovation or reinforcement due to: deterioration; changing design loading; new policies and standards; new requirements; or new demands from users. The asset owner/operator needs to be able to predict when replacement or reinforcement is needed within a whole of life cost-effective or cost-beneficial plan process. Risk-based quantitative assessment approaches are now routinely being used to guide this planning.

Changing environmental drivers, including climate and societal needs and expectations, mean that the ways in which flood defence assets have been provided, operated and maintained up until now are not going to be adequate in the near and longer-terms. New ideas and innovations are needed if flooding is to be managed to acceptable levels at costs that are affordable by NSR countries. Increasingly, nature-based systems are being used in combination with structural measures. For example, the Dutch sand engine (or motor)[2], although engineered in design and construction, provides flood protection from utilising natural processes.

Increasingly, NSR countries are using flood defence systems for more purposes than flood defence, creating and sustaining attractive public spaces, walking and recreational areas and extra opportunities for wildlife and ecosystems, by creating natural capital. This multi-functional use can save money and create a host of added benefits to which new assessment tools are assigning financial value. These initiatives require new ways of working within and between the organisations responsible and across the numerous players involved in providing and maintaining flood defences and these other functions.



2. https://www.dezandmotor.nl/uploads/2016/09/monitoring-and-evaluation-report-sand-motor-eng.pdf

Understanding of existing asset performance and behaviour is needed to inform this process. Asset owners need to have information from continuous monitoring, reliable inspection data, historical data, and on going operational and maintenance data. Knowledge and understanding is needed about the asset deterioration processes, and of changes in loads such as sea level rise. Key to this are understanding potential failure mechanisms, application of analytical probabilistic approaches, and knowing the costs of measures.

Responding to the changing drivers and expectations necessitates the use of assets that are flexible and adaptable as well as robust. Scientific knowledge as to how to ensure this in design and planning new assets has advanced considerably in recent times. Asset Management (AM) processes need to reflect this and it is now essential that the processes used for AM planning within and beyond a responsible organisation need in themselves to be flexible and adaptable, as does the organisation itself. This is a key component of the recent ISO 14090: 2019 on adaptation.

Adaptive assets and adaptive asset management processes are essential. Interventions in AM need to be guided by a quantitative risk approach wherever possible. Uncertainties will be lessened when considering shorter asset timescales, but much greater for many flood protection assets, such as dikes, as these are long-lived.

Planning for shorter asset lifetimes is likely to lead to higher costs as more frequent adaptations will be required as drivers change and knowledge advances.

In contrast, high initial investment in robust defences where a long lifetime is taken into account, i.e. planned for drivers in the future, may not be cost-beneficial, giving a poor return on investment. Life cycle costing (LCC) should, however, help to provide the insight needed as to which approach will be best for a given case.

> Asset management is challenging and there are increasing numbers of interested parties, particularly where the asset has multiple functions.

Flood defences may be located in rural or densely populated urban environments with many varied stakeholders. This will inevitably lead to benefits for some and consequent impacts for others. Measures may for example, require an elevation to the sea wall to protect a community, but will impair the view and reduce the visual enjoyment of the sea for those living nearby. Asset owners/operators will need to be able to engage effectively with stakeholders in planning and operating assets if decisions are to be made that are as acceptable as possible for communities.

There has been a tendency to underestimate the importance of asset maintenance and the need to plan for this effectively over long periods of time; historically investments in capital projects have often been prioritised. During periods of financial stringency, budgets for maintenance, monitoring, adapting the asset, or replacement are often reduced, consequently important asset management measures can be postponed. Flood defences will typically not fail immediately if maintenance is postponed, or even over a longer period. This is because of the robustness of the assets, and the rarity that the design loads on the asset may happen only every 10 to 50 years. When flooding occurs during a politicians' period in office, often reaction decisions are made that are not based on long-term flood defence strategy, best scientific knowledge, or value for money, but for the need to be seen to be doing something. Stop-start funding and lack of prioritisation for asset management planning over decades across the majority of EU countries has resulted in mostly corrective maintenance being carried out in NSR countries. In addition, the important adaptation to keep pace with climate and other changes is not happening as speedily as is needed. This adaptation deficit has to be addressed as part of the on going process to establish an adaptive approach to asset management planning for flood defences in the NSR.

> FAIR has highlighted the need to be able to understand better the deterioration processes of individual types of asset in order to factor this into planning and predictions.

Beneficial outcomes from FAIR

The main outcomes and benefits from FAIR include a review of existing AM practices and AM processes for flood protection and flood risk management; bringing together of practices and knowledge as to how this can be improved in response to current and future challenges based on a number of pilot projects, outlined in individual reports; formulation of a framework around which AM can best be planned and delivered, the FAIR Framework; recommendations for policies that can help to deliver this in a Policy Brief; requirements for knowledge in a Knowledge Agenda report. The separate detailed FAIR Extended Summary report covers the activities and gives a brief overview.

The essential results from FAIR include a framework to help with asset management, developed from the experiences of the beneficiaries, that comprises three essential contexts: (i) strategic planning; (ii); operational asset management; (iii) a linking tactical handshake. The strategic context sets the overall vision and objectives; the operational context is where the day-to-day asset design, operation and maintenance is carried out, and these are linked by two-way information flows via the tactical handshake. The maturity of each of the FAIR beneficiary asset owners in terms of their

internal AM processes for flood protection has been assessed In FAIR using a standardised maturity analysis with a 5-point scale, defined by the Institute of Asset Management. Assessments carried out near the start of the project and towards the end, have shown that each beneficiary has enhanced the maturity of their AM processes as a result of FAIR.

Reviewing the application of the framework in FAIR in the pilot projects detailed in separate reports, has shown that the use of the framework can help to ensure that flood protection assets are designed and used to be as multi-functional as possible, that there can readily be reduced life cycle costs of at least 5%, and a typical prolongation of the lifespan of targeted infrastructure by at least 5%.

There are many challenges for asset managers, including how best to deal with single assets in the context of a network of defences. It is necessary to consider the asset and also the system of flood defences in context to develop integrated and best value multifunctional outcomes, including with the wider context of other interacting infrastructure systems. It is also necessary to try to align asset investment requirements with the timing of budget cycles.

However, where resources are coming from a number of stakeholders, alignment and making the required business case can be very time consuming and costly for the asset owner.

Writing about this, as in this report, is easy, but bringing it into practice is difficult. During the implementation of the recommendations in this report by the various interested parties, barriers will inevitably be put in the way or deliberately raised, by those who resist change. The FAIR project outcomes demonstrate that a risk based quantified approach needs to be used for adaptive asset management. This, for NSR citizens that increasingly refuse to accept risks, but at the same time are unwilling to pay the price for the expected risk control. Many such challenges are faced by asset managers, along with uncertainties, which FAIR has highlighted in a separate report dealing with knowledge gaps. To support this, FAIR has generated a number of policy recommendations, in a separate Policy Brief, alongside the knowledge gaps. These have been derived from and supported by the beneficiary pilot cases.

There are important gaps in knowledge still to be addressed if flood protection AM processes are to become assured into the future. These gaps relate to both the assets themselves and the processes used in AM. Although there are standardised approaches to AM, including ISO 55000: 2014, none of these is ideally suited to flood protection AM, hence the need for the guidance and oversight provided in this report based on the FAIR outcomes, outputs and benefits.

FAIR has highlighted the need to be able to understand better the deterioration processes of individual types of asset in order to factor this into planning and predictions. The increasing use of nature-based systems in particular, for which evidence on long-term deterioration (and even self-regeneration) is limiting their acceptability to traditional policy makers and professionals, constraining innovation in use. Where new techniques are also introduced in the world of flood defences, the wealth of data will increase. Such as sensors in dikes constantly measuring water pressures and deformation. Or in the more advanced calculating techniques (made possible by computational power), and the possibilities provided from smart phones connecting the operational field inspector via app to the theoretical 'back office'. The challenge is to determine which data is relevant and which is not. And how to make adequate information out of the data that helps in understanding the risks of eventualities like extreme storm surges or river discharges.

The FAIR policy brief provides details for four policy recommendations:

1. Break free of the silo;
2. Mind the gap;
3. Prepare for change;
4. Make space for innovation.

The first of these relates to the fragmented responsibilities for flood defence found across NSR countries, necessitating complex and at times, costly efforts to harmonise and integrate approaches, which is even more complex when the myriad of other services and systems and providers is included in the need to integrate planning and action. The second recommendation is at the heart of FAIR, expressed in the framework, and addresses the poor interconnection between strategic and operational AM. This reinforces the view of the need to strengthen the interconnecting tactical handshake. Preparing for change is the third policy recommendation and focuses policy makers on the need to change asset provision AM and AM processes to recognise and cope better with uncertainties. Change may be needed in every aspect of the current policy making, institutions, funding, players, processes and approaches to flood protection AM, in order for these to be sufficiently resourced, flexible and adaptable.

The fourth recommendation is about the innovation that is needed in every human endeavour, and the aversion to change (and with it perceived and real increases in risks) that is understandable on the part of decision makers and professionals. But, in order to cope with the future challenges, innovations will need to be embraced and attendant risks accepted and managed.

Finally, this report shows how FAIR has developed a better understanding of delivering adaptation in a practical way. Findings were confirmed and supported by a joint meeting between FAIR beneficiaries and the Environment Agency (England and Wales) in Oxford in February 2020. This concluded that adaptation is more than just about modifying a flood defence asset; it needs to recognise and factor for a whole of system rationale, set in the context that the world is changing faster than traditional thinking about AM, thus requiring a new approach. Uncertainties are now more than ever before, challenging traditional ways of doing things. To bring about the needed change every actor and player will need to break free of the silo within which they have been constrained to work and think. This needs better ways of: envisioning the future through e.g. storylines; addressing the hard choices and not avoiding them; ensuring that adaptation 'culture' is embedded here and now in everything that is done; understanding the need to perhaps invest more in preparing for rarely occurring hazards, even though this might be politically inconvenient[3]; doing the risk analysis we need without becoming trapped by modelling and information overload.

Above all, adaptation is not something to 'get done'; it is a continuous process that needs to become culturally embedded in NSR countries' infrastructure management practices, for both managing the assets themselves and also in the processes being used for asset management. The FAIR beneficiaries have together brought new ideas, restatements of old, but good ideas, framed around a new continuously running infinity loop that shows how asset management for flood protection and flood risk management can best be carried out to serve current and future generations.

3. FAIR beneficiaries have prepared this report in the midst of the global viral pandemic of 2020, bringing this message into stark prominence. [https://www.aquatechtrade.com/news/urban-water/covid-19-and-the-climate-emergency/?utm_term=&utm_content=AQD2020_NB_18&utm_medium=email&utm_campaign=Nieuwsbrieven_2020&utm_source=RE_emailmarketing&tid=TIDP1782825XD6AE3C76806943C9A341E7030A60BB33YI2&noactioncode=1]

Acknowledgements

This report could only be produced in a close collaboration of both the practice of the asset owners and the scientific knowledge institutions.

In the four years of this project, beneficiaries have learnt to appreciate the knowledge from one another by sharing more and more information. The asset and scientific teams became ever more closely one team, inspiring and challenging one another to a higher level of adaptive asset management for flood defences.

This was made possible by the support and financial arrangements of the European Union. The first acknowledgement therefore is to the Joint Secretariat of the Interreg VB North Sea Region Programme.

It is also important to acknowledge the essential contribution of all of the enthusiastic women and men working for the organisations who agreed to collaborate on this very timely and important task of helping prevent people, houses, infrastructure and valuable land from flooding.

These beneficiaries are : Rijkswaterstaat (NL, Lead Partner), Regional Water Authority of Schieland en de Krimpenerwaard (NL), Agency for Maritime and Coastal Services, Coastal Division (B), The County Administration Board of Skane (SE), Helsingborg Municipality (SE), Danish Coastal Authority (DE), Esbjerg Municipality (DE), Sayers and Partners LLP (UK), IHE Delft (NL), Deltares (NL), Norwegian Water Resources and Energy Directorate (NOR), Hamburg Agency of Roads, Bridges and Water (D), Hamburg University of Technology, Institute of River and Coastal Engineering (D) , HAN University of Applied Sciences, Faculty of Technology (NL),

Our thanks go also to the Policy Learning Group who helped the FAIR project by reviewing the draft results between the project stages, and in considering the best way to disseminate the results to the flood defence organisations in their respective countries. The Policy Learning Group was chaired by Rijkswaterstaat (NL) and the members were Environment Agency (UK), Artlenburger Deich Verband Geschaftsstelle und Betriebshof (D), Regional Water Authority of Schieland en de Krimpenerwaard (NL), Agency for Maritime and Coastal Services, County Administration Board of Skane (SE), Esbjerg Municipality (DE), Dutch Flood Protection Programme (NL) and Hamburg Port Authority (D).

Last but certainly not least, in combining all the input from the beneficiaries into a comprehensive and logical product, and editing and producing the end report, the policy brief, the knowledge agenda and the pilot reports are: Ecofutures Ltd, ResilienServices and Guerilla Creative.

Glossary

Term or abbreviation	Meaning in FAIR
Adapt, adaptation, adaptive, adaptability	Adaptation is the process of adjustment (mainly) to actual or expected climate and its effects (ISO 14090: 2019)
Asset	Item, thing or entity that has potential or actual value to an organization
Asset Management (AM)	Coordinated activity of an organization to realise value from assets.
Asset Management Plan (AMP)	Documented information that specifies the activities, resources and timescales required for an individual asset, or a grouping of assets, to achieve the organization's asset management objectives.
CAPEX	Capital Expenditure
Climate change	Refers to any long-term trend in mean temperature, wind speed, drift rate and its consequences on the mean sea level, wave height, rainfall etc.
Coastal defences	General term used to encompass both coast protection against erosion and sea defence against flooding. Synonym: Coast protection
Cost benefit analysis	Method of economic analysis that assesses both costs and benefits of an intervention, design option or management process, estimating both costs and benefits in monetary units. This analytic technique is useful to compare alternatives
Deterioration	1. A gradual decline, as in quality, serviceability or strength. 2. Decline in the material properties of some or all components of an asset caused by external agents (e.g. freeze/thaw) leading to a reduction in its structural strength. See also Degradation, Weathering
DCA	Danish Coastal Authority
Dike	Flood protection linear structure that can be geotechnical works (levee), masonry, or concrete structure (flood wall). Also relates to sea dikes (breakwater) or the dikes along a canal or the auxiliary structure associated with a dam that serves to retain the reservoir. Also relates to river training structures. These structures are typically constructed using rock. Synonym: Wingdam.
FAIR	Flood defence infrastructure Asset management & Investment in Renovation, adaptation, optimisation and maintenance
Flexibility	Absorb loading without failure (deform). The ability to be easily modified or ability to change
Flood	1. Discharge of water beyond the mean discharge under conditions of high water level. A flood is described by its probability of not being exceeded, its hydrograph, max discharge, duration, and volume. 2. An inundation (by overflowing or overtopping) that comes from a river, a sea or other body of water and causes or threatens damage. Also, any relatively high stream flow overflowing or overtopping the natural or artificial banks in any reach of a stream
Flood risk management (FRM)	Flood risk management aims to reduce the likelihood and/or the impact of floods. Experience has shown that the most effective approach is through the development of flood risk management programmes incorporating the following elements: Prevention, Protection, Preparedness, Emergency response, Recovery and lessons learned
Flood protection (FP)	Preventing damage caused by floods by avoiding the construction of houses and industries in present and future flood-prone areas, as well as by adapting future developments to the risk of flooding and by promoting appropriate land-use, agricultural and forestry practices.

Term or abbreviation	Meaning in FAIR
HHSK	Waterboard of Rotterdam (Hoogheemraadschap Schieland en Krimpenerwaard)
Infrastructure	Collective term for a group of assets needed for the operation of a society or enterprise or the services and facilities necessary for an economy to function. It includes physical resources, services and information technology facilities, networks and assets that, if they were disrupted or destroyed, would have a serious effect on the health, safety, security or economic well-being of citizens or the effective functioning of government. Examples include roads, railways, public services, power supplies and telecom equipment
Integrated Asset Management (IAM)	Provides knowledge and best practice in asset management to ensure the best total value is derived for the individual, organisations and wider society.
Joint Research Centre (European Commission) (JRC)	https://ec.europa.eu/info/departments/joint-research-centre_en
Life Cycle Cost (LCC)	Total cost of managing an asset over its design life (or service life), i.e. the assumed period of time after construction or refurbishment when an asset meets or exceeds its functional performance requirements with anticipated maintenance but without major repair being necessary
LSBG	Agency of Roads, Bridges and Waters, Hamburg (Landesbetrieb Straßen, Brücken und Gewässer)
Mainstream	1. A prevailing current or direction of activity or influence 2. To utilise one form of planned development to include an additional or more services, e.g. property renovation can include climate proofing

Term or abbreviation	Meaning in FAIR
Maintenance	All activities whose purposes are to maintain or restore a system in a state or in given safety or working condition, to perform a required function. It includes preventative maintenance and repairs (exclusive options). Generally it consists in repairing or replacing the components of a structure whose life is less than that of the overall structure, or of a localised area that has failed or will fail
Maturity analysis	Maturity is a measurement of the ability of an organization for continuous improvement in a particular discipline. The higher the maturity, the higher will be the chances that incidents or errors will lead to improvements either in the quality or in the use of the resources of the discipline as implemented by the organization.
Nature based assets	Assets that both provide a service like flood protection and also benefit from providing natural capital and ecosystem services
NSR	North Sea Region
Operational context	A continuous process of activities of planning of measures for the assets, design & construct, monitoring, maintenance & operation and performance of assets.
OPEX	Operating Expenditures
Probability or likelihood	Likelihood is a measure of the chance, or degree of belief that a particular outcome or consequence will occur. A probability provides a quantitative description of the likelihood of occurrence of a particular event. Probability is expressed as a value between 0 (impossible) and 1 (certain). Likelihood can be expressed qualitatively as well (e.g., high, medium, or low).
Resilience	The ability to avoid, minimize and recover from the effects of adversity, whether natural or manmade, under all circumstances of use

Term or abbreviation	Meaning in FAIR
Risk	Risk is defined as being a function of the probability that an event will occur and the consequence associated with that event. Risk = f (probability x consequence). A measure of the probability and severity of undesirable consequences or outcomes
Risk management	The systematic process of risk assessment, options appraisal and implementation of any measures to control or mitigate risk.
Robustness	the ability to withstand or overcome adverse conditions or rigorous testing
RWS	Rijkswaterstaat
Scenario	Account or synopsis of a possible course of action or events.
Shareholder	An individual or a group with a defined share in the asset and/or the asset operation
Stakeholder	An individual or group with an interest in, or having an influence over, the success of a proposed project or other course of action.
Storm surge	A rise of sea elevation caused by water being pushed up against a coast under the force of strong onshore winds such as those accompanying a hurricane or other intense storm. Reduced atmospheric pressure may contribute to rise.
Strategic context	A continuous process of data and information gathering, analysis, adjustment and the adaptation of policies and assets (including modifying the probability of flooding and its severity as well as the vulnerability and resilience of the receptors threatened) to appropriately manage an ever changing risk
Sustainable development	The concept of development that meets the needs of the present without compromising the ability to meet future needs.

Term or abbreviation	Meaning in FAIR
System	Assembly of elements, and the interconnections between them, constituting a whole and generally characterised by its behaviour (e.g. elements in a structure, or assets in an asset system)
Tactical context/ handshake	Links the strategic and the operational contexts with information and ensures communication is constantly flowing between them
TOTEX	Total Expenditure
Uncertainty	Lack of sureness about someone or something ranging from almost complete sureness to almost complete lack of conviction about an outcome. Caused by (a) natural variability (inherent uncertainty), or (b) incomplete knowledge (epistemic uncertainty)
Upgrading	Improved performance against a particular criterion.
Visual inspection	A visual inspection of a flood defence asset to assess its condition in line with a fixed risk-based programme. The result of this inspection is used to report both externally and internally on the condition of the asset.
Vulnerability	The susceptibility of people and assets in the flood risk area to physical or emotional injury or damage during an event
Water level	Elevation of still water level relative to a datum.

Sources:

An Anatomy of Asset Management version 3 December 2015

CIRIA (2013) International Levee Handbook

1 Adaptive asset management for flood protection

1. Adaptive asset management for flood protection

This Chapter sets the scene for the ensuing Chapters by highlighting:

- The key facets or trends for adaptive Asset Management (AM) for flood protection, which include:
  - Integrated Asset Management (IAM)
  - Increasing knowledge base associated with AM
  - Using nature based assets
  - Inclusion of (local) Flood Risk Management (FRM) assets
- The principles for an adaptive AM approach to flood protection;
- The benefits from taking an adaptive AM approach for flood protection.

1.1. Setting the scene: Assets and flood protection in the North Sea Region

Two-thirds of European citizens are expected to be at particular risk from climate change weather-related events by the year 2100 (Krona *et al.*, 2019). A real-time online facility reporting flooding incidents shows how these are increasing in most parts of Europe[4]. Countries with significant coastal populations will be particularly affected, including The North Sea Region (NSR), where communities are vulnerable to changes in sea level and added storminess. Inland, increased rainfall intensities and volumes will increase localised fluvial and pluvial flood risks, although not in Southern Europe where these will decrease (Blöschl *et al.*, 2019). Estimates of the expected annual damages in Europe from coastal flooding, under a high-emissions scenario, for example, show that Europe may suffer economic losses of around €39bn per year by 2050 and up to €960bn per year towards the end of the century (Vousdoukas *et al.*, 2018). River flooding is also predicted to increase substantially in Northern Europe, especially in the NSR countries, due both to higher rainfall and also backup surges from increased sea levels (Guerreiro *et al.*, 2018). Pluvial flooding, which impacts mainly urban areas due to rainfall, is also increasing and managing this is complex due to the need to maintain water cycle services, such as water supplies and in rural areas, irrigation (Ashley *et al.*, 2020).

Vulnerabilities are especially intense for communities in the NSR as these comprise some of the most active globally for transport and commerce. Hence, flood protection is vital for the NSR.

NSR economies and societies currently depend heavily on existing flood protection infrastructure. Much of the existing assets are in poor condition due to a variety of factors, including ageing and inadequate maintenance, uncoordinated planning between capital and maintenance investments and the use of obsolete technology. In the NSR many existing assets used for flood protection were built in the early 1900s and after WWII, with a life span of 80-100 years, i.e. end-of-life has occurred, or will between now and 2050. Moreover, the land use of the protected areas has significantly changed after the construction of the flood defences. Building houses, developing infrastructure and more and more industrial activities mean that the consequences of flooding have changed and that the benefit-cost analyses on which the original flood protection standards were based are often no longer valid.

4. http://floodlist.com/europe

Deciding whether or not to abandon, improve, upgrade or replace the original assets is an enormous challenge for the NSR, especially as the employment of safe and secure assets has created an often false sense of security amongst populations (e.g. Ballinger *et al.*, 1994). As flooding seemingly occurs relatively rarely (albeit with increasing frequency in the NSR), policy makers and populations as a whole, rarely prioritise the need to spend money on flood protection. It is only those who experience flooding who call for increased and effective investments, although infrastructure providers in other sectors, such as energy supply, are becoming increasingly concerned with the vulnerability of their assets to flooding (e.g. Unterberger *et al.*, 2019). There is often a generational issue, with populations who experienced flooding, like those alive today after 1953, being highly sensitised and willing to engage in and fund new defences. Whereas generations without such experience often deem such investment as not a priority.

Notwithstanding the above, currently NSR countries' policies aim to renovate, adapt, and maintain systems and assets used for flood protection. This includes dikes, sluices, dams, flood gates, pipe or channel systems, pumping stations and increasingly, nature-based measures (e.g. Reguero *et al.*, 2018). Most traditional flood protection systems comprise 'structural' components, relying on engineered infrastructure, including concrete, earth-filled dikes and buried pipes. These have often been used in isolation as localised defences. Only since the mid 20th Century has a risk-based, rather than a 'protect-at-all-costs' approach been utilised in their design and management (e.g. Oostendorp *et al.*, 2016). Increasingly, the growing understanding of the need to manage risks by taking a systems approach has positioned individual measures like sluices, into an integrated, holistic perspective. Alongside this shift has been the development of reliability scientific knowledge (e.g. Klerk and den Heijer, 2017) and asset management (AM) as a distinct endeavour[5]. The latter state: *"The reliability of a flood defence is therefore the main performance indicator to be used in finding optimal asset management strategies."* The definition of AM is given by ISO 55000: 2014 as: *"the coordinated activity of an organization to realise value from assets".* Assets are any *"item, thing or entity that has potential or actual value to an organization".* Flood related assets are, of course, designed to bring value to communities and individuals, rather than to an organisation. Whereas in other contexts, such as water services, there can be too much of a focus on the value of the assets themselves and not enough on the service these assets provide (e.g. Jones *et al.*, 2014).

There is an adaptation 'deficit' in NSR countries, where there are shortcomings in services such as those providing flood protection (e.g. Pathirana et al., 2017). Hence, projects such as FAIR are dealing not only with the need to plan for how best to adapt assets in the future in response to change, but also the need to adapt existing assets now, in order to remedy the already existing and increasing deficit.

1.2. Drivers and trends for adaptive asset management

Understanding of the significance and challenge of dealing with the ageing of the existing flood protection assets in the NSR is growing (e.g. Klerk and den Heijer, 2017). Also, there are challenges when needing to decide when to invest in new defence systems or to abandon indefensible areas, particularly at the coastline. In particular, three drivers are increasing understanding of and motives for, a change in practice as regards AM:

5. e.g. The Institute of Asset Management (IAM) are "the international professional body for whole life management of physical assets". [https://theiam.org/]

- **Autonomous and Semi-Autonomous drivers** such as natural geophysical phenomena and other factors that can increase sea levels, cause soil subsidence in urban areas, and sedimentation in rivers, alongside the deterioration of existing hydraulic structures. Although many drivers are as a consequence and outcome of human actions (e.g. increased CO_2 emissions), many of these are effectively uncontrolled, requiring responses to mitigate or adapt to their affects.
- **Societal drivers** include aspirations to promote sustainability, to utilise a circular economy approach and to be more transparent in decision making, need to be incorporated as far as practicable into any changes in AM processes and practices.
- **Professional drivers** have changed significantly from an engineer-led mono-utility perspective to one that aspires to provide multi-functionality from all utility, service and infrastructure assets. This necessitates new approaches, cross-disciplinary working, working with and in communities, and innovation, together with new ways of understanding, sharing and allocating risks.

Traditional static, defined for a lifetime, AM processes and procedures are no longer adequate to cope with these and other drivers. As a result, contemporary drivers are encouraging growing moves to utilise life cycle approaches for AM, together with new ideas and techniques that will be able to better ensure service is provided from society's infrastructure into the future, notwithstanding the uncertainties faced. The management of flood related assets has therefore evolved into a more integrated and optimised process that has a number of facets. What was originally seen as a systematic way of allocating limited resources to optimally manage risk to service levels provided by infrastructure assets (formalized by ISO55000), has been broadened over the last decades to include effective means of improving, rather than just sustaining current service levels. The key facets or trends relevant for adaptive AM are elaborated below.

a. Integrated asset management (IAM)

AM has moved on from ensuring an individual asset provides the required service in isolation (although ensuring the service is provided by each asset is still important), to a broader perspective that encompasses interdependent infrastructure assets (e.g. Pant *et al.*, 2018) and an integrated perspective across and between assets, i.e. an IAM (integrated asset management) approach (e.g. Sayers *et al.*, 2010). This applies especially to the Flood Risk Management (FRM) domain. FRM is the process for the analysis, assessment and management of flood risk, which aims to reduce the likelihood and/or the impact of floods. In the FRM domain, there are two types of asset: (i) the asset designed to manage flood risk, and (ii) the assets being protected by the flood risk management assets. For (i), flood protection[6] infrastructure should have very high protection levels, as failure should be avoided virtually at all costs. Whereas FRM infrastructure may accommodate more frequent failure, especially where the consequences are relatively low, as illustrated by the upper left quadrant in Figure 1.1. in (i), there are differences between coastal protection needs and how potential floods should be managed in inland and urban areas. In the latter, inland waterways and urban drainage systems also provide important opportunities as part of the water resource cycle, and excess rainfall and flows need to be handled carefully in order to best balance resource opportunities and potential risks (Ashley *et al.*, 2020).

6. Flood protection should not be confused with seeing water on surfaces occasionally where it causes little disruption, which is flood risk management (FRM). Although communities often consider this to be flooding, such occurrences will need to be tolerated more often in the future in order for flood protection from larger events to be affordable (Ashley et al., 2020).

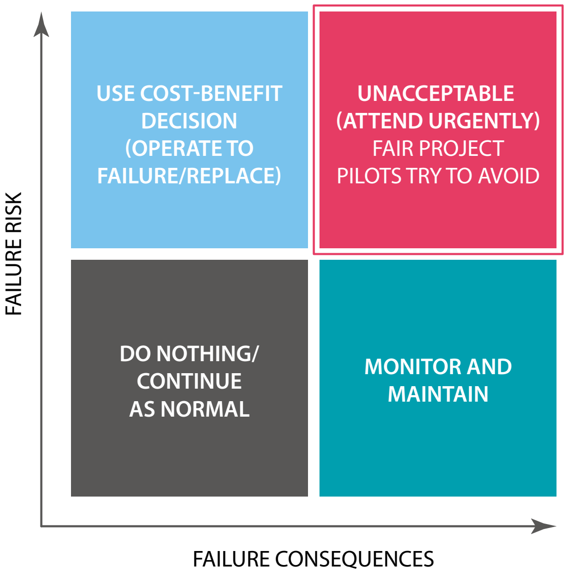


Figure 1.1 The traditional risk-consequence diagram – FAIR aims to ensure that all asset owners/operators manage assets in the safe regions outside the unacceptable zone

Coastal protection aims to prevent both flooding and the associated coastal erosion where this is likely to lead to hazards. Thus, FRM is broader than flood protection in that it aims to manage risks to acceptable levels at the same time as exploiting the wider opportunities, and could function, albeit only under careful management, in the upper right hand quadrant in Figure 1.1.

IAM can nowadays be seen as a necessity that has arisen from the relative inability of traditional engineering to deal with resource-constrained situations and has evolved in infrastructure domains that have higher investment returns than for flood defences (e.g. Sarvestani *et al.*, 2019). IAM enables better targeting of resources by using a combination of operation and maintenance strategies for flood defence assets with different failure risks and consequences. This process aims to avoid system risks moving into the unacceptable region, as shown in the upper right quadrant of Figure 1.1. Since its broad introduction in the 1990s, many new ideas and methodologies have been developed to ensure that the IAM process is itself adaptable, and delivers the right assets that are adaptable for both existing and new infrastructure.

b. Increasing knowledge base associated with AM

The knowledge associated with AM has advanced considerably as this field has grown within the financial services domain, where maximising asset value is the goal. Applying this in the flood protection domain is, however, not straightforward. In the FRM domain, there are major differences between the supply of other services, such as telecommunications by a single major utility. In contrast, every aspect of society has a role to play in managing the FRM systems and assets needed to cope affordably with the potential impacts. AM has taken on a new form in this millennium. ISO 55000:2014; ISO 55001:2014 and ISO 55002:2018 (asset management) frame concepts for AM around maximising asset value and return on investment, providing guidance as to how to achieve this. Whilst applicable in general in the flood protection domain, the guidance requires careful interpretation in this context. Concurrent with FAIR, ISO 14090: 2019 (adaptation to climate change) has been published and set out the *"principles, requirements and guidelines for adaptation to climate change. This includes the integration of adaptation within or across organizations, understanding impacts and uncertainties and how these can be used to inform decisions"*. This not only applies across organisations, but within organisations and also across sectors. The ISO defines adaptation as the *"process of adjustment to actual or expected climate and its effects"*. Such adjustments apply to every aspect of flood protection, FRM and the associated organisational and other processes as well as the assets used for this. These reflect the findings of FAIR and this report illustrates the need to follow the ISO recommendations.

Several aspects of ISO 14090: 2019 are especially significant for FRM, regarding the responsible organisation's processes and behaviours:

- **Foster a change oriented perspective**: *"When adapting to climate change, an organization prepares, supports and facilitates organizational change at all relevant levels. Change may be proactive in anticipation of changing circumstances or reactive in response to conditions that have altered. The magnitude of change can range from incremental, involving minor adjustments, through to transformation."*
- **Be flexible**: *"The organization continually reviews, responds and adapts to new conditions, information, methods and solutions as they emerge. It uses continual learning and adaptive management processes, adopting an iterative approach to improve understanding, decision-making and implementation processes."*
- **Mainstream and embed the processes**: *"Climate change adaptation is most effective when it is integrated into the organization's processes (such as policies, plans, procedures and implementation)."*
- **Points for change**: *"In organizations driven by policy and investment cycles, decision points (e.g. maintenance cycles and asset replacement needs) can be useful entry points for adaptation action."*

As for ISO 55000, the applicability of ISO 14090 to flood protection and AM requires careful consideration.

c. Using nature based assets

As well as continuing to utilise traditional infrastructure, actors involved in FRM will increasingly need to consider the place of nature-based asset (NBA) systems[7] and how these need to be managed as assets (e.g. Papacharalampou *et al.*, 2017; Hobbie & Grimm, 2020). There is a growing initiative to adopt hybrid systems as explained by Sayers *et al.*, (2015) and illustrated recently by Kapetas & Fenner (2020), where both traditional and nature based assets are used together in an integrated way (IAM), as illustrated by the Middelkerke sea dike renewal in FAIR (Table 2.1). Nature-based systems can provide significant added benefits in oceanic and coastal regions as well as inland, in urban areas (e.g. Natural Capital Committee, 2020).

Although there are well developed methods for managing traditional assets for FRM, there are significant differences in the way in which the equivalent NBA need to be considered. NBA have the capacity to self-regenerate, unlike traditional infrastructure, hence the potential service levels NBA can provide need to be considered in new ways, for which appropriate AMP processes are still under development. Although there have been initiatives to define AM for stormwater managing blue-green measures in Australia and New Zealand (e.g. Browne *et al.*, 2017).

d. Inclusion of local FRM assets

- As well as large-scale centrally coordinated flood protection, NSR countries require essential on-the-ground engagement with planning authorities, landowners, property dwellers and local communities for effective delivery of FRM schemes, together with appropriate AM. Hence there is a need to develop targeted guidance for local and sometimes private, asset owners for investment in flood protection infrastructure (e.g. Bisaro & Jochen, 2018). Examples include property resistance measures and to facilitate resilient recovery.
- Moreover, the services provided by flood protection assets may not always be expected to provide an 'infinite' lifetime of protection. This is unlike other public service infrastructure assets, like water and wastewater services (e.g. Alegre & Covas, 2015), that are typically intended to provide an effectively infinite life of providing the essential service, independent of the assets themselves, which will have finite lives. Flood protection, in the rapidly changing world, may no longer be provided in a given area or to a given community, due to the need to focus on alternative areas or priorities. This is why the abandonment or moving of communities is now seen as a main component in overall flood protection, within a strategy that encompasses a wider region or even country (e.g. Committee on Climate Change, 2018).

1.3. Adaptive asset management

The practice of AM as either or both IAM or Asset Management Planning (AMP) may or may not be formalised into a defined process. Adaptive asset management applies to both the processes used for IAM / AMP and also to the assets themselves. ISO55002: 2018 states that: *"The organization should establish, implement and maintain processes and (as applicable) procedures for the continual improvement of its assets, asset management and the asset management system. These processes and procedures should define the decision-making criteria for continual improvement and the necessary responsibilities and authorities….. Continual improvement processes should be commenced and also stopped based on changing risks to the organization, or to its objectives and value".*

7. Examples for natural water retention measures: http://nwrm.eu/measures-catalogue

From Section 1.2, it is clear that there are numerous challenges to delivering adaptive asset management, and these are at every level in the current approach to policy, planning and delivery. There is a need to consider individual asset performance within and as part of a system or network of flood protection infrastructure, for example, Jongejan *et al.*, (2020) point out that major dike systems are series systems with little to no redundancy, hence understanding the difference between component and system reliability is essential for reliability analyses of flood defences. Any approach should to aim to optimise investments across system assets, requiring also the use of innovative technical designs for assets that are adaptable.

Mainstreaming in FAIR is about seeking opportunities to connect investments in flood protection infrastructure with other complementary investments, such as for transportation, recreation and ecosystem restoration, to deliver multi-functional infrastructure (Rijke *et al.*, 2016; Wamsler et al., 2017). Much of the new infrastructure will be nature-based, as this is both multi-functional in performance as well as more readily adaptable than traditional infrastructure (Kabisch et al., 2017; Dawson *et al.*, 2018; Kapetas & Fenner, 2020).

This will bring many benefits, not least economies due to integrated system use, but also numerous subsidiary 'knock-on' or unintended, benefits (e.g. Fenner *et al.*, 2019).

In view of the rapidity of change in current and future drivers, the processes used for AM and AMP as well as the assets themselves need to be readily adaptable in response to new information and knowledge as this comes to light.

Box 1.1: Characteristics of adaptive AM that have emerged from FAIR

FAIR (refer to Chapter 2) has demonstrated that compared with traditional AM:

- There is clearly now a greater focus on functionality and service performance at network and system level rather than at the level of a single asset;
- The focus has broadened to encompass the functional and economic lifetime of assets rather than concentrating only on the technical lifetime;
- There is more focus on the life cycle cost rather than the cost of a single intervention at a single point in time;
- There is increasing interest in finding a cost, risk and performance balance rather than looking for a cost optimisation;
- New decision criteria have recently emerged: adaptivity, resilience and robustness, although considered implicitly in past decisions, these have now become primary criteria for the necessary integrated analysis and comparison of AM strategies and measures;
- Decisions and asset management are now informed by the quantification of the outcomes of a particular AM strategy and process, supported by novel data, techniques and approaches including the use of more information and Big Data (in itself an asset);
- Risk based planning, processes and analyses are used at every stage of AM in order to facilitate multi-objective optimisation to understand and decide on trade-offs between risks and benefits;
- Increasingly, multi-functional assets are being utilised, especially nature based assets that both provide a service like flood protection and also benefit from providing natural capital and ecosystem services, however, knowledge as to how to best include these, or hybrids with traditional in combination with natural assets in IAM processes, is lacking for robust utilisation.

- Knowledge of the location of, condition of, and performance trajectory of, existing assets is growing, helping to better understand the ageing and degradation/ deterioration process of FRM assets;
- The new approach to IAM has increased awareness of the need, and means, to communicate more transparently and in appropriate ways to the variety of stakeholders involved, ensuring that the responsibilities for the planning of assets, their delivery, maintenance, operation and life performance are vested appropriately in groups or individual actors, each of which are appropriately resourced;
- The traditional funding planning cycles for AM need to be reformed, as these more often than not lack synchronicity with both the needs for investment and the potential to maximise propitious mainstreaming opportunities;
- There needs to be no preferential differentiation between so-called capital investments (CAPEX) and revenue investments (OPEX) in AM planning; rather a whole-of-life approach is required, i.e. 'total expenditure' (TOTEX).

Traditional perspectives on AM have envisaged the need to maintain functionality by periodic maintenance, as illustrated in Figure 1.1(a). Over the lifetime of an asset, ageing/deterioration will require investment to make sure that the asset performs as required, although over this time societal needs may also require performance to be even better than when first designed and commissioned. Rapid changes to external factors, like climate, may also necessitate significant investments in the asset(s) to keep pace with these, i.e. adaptation over time.

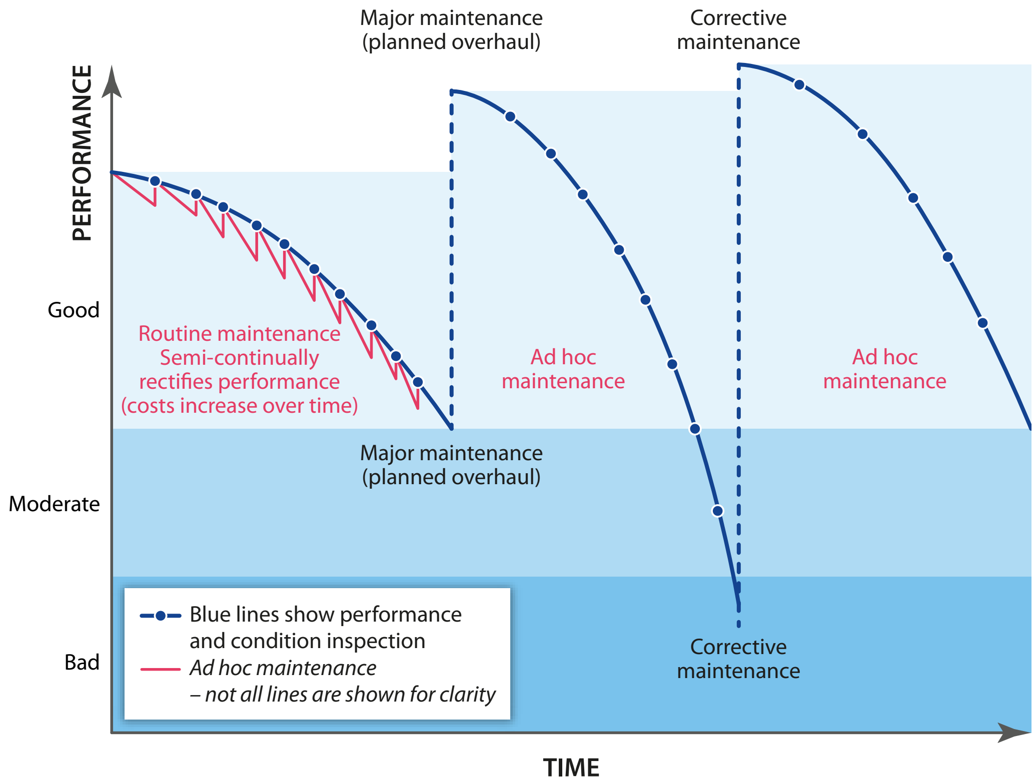


Figure 1.1(a) Traditional asset maintenance 'saw-tooth' diagram (various sources, e.g. Lloyd, 2010)

The adaptive AM approach includes two primary forms of positive intervention during the lifetime of assets: routine maintenance; and adaptation. Each of these may be required several times during the life of an asset. In general, maintenance relates to the investment in maintaining the as-designed performance, whereas adaptation may change the performance from the original design as shown in Figure 1.1(b); potentially also adding additional functions. Figure 1.1(b) shows the performance thresholds rising over time, due to the need to ensure assets respond to e.g. changing climate, and also to societal needs and expectations.

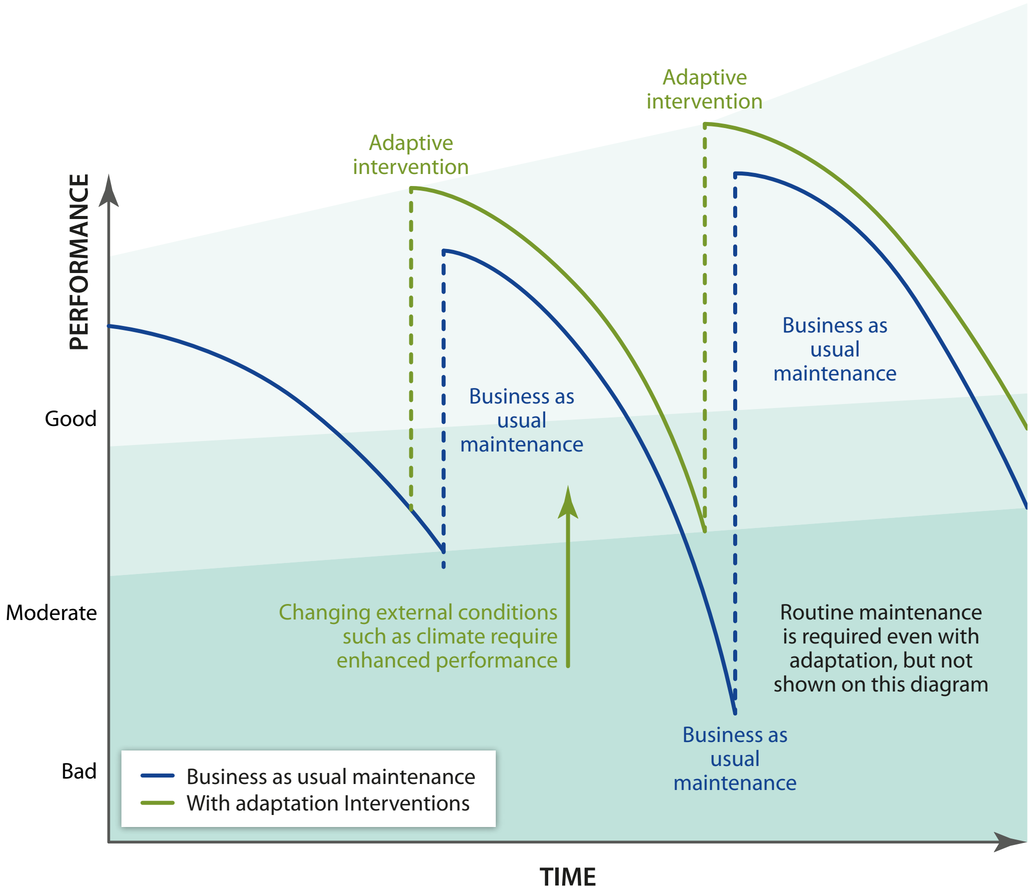


Figure 1.1(b) Adaptive asset management and the 'saw-tooth diagram' as contextualised in FAIR

Maintenance is usually pre-defined as being required at various stages in the asset lifetime based on historical information about performance. For example, mechanical and electrical equipment will need maintenance frequently, and even replacement regularly. There are also typically specific time intervals set for routine maintenance inspections of condition and by implication, asset performance, as illustrated by the dots in Figure 1.1(a). There is an option for enhancing the maintenance efforts before the end of life to bridge the period between not knowing what the effects of change in external factors will be, and the outcome of research studies related to these effects; hence narrowing the uncertainty risk.

Adaptation interventions are more often based on external drivers, using indicator thresholds, such as sea level rise, or rate of rise, and based on lead-times, i.e. how long in advance of a threshold adaptation action is needed (e.g. Rayner, 2010).

These set the conditions for the pre-warning of the need to intervene/effect an adaptation. The indicator warning period depends on the uncertainty associated with predicting the change estimate, or time of arrival of the key threshold, e.g. when will the sea level rise to the critical threshold? The Thames Barrier in London has been operated significantly beyond its' originally designed life by means of this approach and using adaptation pathways (see Box 4.4).

In Figure 1.1(b), the maintenance activities shown in Figure 1.1(a) are represented by the blue lines, although the 'saw-tooth' maintenance activities shown in pink in Figure 1.1(a) are not shown. The changing external drivers mean that the thresholds for the performance conditions 'bad', 'moderate' and 'good' change over time. Because of this, the business as usual maintenance in Figure 1.1(a) will not cope with the changes needed, hence adaptation interventions are shown in the green lines, ensuring performance is sustained to be at least of a moderate standard.

Details of types of adaptation measures that may be used are not included in this report, other than in the pilot cases (Table 2.1). As well as traditional 'engineered' adaptations, Nature Based Assets (NBA) potentially may adapt autonomously in response to changes, even without operator intervention.

In the light of the above, it is possible to define principles for the on-going approach to flood protection AM and AMP based on FAIR:

1. **Asset performance** - consider individual asset performance especially reliability, including adaptability (flexibility), and also the role of the asset within and as part of the wider system – even beyond flood protection – seeking to optimise investments through innovation.
2. **Mainstreaming** – take this approach to conjunctively link flood protection with assets in various infrastructure sectors to collectively build in adaptive capacity.
3. **Multiple functions** - look for how assets can deliver other services beyond flood protection – the wider vision of flood risk management will provide opportunities that may be realisable at no, or limited, added costs.
4. **Nature-based infrastructure** – should be used where possible, as this will inherently include the above aspirations.
5. **Approach to and processes used for AM & AMP** – need to be kept under continuous review and adapted in the light of new information and knowledge about the processes used to ensure robust, resilient and reliable asset performance.

1.4. Benefits and delivery of adaptive asset management

Adaptive AM is about ensuring asset flexibility, accepting the need to make changes to respond to the changing drivers, but at the same time maintaining service performance and robustness. Since AM aims to ensure service provision reliably over time, it focuses on balancing performance, risks and cost in a changing world, not only with respect to climate and asset deterioration, but also with respect to use and function. Thus the various decisions and interventions decided upon during the lifetime of an asset, or for a group of assets, are an effective way to both bring and utilise adaptability in asset management. Ultimately once it becomes the norm, the use of adaptive asset management will lead to more reliable and robust assets that will consequently reduce the probability of flooding and minimise the impacts across the NSR in the most effective and efficient way.

Specific benefits of taking an adaptive AM approach for flood protection include (Sayers *et al.*, 2006):

- **Priorities:** AM can focus on priority areas (however defined) in terms of flood risk reduction or protection;
- **Options:** Flood risk managed using a range of possible options can be assessed; so that best value AM options (that is, not necessarily cheaper) can be selected. Owners, operators and stakeholders can define what their objectives are in terms of best value;
- **Best value:** Innovative methods and tools can help to justify type of infrastructure, maintenance, renovation and adaptation actions in terms of flood risk reduction and other requirements, such as ecosystem restoration and/or mainstreaming with other services and infrastructure;
- **Evidence:** Assets will best be managed based on evidence of their condition and contribution to reducing flood risk;
- **Information:** An AM system will steer the collection of relevant data and develop improved risk information for investment decision making based on AMP;
- **Consistency:** There will be a consistent approach to flood risk management at the national or regional level; providing more coherent and most needed protection across the country or region; and bringing efficiencies and opportunities in terms of capacity development.

1.5. Structure of this report

The FAIR project (see Chapter 2) has concentrated on AM and the latest developments in IAM. This report sets out the key findings from the project related to the realities of adaptive asset management for flood protection. Specific scientific and technical guidance on the analysis of flood risks and the responses thereto is not included. This may be found in numerous other project publications and national guidance[8]. Reading guidance is provided in the Summary for each of the various likely interested parties in AM for flood protection.

In Chapter 1 the current approach to AM and associated processes are described, together with some recent developments. Importantly here, the development of an adaptive IAM perspective as a key approach for coping with uncertainties.

8. e.g. From the European FLOOD Site project: http://www.floodsite.net/html/publications.asp

In Chapter 2 the FAIR project is introduced giving an insight into the working methods. Chapter 3 provides details of the framework for adaptive asset management for flood protection. The chapter defines the strategic and operational action contexts and necessary interconnecting tactical handshake. More details of strategic asset management is described in Chapter 4 with reference to FAIR beneficiary case studies. This Chapter describes the objectives and requirements of AM and provides a framework for understanding the behaviour of the 'whole system'. Chapter 5 gives insight into the operational contexts, i.e. the process of planning, designing and related maintenance and operations based on the information from the strategic context. This provides information to support the monitoring and inspection of flood defence infrastructure to help with estimating the reliability of the asset over time, and how this might be extended. Chapter 6 considers tactical asset management, linking the asset operations to the strategic contexts. Chapter 7 provides evidence from the pilot projects to demonstrate the outputs, outcomes and likely long-term effects from the application of the FAIR framework. Chapter 8 considers the current challenges to taking an adaptive AM perspective, from the governance challenges to the need for innovation. Chapter 9 looks forward, including what can be improved compared with our current position, especially the need for information about assets and the knowledge needed regarding their performance in order to plan for adaptation. Finally, some of the practicalities of delivering adaptive AM are set out in terms of what these imply for both policy makers and practice.

2 The FAIR project

2. The FAIR project

This Chapter covers the Why, What and How of the INTERREG V NSR project FAIR, which are summarised below.

- **Why:** The required large scale of investments for FRM across the NSR provide a unique opportunity to simultaneously improve flood protection and implement climate change adaptation measures that are fit for the future; i.e. that are flexible and adaptable.
- **What:** The project aims to reduce flood risk across the NSR by developing and implementing improved approaches for AM of flood protection infrastructure. The specific result indicators for the project are:
  - Increase the life span of flood protection infrastructure – through smarter maintenance and renovation;
  - Reduce the life cycle costs of flood protection infrastructure – through better targeting of investment;
  - Encourage the multi-functionality of flood protection infrastructure – through mainstreaming (that is, connecting) investments with other policy objectives.
- **How:** By utilising a framework comprising three 'planning and decision contexts' to consider the approach to and processes for AM and AMP: 1. Strategic (corporate and long-term view); 2. Tactical (ensuring effective interconnections between strategic and operational); 3. Operational (focusing more on day-to-day measures and activities).

2.1. Motivation for the FAIR project (Why?)

Countries in the NSR face a number of threats related to flood protection, especially climate and socio-economic changes, at the same time as existing flood protection assets continue to age (e.g. Abadie *et al.*, 2019; Calafat & Marcos, 2020). However, many European countries still have inadequate data or knowledge about flood risks, despite the European Directive[9].

Amsterdam, Netherlands is ranked the European City with the greatest risk from sea level rise, with protection costs estimated as up to €66bn under RCP4.5 projections (assumed 3m sea level rise, Abadie *et al.*, 2019). Antwerp, Belgium is ranked second with estimated costs up to €16bn, and Hamburg is highly ranked with costs of up to €16bn. Copenhagen in Denmark, will require €10bn of investments. Stockholm in Sweden is lower ranked, but still requires some €2bn investment. The beneficiaries in FAIR are from these countries, albeit different cities and regions. However, the scale of investments illustrates the level of the future challenge arising from potential coastal flooding risks.

9. https://www.eca.europa.eu/Lists/ECADocuments/SR18_25/SR_FLOODS_EN.pdf

Large investments are needed in order to face these challenges and to keep the NSR as safe as possible from flooding, both in maintaining existing and constructing new, assets. Economic constraints mean that adaptation of existing infrastructure needs to be smarter, utilising innovations and latest knowledge, and this can both reduce overall costs and at the same time control the potential impacts. This requires adaptation which needed to be implemented as soon as possible (Costa *et al.*, 2009; EEA, 2016).

In 2009, the PESETA project (Richards & Nicholls, 2009) considered the impacts of climate change on coastal systems in Europe for Joint Research Centre (European Commission), including the range of risks using various climate models and the potential for adaptation to offset the impacts. There are numerous publications purporting to analyse and cost the potential damages from changes in flood risks in Europe as the climate changes. None of these are definitive and various estimates are available. However, these have in common that investments in adaptation are always economic and will lead to cost-effective savings in expenditure.

Avoided cumulative impact costs and adaptation costs by 2100 as % of the country GDP (for 2007).

Assumptions: A2 scenario forcing assumed; sea level rises of between 0.5m for Southern Europe and 1.0m for Northern Europe; adaptation to provide a minimum 1:100 year level of protection

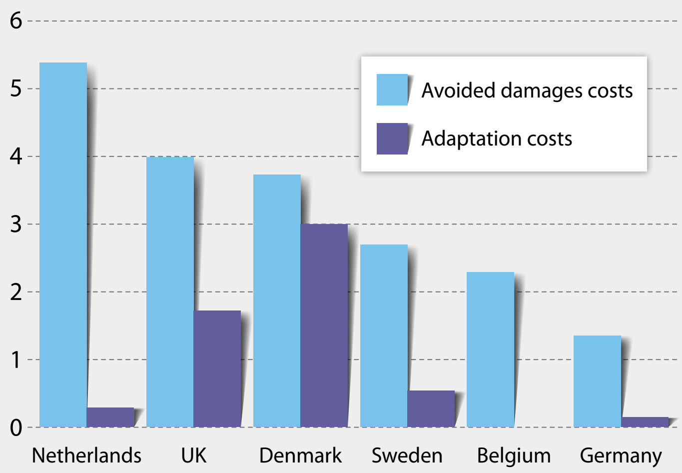


Figure 2.1 Illustration of how, by investing in adaptation (dark blue lines), there can be substantial reductions in damage costs due to coastal flooding, expressed as % of national GDP (2007) (light blue lines) for the FAIR beneficiaries.

As an illustration, one estimate of the potential value of implementing adaptation measures to offset coastal flooding impacts from Costa *et al.*, (2009) is shown in Figure 2.1. The Figure shows estimates of how impacts on national GDP can be reduced significantly from even modest investment in adaptation measures. Note that the investment needed for Belgium is too modest to show on the Figure.

Investment programmes for flood protection infrastructure are well established in many European countries, especially following the requirements of the EU Floods Directive[10]. Each of the beneficiary countries in FAIR have different approaches to investment in flood protection. For example, UK Flood and coastal erosion risk management investment programme 2015 to 2021[11], led by the Environment Agency (for England and Wales) includes long-term investment scenarios; although according to UK National Infrastructure Commission[12] there is not a clear long-term strategy for the level of flood protection that the UK Government is seeking to achieve, and how this will be addressed in the face of rising pressures. The Netherlands have established a National Flood Protection Programme (VNK, undated) which is embedded in the National Water Plan (Government of the Netherlands, 2015) and for which resources are allocated.

10. https://www.eca.europa.eu/Lists/ECADocuments/SR18_25/SR_FLOODS_EN.pdf
11. https://www.gov.uk/government/publications/programme-of-flood-and-coastal-erosion-risk-management-schemes
12. https://www.nic.org.uk/wp-content/uploads/Congestion-Capacity-Carbon_-Priorities-for-national-infrastructure.pdf

In Denmark responsibilities for producing risk management plans are dispersed between municipalities, with the Danish Coastal Authority (DCA) identifying coastal flood risks. With different municipalities allocating variable levels of funding. However, the necessary coordination of actions and engagement with land owners and other stakeholders is limited as it has only been with the advent of the EU Floods Directive that Denmark has begun to develop an overall approach (e.g. Jebens *et al.*, 2016).

The required large scale of investments for FRM across the NSR provide a unique opportunity to simultaneously improve flood protection and implement climate change adaptation measures that are fit for the future, i.e. that are flexible and adaptable, rather than using the traditional infrastructural flood protection systems, which are difficult to change and thus 'locked-in' for their lifetime of use (e.g. Lawrence *et al.*, 2018). Traditional approaches are no longer fit for the challenges ahead (Ashley *et al.*, 2020) and it will be important to utilise the most recent innovative approaches, systems and technologies. But it is not only the approaches that need to be innovative; changes in institutional, regulatory and financing processes and procedures are required if the uncertainties due to climate and societal change are to be managed acceptably and affordably.

A number of improved approaches and methods for the planning, design and management of flood protection infrastructure are emerging to support decision making. In the INTERREG V NSR project FAIR, several NSR countries have collaborated to better reflect on, and hence make recommendations for adaptive AM for flood protection. The FAIR project[13] has built on previous INTERREG IV NSR projects (i.e. MARE[14], SAWA[15]) and earlier NWE projects (i.e. FRC[16], ALFA[17]) and state-of-the-art EU research from scientific beneficiaries (Deltares, TUHH, IHE, EcoFutures and Sayers and Partners). The project has brought together major flood protection asset owners and policy makers in the NSR under the leadership of Rijkswaterstaat (Netherlands) with other beneficiaries in Belgium, Germany, Denmark and Sweden.

2.2. Project aim and expected results (What?)

The FAIR project aims to reduce flood risk across the NSR by developing and implementing improved approaches for AM of flood protection infrastructure. It sets out to optimise investment planning by exploring the mainstreaming of these investments with other policy domains; and by mapping planned investments across a wide portfolio of flood protection assets. FAIR also identifies cost-optimal adaptive infrastructure upgrades by exploring a variety of technical designs: with an adaptability and life cycle costing (LCC) perspective for set performance levels.

The FAIR project has several outputs as illustrated in Figure 2.2. These outputs are listed below.

- **End report:** This report is the end report. It provides guidance on the (full-scale) implementation of reinforcement, upgrade and maintenance programmes for flood protection and FRM assets. It also includes examples from the pilot sites used to illustrate the results. (targeted at practitioners and researchers).

13. https://northsearegion.eu/media/3753/hr-2017_06_21-rws-factsheet-interegg-fair_def.pdf
14. https://www.keep.eu/project/6399/managing-adaptive-responses-to-changing-flood-risk-in-the-north-sea-region
15. https://www.keep.eu/project/6413/strategic-alliance-for-integrated-water-management-actions
16. https://www.keep.eu/project/7072/improved-integration-of-increased-urban-development-and-flood-risks-in-major-cities-floodresiliencity
17. https://www.keep.eu/project/7081/adaptive-land-use-for-flood-alleviation

- **Pilot reports**[18]**:** A report covers each of the individual pilots in Belgium, the Netherlands, Germany, Denmark and Sweden. The pilot reports include the results and lessons learned. Examples from the pilot sites have also been used to support this end report and for the separate policy brief and knowledge agenda (targeted at practitioners).
- **Policy brief**[19]**:** four priority policy recommendations have been identified in order to improve AM practice for flood protection. The Policy Brief presents the drivers behind the challenges facing the NSR and sets out details of the four policy recommendations, supported by good practice illustrative examples from across the project (targeted at policy makers).
- **Knowledge agenda**[20]**:** A number of knowledge gaps were identified during the project. These gaps have been explained in the knowledge agenda and suggestions to overcome the gaps have been made (see also Section 9) (targeted at practitioners and researchers).

The outputs from FAIR are especially aimed at National governments and Regional Authorities with legislative and executive power in NSR countries. The improved approaches to AM and AMP developed in FAIR can be used to optimise and better implement investment programmes and deliver the requisite policy changes, as outlined in the Policy Brief. On a national level, the FAIR outputs can be used to support national policy debates that guide AM and investment planning in flood protection infrastructure. To this end, the FAIR Policy Learning Group has engaged with existing national networks to facilitate this and also the uptake of the outputs.

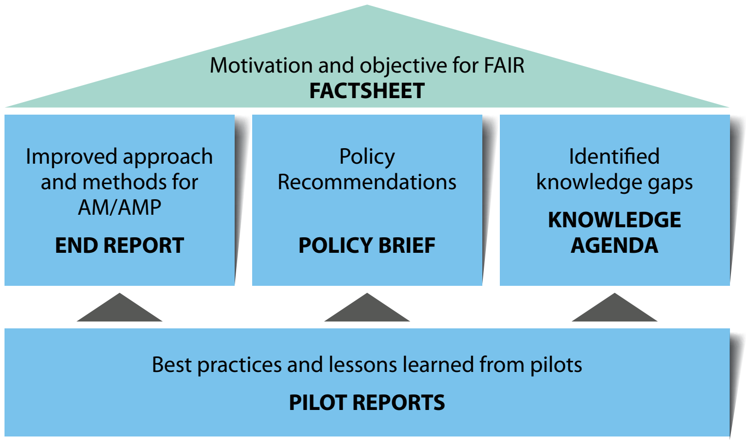


*Figure 2.2 Outputs from the FAIR project (**in bold**)*

The demonstration and subsequent widespread implementation of the improved approaches and methods (provided in the outputs) will reduce the probability of flooding across the NSR, and thus will improve the climate resilience at pilot sites. The results are captured by 3 project indicators for the FAIR project:

1. **Increase the life span** of flood protection infrastructure – through strategic planning and smarter maintenance and renovation;
2. **Reduce the life cycle costs** of flood protection infrastructure – through better targeting of investment in both capital management planning and operational functioning;
3. **Encourage the multi functionality** of flood protection infrastructure – through mainstreaming (that is, connecting) investments with other policy objectives.

Chapter 7 provides an overview and reflection on how the implementation of the guidance in the end report and its pilots delivers the 3 project result indicators.

18. Link to pilots
19. Link to policy brief
20. Link to KA

2.3. The approach taken in FAIR (How?)

The approach taken in the FAIR project has been based on demonstration of the points and conclusions being drawn (e.g. implementation, testing, analysis, comparison and improvement) regarding innovative approaches for flood protection AM and AMP. Although the countries in the NSR face similar challenges, there are many differences between regions and even within countries in the planning and delivery of flood protection. FAIR has explored how each of the beneficiary countries currently plan, manage, maintain and operate flood protection assets. There are clear differences in terms of strategy, delivery, operation and responsibilities. Each beneficiary has to operate within unique funding processes, unique institutional arrangements, delivery and operational approaches; despite responding to the common unified EU Floods Directive requirements. Private and public landowners have more or less roles and responsibilities in the various countries, NGOs, centralised or municipal agencies also have different roles in FRM and crucially in land use management and development planning processes.

The FAIR project has been able to utilise the concept of three 'planning and decision contexts' to consider the approach to and processes for AM and AMP: 1. Strategic (corporate and long-term view); 2. Tactical (ensuring effective interconnections between strategic and operational); 3. Operational (focusing more on day-to-day measures and activities). The need to consider the strategic and operational contexts has been a recurrent theme in various national programmes and projects from the end of the last millennium. These have been used variously in flood IAM (e.g. in the England and Wales, Performance-Based Asset Management System For Flood Defences (PAMS), Defra/EA, 2004; EA, 2009 & Sayers *et al.*, 2010) and in water and wastewater AM and IAM (e.g. Marlow & Burn, 2008; Alegre & Covas, 2015; Ward, 2015; Alegre *et al.*, 2016).

PAMS set out the need for both strategic and operational perspectives in providing the evidence to support asset managers and practitioners across the delivery of the entire asset management cycle, in particular in planning when and how to make AM interventions. Some reference is made to 'tactical' planning and design, although the format for this is slightly different in FAIR, nevertheless the importance of the link between strategic and operational contexts is stressed in the PAMS approach.

In earlier considerations of asset condition assessment and management in the context of overall AM processes, for example Marlow & Burn (2008), the importance of both temporal and spatial scales for AM, as illustrated in Figure 2.3, are stressed using the three contextual aspects of AMP. The latter refer to these as 'levels' and in application, the levels are sometimes used in a hierarchy, with strategic comprising the upper planning level (longer term) and operational, the lower base level (short term), with tactical activities in between (medium term).

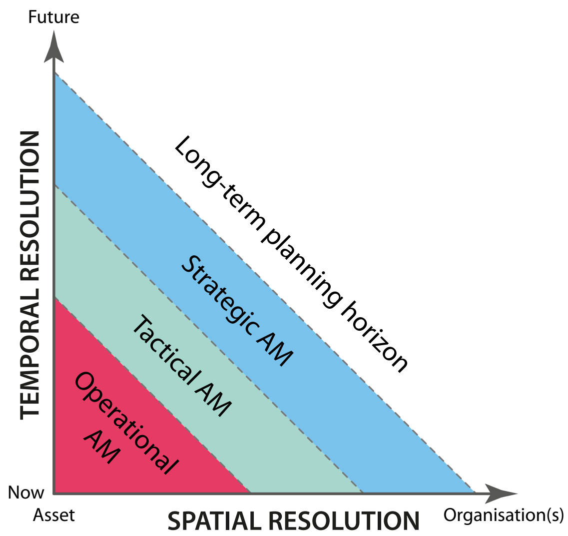


Figure 2.3 Range of temporal and spatial scales covered by the AM processes (adapted from Marlow & Burn, 2008).

Ward (2015) for example, uses the hierarchy for water service AM in England, differentiating the contexts by, e.g. aiming to manage *"Long-term investment planning informed by deterioration and failure modelling for low value – high volume infrastructure"* at the tactical level, which is envisaged as being where the medium term planning is undertaken.

The TRUST project (Alegre & Covas, 2015) developed a framework that covers a three dimensional matrix, including the 3 planning and decision contexts, together with 3 dimensions of analysis: cost, risk and performance, and 3 competencies: information, engineering and management. The wider aspects of this approach are considered further in Section 3.2.

FAIR has created the infinity shaped Figure 2.4 to represent the processes diagrammatically, which set the framework for the project. The framework has modified the perspective from the earlier approaches above, in order to ensure that the framing works for flood protection, and that each context is considered equally, rather than in a hierarchy of, e.g. strategic on a level higher than operational, or strategic dealing only with the longer term, and operational, only with the short-term, in contrast to Figure 2.3. The infinity shape used in FAIR represents the continuous process of individual and group asset management, and also applies to the IAM process used to decide on how best to manage assets.

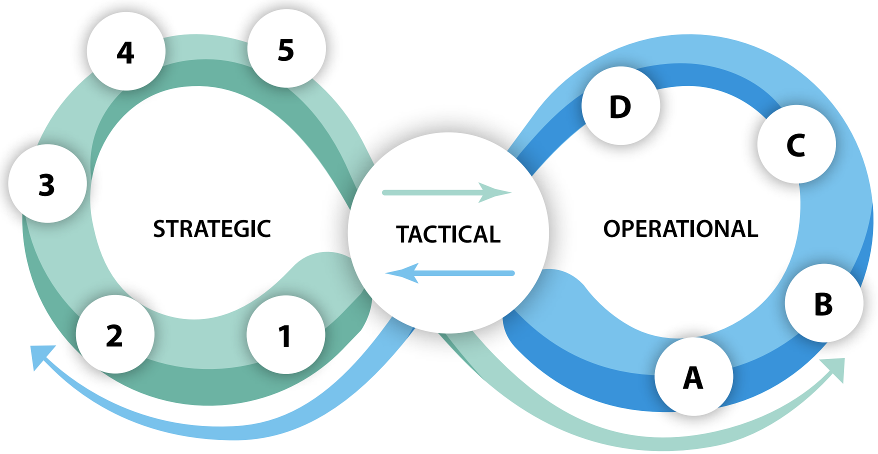


Figure 2.4 The three FAIR action contexts – strategic, tactical and operational - that define the process framework used in the project (the components 1-5 and A-D are explained in Section 3.2)

The FAIR project has found that there is an essential need to manage assets by connecting and aligning actions across the strategic and operational contexts, via the tactical handshake, as illustrated in Figure 2.4. Although appearing to be a route map, to be followed sequentially, the various numbered and lettered components will not necessarily be followed in the sequence shown. Further details of the planning and decision contexts and the various components 1-5 and A – D are provided in Section 3.2.

This framework provided a common focus as to the key elements by which the beneficiaries could assess the fitness or otherwise of the processes they were using for AM and AMP. For this, a maturity analysis was undertaken by each beneficiary, based on best practice. Maturity analyses were undertaken at the start of FAIR and again in the final year of the project to see if and how the beneficiaries had developed their AM and AMP processes in conformity with the framework in Figure 2.4; i.e. were they evolving in their approach to adopting adaptive AM and assets that in themselves would be more adaptable? This is considered further in Section 3.3.

Alongside the framework and self-assessments above, individual beneficiaries reviewed and assessed how best to adopt improved practices for flood protection AM, to ensure adaptability and reliability. Technical aspects of designing and planning for flood protection have been framed around the Source-Pathway-Receptor (SPR) model that is commonly used across the world (e.g. Sayers, 2012), which is described further in Chapter 4. Chapter 5 considers the operational contexts of the framework and Chapter 6 the tactical interaction (handshake) between the strategic and operational contexts. Chapter 7 considers the framework in action, with examples from the FAIR project.

2.4. Working method of FAIR (How?)

In the context of FAIR the asset owners/operators have shared experiences between countries and jurisdictions, each facing similar problems and challenges. This has enhanced the learning experiences across the beneficiaries. Asset owner collaboration with the scientific team has brought together previously untapped expertise in AM and innovative approaches. The scientific team has functioned across the project, assimilating and dispensing knowledge from monitoring, in a process of continuous interactive learning, connecting to other research and developments going on in parallel and supporting capacity building programmes.

The project functioned around two main threads: investment planning and AM; and adaptive and multifunctional technical design.

a. Investment planning and asset management

FAIR has considered a number of on-going investment programmes, including: the Maintenance and Renovation programme of Rijkswaterstaat and the National Flood Protection programme (HWBP, NL); the Coastal Safety Master Plan (BE); Maintenance and repairs Programme HH (D); the national Long Term Investment Strategy and Regional Asset Management Strategies (UK). In contrast, in Denmark and Sweden there are no national programmes for flood protection planning. (See Table 2.1). Decision-making approaches for flood protection AMP in the FAIR beneficiary countries have been reviewed by the scientific team (Jordan et al., 2019). Overarching lessons (e.g. on how to apply risk-based, life-cycle approaches) have been collated in this end report. This applies to individual assets and also at a system level, with a focus on how to develop/improve AM strategy based on system risk assessment (e.g. reliability) and taking an adaptive pathway approach. At the asset level, the focus is on how to allow for appropriate investment choices between maintenance, renovation, abandonment or new build, and on how asset owners/operators have and may be able to incorporate adaptive, innovative and other than traditional measures, like nature-based options.

b. Adaptive and multifunctional technical design

FAIR considered the delivery of local upgrade or maintenance projects and schemes for flood defence assets or systems in DK, NL, B, D, SE, UK. Pilot sites shown in Figure 2.5, are those areas being protected by an over-arching flood protection system (e.g. the Danish coast and lake district, Dutch Delta, Flemish Coast, Elbe Estuary, Skane region respectively) and also the individual assets, as part of the provision of these protection measures (e.g. Flood Protection Hollandse IJssel storm surge barrier, Hamburg flood gates).

A summary of the pilot cases and flood protection AM processes being used in each of the beneficiary countries in FAIR is shown in Table 2.1. Designs that will be flexible and adaptive have been explored in the pilot sites with the aim of balancing long-term and short-term requirements and investments. These have also identified multi-functional, rather than single-function measures that can be part of a mainstreaming approach, together with other policy objectives.

Figure 2.5 Pilot sites in FAIR

Thereby contributing to coherent, multi-functional and resilient spatial and urban developments through a multi-stakeholder planning process. Where opportune, nature-based options have been highlighted in FAIR (e.g. Middelkerke, Table 2.1).

In Table 2.1:

- The beneficiary countries each have their own defined estimates of how the impacts of climate change will alter hazards, such as sea level rise;
- Each beneficiary has formalised development planning processes and building standards related to flood risk;
- Virtually all of the beneficiaries assess asset condition visually; with only some monitoring condition;
- Most beneficiaries benefit from central government funding based on some form of value for money assessment (e.g. LCC/CBA) but many are constrained by separate budgets for capital and maintenance (revenue), and the need to seek alternative sources to fund multi-functionality;
- Concepts of citizen justice are either procedural or based on outcome equality. Most beneficiaries aim for the latter, but for some, e.g. Sweden, the decisions are political.

Table 2.1 Brief overview of pilot cases and flood protection AM processes for the beneficiaries in FAIR

Beneficiary	AM Pilot case	Primary responsibilities and funding	Asset management
Belgium (Middelkerke) *Context: operational and tactical*	Renewing North Sea dike – combination of measures, including new stilling wave basin and sand dunes with beach nourishment.	The National masterplan for coastal safety is funded by the Flemish Government. The capital funding is treated differently from the maintenance funding, constraining integrated approaches. Enhanced measures (multi-functional and nature based) are funded by the municipalities.	Structural AM is undertaken for the individual assets by the Flemish government. The daily maintenance of the assets in the municipalities is the responsibility of the local government.
Denmark (City of Ribe Polder, Esbjerg) *Context: strategic*	Reviewing and enhancing performance of Storm sluice, 3 locks and dikes - taking an integrated perspective.	Dikes are owned/managed by local dike associations, with Municipality funding and guidance from DCA. Each landowner is responsible for their own area and receives indirect funding. This is perceived as a barrier for efficient holistic asset management. Defined safety standards.	Kammer Sluice is managed by the Municipality. The dike is managed by the dike associations.
Germany (City of Hamburg) *Context: operational*	Ensure security and effective functioning of three public defence gates protecting the City from River Elbe in Hamburg.	Among other tasks, the "Agency of Roads, Bridges and Waters" (LSBG) is responsible for the maintenance of most of the public flood defence gates in Hamburg. This includes their planning, construction and maintenance phase. Funding is primarily from Federal government, but capital funding is treated differently to maintenance funding, constraining integrated approaches.	The LSBG is responsible for the AM. The process to optimize this has already begun with the awareness of all affected departments.
Netherlands (Flood protection Hollandsche Ijssel) *Context: tactical*	Improve the performance, operation and reliability of the Hollandsche IJssel Kering (barrier) and the River Hollandsche IJssel dike system.	Part of the Dutch Delta Programme (overarching). Defined safety standards. Dikes along the River Hollandsche IJssel are operated by the regional water authority (HHSK). The Hollandsche IJssel Kering (barrier) is operated by Rijkswaterstaat (RWS). Funding is primarily from government, but capital funding is treated differently to maintenance funding, constraining integrated approaches.	AM is undertaken for the individual assets by the respective owners HHSK and RWS. Cooperation has enabled joint and integrated planning to develop optimised co-operation.
Sweden (Helsingborg) *Context: strategic*	Improve the flood protection of the inner part of the City.	Maintenance and operation of flood protection assets is under the responsibility of the city of Helsingborg. The City owns and operates the current flood protection assets. On-going discussions with central government for better funding arrangements. There are no defined safety standards.	The City is responsible for AM and also city planning. Coordination provides opportunities to optimise the changes needed to improve the assets and operate them.

Beneficiary	AM Pilot case	Primary responsibilities and funding	Asset management
UK (knowledge leader)	There is not a pilot in the UK. The knowledge leader brings information from practice in England.	In England the Environment Agency (Government agency) has overall responsibility (Defra, 2019). But, sewerage undertakers are responsible for sewer flooding. Municipalities for some pluvial flood protection, and land use planning. River Boards have some responsibilities for large rivers and private landowners also have various responsibilities. Funding is primarily from government, but capital funding has traditionally been treated differently to maintenance funding, constraining integrated approaches. Recently there has been a shift to Totex and direct community funding in partnerships and Benefit-Cost analysis (BCA) used to prioritise investments.	AMP is a well-established process in the main agencies. The various organisations each have AM responsibilities for their individual assets, although partnership working is becoming the norm between responsible agencies. Economic development and environmental protection are material considerations alongside issues of social justice (with greater weighting given to vulnerable groups within the BCA).

3 The framework for adaptive flood asset management

3. The framework for adaptive flood asset management

In this Chapter, the FAIR framework is further elaborated, encompassing the points below.

- The FAIR framework comprises three planning and decision contexts. The strategic context will produce the adaptive management plan for the assets, and the operational context will deliver and maintain the plan requirements. Interconnecting these is the tactical handshake that will feed information in both directions to inform both strategy as to the need for adaptations, and operational practices as to what is expected from the strategic plans.
- The FAIR framework includes four fundamental principles needed to ensure that appropriate connections between contexts are in place:
  - Principle 1 - as frequently as possible, re-evaluate the performance, risk and cost, and the AM processes being used.
  - Principle 2 - define comprehensive metrics (indicators) and assessment criteria.
  - Principle 3 - ensure that appropriate consideration is given to the temporal and spatial scale.
  - Principle 4 - a component of the physical scale above; the management scope; who owns and who operates the assets, individually, collectively or interactively.
- The Framework has been used by the beneficiaries to assess their own position regarding their internal processes for management of flood protection assets. This has been undertaken using a 'maturity analysis', which combines best practices and competences into a qualitative scale along which AM maturity can be tested. Two maturity analyses have been carried out at different times to track whether or not there have been any changes in maturity of AM practice for each of the beneficiaries during the FAIR project.

3.1. Asset management for flood risk management (FAIR Context)

As outlined in Section 1.2, there are various guidance documents available that may be utilised for asset management (AM) for traditional infrastructure, such as the ISO 55000 series of standards. These collectively provide the principles and a framework for strategic and operational AM and benchmark opportunities for those who wish to implement best practice. Several organisations have implemented strict and formalised internal processes in conformity with the ISO 55000 standards and have achieved accreditation for this compliance. These standards need careful interpretation for application to the flood protection domain as they have been produced to maximise value from assets for an organisation, rather than to maximise service.

Flood protection infrastructure is planned and designed to maximise value to society rather than to an organisation.

Various countries and infrastructure domains have guidance and applications for specific AM, e.g.[21]. However, the scientific foundations of AM and value of formalised AM processes are still under review. For example, Hodkiewicz (2015) in reviewing the contribution AM makes to *"improved financial performance (improved services, outputs, return on investment and reduced costs), improved safety performance, reduced environmental impact and improved ability to demonstrate socially responsible and ethical business practices",* identified the need for organisations to: 1) identify the factors that characterise their AM practice; 2) measure the cost of AM; 3) demonstrate that AM practice delivers AM and organisational outcomes; 4) determine if ISO 55001 certification would deliver improved organisational performance. Accreditation for FRM organisations is rare and often perceived as not necessary. However, the Environment Agency in England has attained ISO 55000 accreditation, for various reasons, including to demonstrate best practice AM, as explained in (EA, 2015).

A life cycle (LC) approach to AM is essential, for which asset performance is considered not only at the design stage, but regularly (ideally continually) throughout the lifetime in terms of reliability. The approach of looking at individual assets as part of an, ideally, integrated system can also expose challenges as well as opportunities that will otherwise remain hidden. Looking at opportunities to create flexibility in assets' and asset systems' has become much more relevant in the context of climate adaptation. A LC approach, aiming at keeping options for change open, provides opportunities to adapt or otherwise intervene to ensure that the expected service is maintained even after significant changes in drivers. For example, the Thames Barrier is a major asset protecting London from flooding that has been used beyond the originally planned end-of-life, by carrying out 5-yearly reviews of performance based on 10 indicators, and keeping operational change options open via a dynamic adaptation pathway approach (more details in Box 4.4). The recent ISO 14090: 2019 sets out the need for and examples of, such adaptive approaches (See especially Example 5 in ISO 14090 that illustrates coastal flood risk adaptation).

The results from the FAIR project have demonstrated that in order to achieve the specific project objectives (increase life-span, reduction in life-cycle costs (LCC) and encourage multi-functionality), the AM process should provide clarity and guidance for:

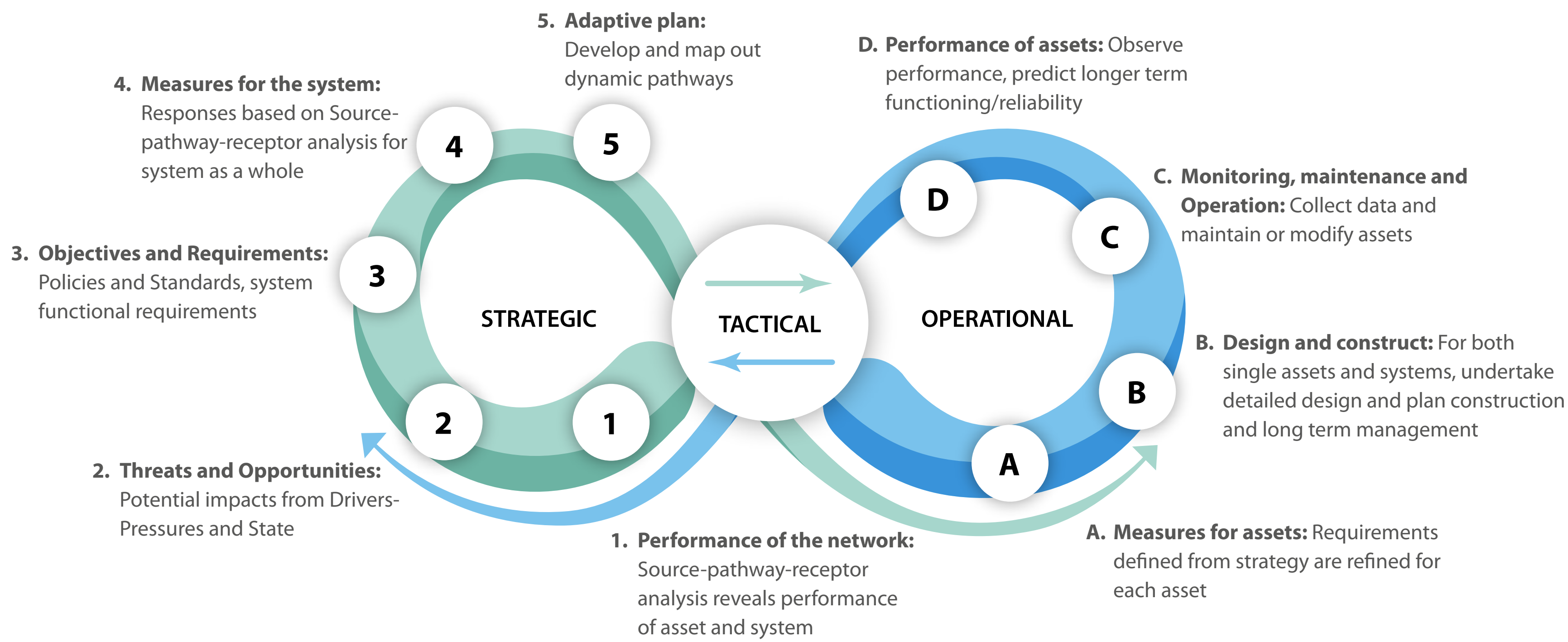
- **How to take a life cycle (LC) approach** that will encompass all aspects of AM to deliver multi-functional and adaptable assets;
- **Linking between strategic and functional contexts** (strategic and operational linked via tactical);
- **Linking between individual asset and asset systems** for short, medium and long term functioning of reliable assets.

These have been found essential in the AM process for minimising the life-cycle costs and maximising the benefits from flood protection assets over the long-term. These correspond with ISO 14090: 2019 which helps:

> *"organizations to prioritize and develop effective, efficient and deliverable adaptation tailored to the specific climate change challenges they face…to provide organizations with a consistent, structured and pragmatic approach to prevent or minimise the harm that climate change could cause and also to take advantage of opportunities."*

21. In England the AMP process is well defined for the sewerage undertakers as part of the economic regulation process in conjunction with Ofwat and the Environment Agency (e.g Black, 2019), albeit the focus is on 'customers' and value.

Figure 3.1 The FAIR framework



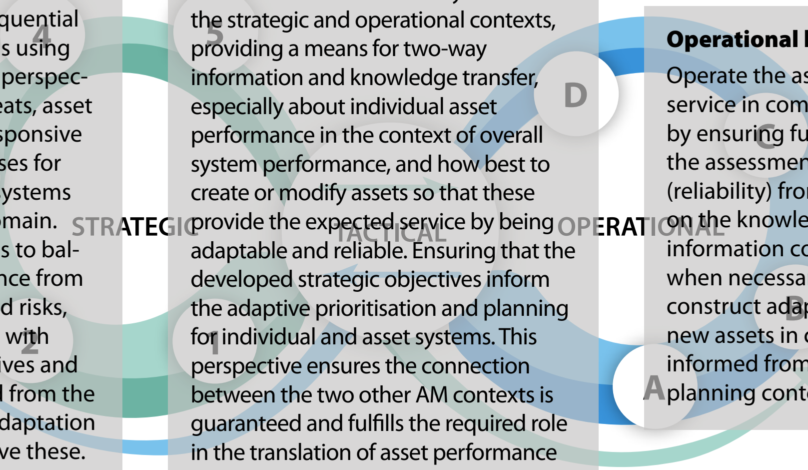
3.2. The FAIR framework (structure)

The framework has been introduced in summary in Section 2.3 and in Figure 2.4. Figure 3.1 shows the Framework in context with the other processes utilised in FAIR, in the 1-5 and A-D components of the left and right hand loops. Figure 3.2 defines the three 'planning, decision and action' contexts used in FAIR for AM.

This perspective has been used in other applications, e.g. for investment planning for water infrastructure in Lisbon (Ferreira & Carriço, 2019), which also included stormwater management assets. Earlier, Sayers & Meadowcroft (2006) in reviewing the AM processes current for the Environment Agency in England identified the need for stronger linkages between the strategic and operational functions, as also identified in the Lisbon application above. This stronger and explicit linkage is termed the tactical 'handshake' in FAIR, linking tactical planning (considered in Defra/EA, 2004) with the operational processes.

In Figure 3.1, the strategic (left hand) loop would typically be processed at lesser frequency than the operational loop (see also Figure 2.3).

Figure 3.2 Definitions for the three planning and decision contexts of the FAIR framework



Strategic loop – the why and what?
Establish strategy and consequential long term planning processes using an overall integrated system perspective from understanding threats, asset operational effectiveness, responsive policy, standards and processes for interactions within FP asset systems and beyond the flood risk domain. Develop investment priorities to balance cost, risk and performance from an understanding of the flood risks, the opportunities associated with alternative strategies, objectives and functional requirements, and from the performance of alternative adaptation measures necessary to achieve these.

Tactical (handshake) actions – the when, where and what order?
Sustain the interconnectivity between the strategic and operational contexts, providing a means for two-way information and knowledge transfer, especially about individual asset performance in the context of overall system performance, and how best to create or modify assets so that these provide the expected service by being adaptable and reliable. Ensuring that the developed strategic objectives inform the adaptive prioritisation and planning for individual and asset systems. This perspective ensures the connection between the two other AM contexts is guaranteed and fulfills the required role in the translation of asset performance to system/network performance.

Operational loop – the how?
Operate the assets and maintain service in compliance with strategy, by ensuring functioning through the assessment of the performance (reliability) from monitoring, based on the knowledge gained from the information collected. Where and when necessary, modify, design and construct adaptations to existing and new assets in conformity with and as informed from, the overall strategic planning context.

Typically, strategy may be reviewed on a scheduled cycle, e.g. once every 5 years, although there may be a need to respond to information from the operational loop, which needs to be continually actioned (Figure 3.1 and 2.3). For example, when there is flooding that is unplanned for (i.e. water in areas it is not normally, and the area is not a sacrificial or managed flood storage area), there may be an opportunity to reconsider strategy immediately, as flooding impacts always bring opportunities to influence policy, or at the least to seek funding from a wide range of sources to help communities affected. Strategy ideally should be established in such a way as to be ready to take advantage of such situations; i.e. it should be already in-built into the strategy that hazardous events will provide opportunities to be pursued.

In addition to the infinity loop in Figure 3.1, central to effective IAM processes are three main dimensions of analysis: cost, performance and (related to the latter) risk.

Each of these can be assessed for individual assets, or for a system/network for both present conditions and for future scenarios and need to be included in all three strategic, operational and tactical contexts, alongside the competences of the owner/operator organisation: information, engineering and management, i.e. a matrix of 27 areas to consider (e.g. as shown in Alegre *et al.*, 2016).

The FAIR project has identified that there are often gaps between the strategic and operational contexts in Figure 3.1 for flood protection (as has Alegre *et al.*, 2016 for water assets). The strategic and operational contexts often function largely independently of one another, with separate players, agencies or departments ignoring (or not properly accounting for) their interdependency and interconnectedness. The tactical 'handshake' has therefore been defined in FAIR to ensure appropriate connections are in place. The handshake ensures that knowledge about the performance of the assets (operation) as part of the overall system, can inform an adaptive AM plan developed by the asset owner or operator, and that the strategies planned are effectively embedded in the operational processes.

Planning & decision aspect	Beneficiary Country	Pilot case	Includes
Strategic	Denmark	Hvide Sande Ribe	Discussion on safety standards. Improved adaptation of flood protection to future climate (the flood defence system may lack robustness in the face of climate change, as shorter dewatering times at the sluices are expected in the future, coupled with increased discharge in the rivers.)
	Sweden	Helsingborg	Introduce long term strategy for dealing with climate change.
	Netherlands	Delta Programme: flood safety, freshwater and spatial adaptation	Explore adaptation measures accelerated to cope with sea level rise. https://www.h2owaternetwerk.nl/h2o-actueel/vier-opties-om-grote-zeespiegelstijging-het-hoofd-te-bieden
Tactical	Netherlands	KIJK & HWBP	System-approach; trade-off costs and benefits between dike and barrier improvements to reduce whole lifecycle costs Prioritize dike reinforcement projects
	Denmark	Ribe	Develop an coordination and planning strategy with regards to maintenance and administration of flood defence infrastructure, which include the functionality of Kammerslusen, and the management of diverging stakeholder interests.
Operational	Belgium	Middelkerke	Design of an adaptive dynamic nature based flood defence which can deal with climate change
	Germany	Hamburg	Analysis of maintenance processes and strategies to improve maintenance in respect to the reduction of costs and the optimisation of investments. Development of a risk based maintenance strategy to advance asset management through optimisation of design and emergency management procedure. Development of a web based "Dike Information System" (DIS) where all relevant flood protection data can intuitively be found.
	Sweden	Helsingborg	Search for practical guidelines for redesign of the city that help include FRM in other infrastructure developments.

Table 3.1 Correspondence of the FAIR pilot cases with the 3 planning and decision contexts in the FAIR framework

The main components incorporated in the framework in Figure 3.1 are, for the strategic planning and decision loop: Component 1) situated at the intersection of the two contexts, is for assessing the performance of the network as passed on from the operational context: 2) identifying threats and opportunities; 3) setting objectives and requirements; 4) identifying and analysing measures for the AM system; 5) developing an adaptive plan. For the operational contexts, these are: A) identifying and analysing measures for individual assets and groups; B) designing and constructing; C) monitoring and maintaining; D) assessing the performance of individual assets and groups.

As the assessment of individual and asset networks can provide new insights and information; threats and opportunities are adjusted, and the AM process continues. Hence, Figure 3.1 illustrates the continuous process of adaptive and IAM in an infinite loop. External factors influence all components defined in the framework, of which the most important include climate and socio-economic change.

The FAIR framework reflects key components in ISO 55000: 2014, in that it illustrates the important links between decision areas for AM in terms of the strategic, tactical and operational contexts and the essential links between individual asset performance and system performance that need to be properly understood for effective flood protection/risk management.

Table 3.1 illustrates the correspondence of the FAIR beneficiaries' pilot case studies with the three planning and decision contexts in Figure 3.1 (refer also to Table 2.1). The various pilots cover the three contexts, although all three are not necessarily included in each one of the pilot projects.

The Framework has been used in FAIR for the beneficiaries to assess their own position regarding their internal processes for management of flood protection assets. This has been undertaken using a 'maturity analysis' modified from a procedure that has been defined for the assessment of how different dimensions or processes within an organisation are able to contribute to a set of pre-determined organisational outcomes (Volker et al., 2013). This type of assessment has become commonly used in a number of areas of infrastructure AM to assess the capability, strengths and weaknesses of an organisation in relation to their intended goals, albeit in domains other than flood protection (e.g. Mahmood et al., 2015). The maturity analysis undertaken in FAIR has also helped to affirm that the FAIR framework in Figure 3.1 is sufficient and encompasses everything needed to develop adaptive assets and AM processes.

3.3. Maturity analysis for the FAIR beneficiaries

The asset owners and operating authorities in the FAIR project have self-assessed their capabilities, strengths and weaknesses in managing assets, using the maturity model introduced above. Such models can be used to combine best practices and competences into a qualitative scale by which relative maturity of AM can be tested. This has allowed beneficiaries in the project to understand their own and each other's strengths and weaknesses, making effective sharing of knowledge and experiences possible. The maturity levels have been used in FAIR to rate the various organisational dimensions and AM strategies of the organisations using the 5-point scale defined by the Institute of Asset Management, ranging from an 'ad hoc' level (that is, limited experience and reactive) to an optimised level (that is, continually improving as best practice) of maturity.

The organisational dimensions are based on the Infrastructure Management Maturity Matrix (IM3) model of Volker *et al.*, (2013), chosen for use in FAIR because it has been specifically developed for public (highway) infrastructure AM; i.e. for a public good, similarly to flood protection infrastructure. Moreover, the IM3 has been further developed to be more applicable to Rijkswaterstaat, the lead beneficiary of FAIR. The 7 organisational maturity dimensions have been defined as shown in Table 3.2, which also shows 3 organisational competencies defined by Alegre et al. (2016), and how the maturity dimensions include these. More details of the way in which the 5-point scale links to the 7 maturity dimensions and also to the 3-fold decision contexts of the FAIR framework (Figure 3.1) are provided in Appendix A.

Two maturity self-assessments have been carried out to track whether or not there have been any changes in maturity of each of the beneficiaries during the FAIR project: the first, a baseline round, in Summer 2017 and the second, an assessment in September 2019, in the last year of the project. The self-assessments were carried out by each organisation in an interactive session with 3 to 5 employees in various roles, such as

Maturity Dimension (Volker *et al.*, 2013)		**Correspondence with organisational competencies (Alegre *et al.*, 2016)**		
	DESCRIPTION	INFORMATION	ENGINEERING	MANAGEMENT
1. Asset management decisions	The use of risk management methods and LC approaches in decisions at strategic and operational AM contexts.	✓	✓	✓
2. Information management	The availability and use of (standardised) static and dynamic data-bases for decision making	✓		✓
3. Internal coordination	Coordination and problem solving between the different departments of the organisation		✓	✓
4. External coordination	Coordination and problem solving between the different stakeholders of a project, including communication with users		✓	✓
5. Outsourcing activities	Strategy about and implementation of integrated and performance based contracting and innovative procurement methods	✓		✓
6. Processes and roles	Clarity, definition and implementation of job responsibilities and roles within the organisation	✓		✓
7. Culture and leadership	Level of knowledge, implementation and support of asset management related issues	✓		✓

Table 3.2 Beneficiary organisational dimensions used in the FAIR maturity assessment

strategic advisers, programme managers and/or operational managers. This broad participation was important from the perspective of the organisation's shared internal responsibility for AM. These were informed by definitions, as summarised in Appendix A.

The results from the two maturity analyses are shown as spider diagrams for each of the Asset Owners/operators in Figure 3.3, illustrating any maturity developments for the 7 organizational dimensions during the project.

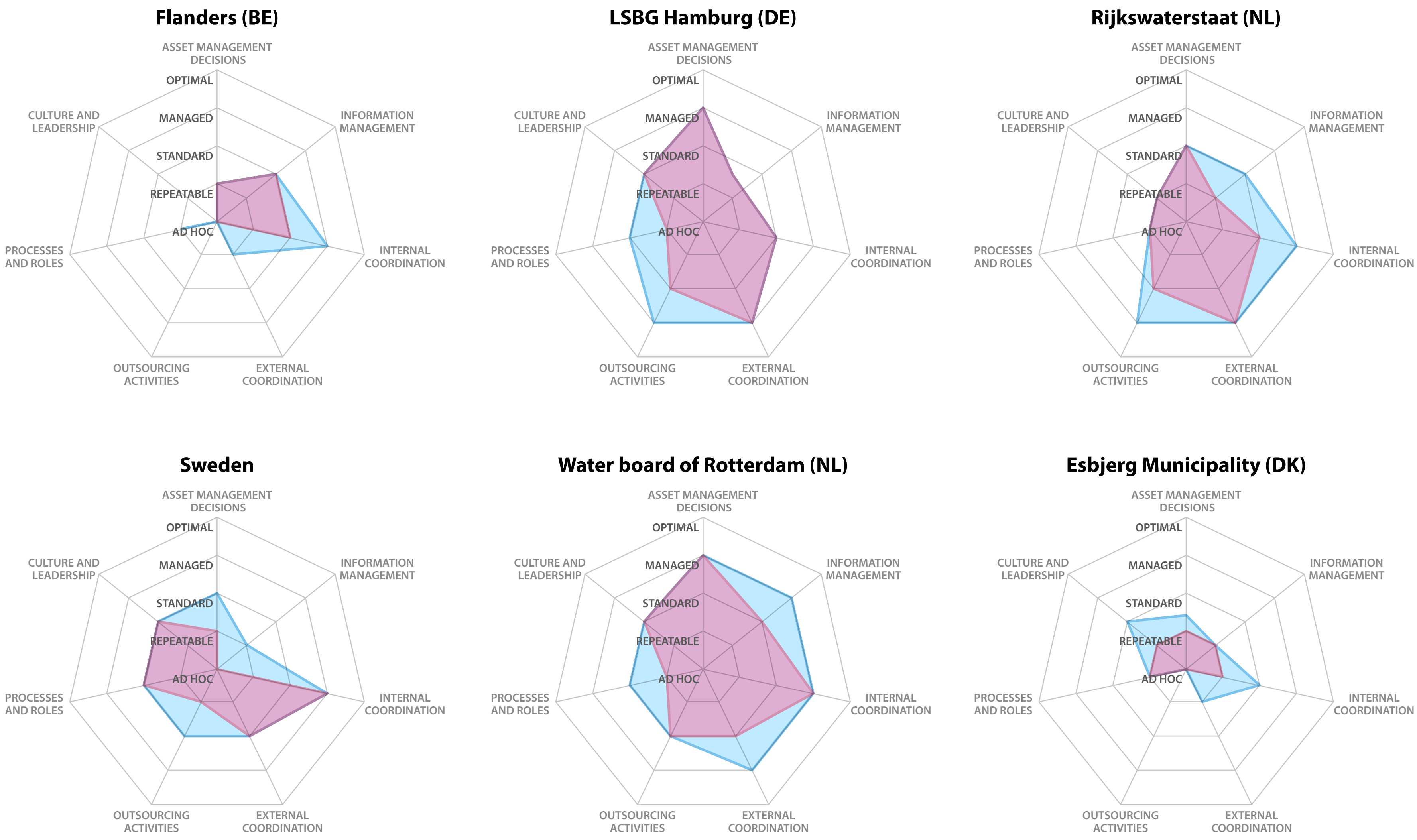


Figure 3.3 Self-assessed maturity levels for each of the FAIR beneficiaries for the start of the project (in red) and in the final year of the project (in blue); Water board of Rotterdam (NL) is the Regional Water Authority, HHSK

The 5-point integer scale used was:

0 – Ad hoc
1 – Repeatable
2 – Standard
3 – Managed
4 – Optimal

With the more mature organisations allocating a higher score to each category.

The maturity levels increase incrementally with increasing distance from the centre, with the extent of the coloured areas representing the overall organisational maturity. Not one of the beneficiaries believes that they are fully mature in their AM processes, although each of them improved their overall maturity for at least 3 of the 7 dimensions during FAIR. The beneficiaries indicated that new insights from FAIR were central to some of the improvements, but that other factors (other projects, general development) contributed to the progress towards more mature AM.

Overall, the self-assessment results highlight clear differences in the overall perceived maturity of the different beneficiaries, with some indicating a low baseline maturity (Flanders and Denmark) and others a high overall baseline (Hamburg and HHSK). Also, the approach to flood AM differs between beneficiary organisations. For example, the self-assessment suggests that there are self-perceived strengths in a decentralised model (SE and DE) in terms of coordination and problem solving between the different departments of an organisation. None of the beneficiary organisations regressed in maturity during FAIR, although there were relatively few showing overall improvements.

The maturity improvements for the Dutch beneficiaries (Rijkswaterstaat and HHSK) were reportedly the result of innovative FAIR insights, specifically on 'information management' and 'external coordination'. The shift to a system-wide and strategic perspective, from a mono-perspective during FAIR, are illustrated by the changes to the planned investments in dike reinforcement by the Water Board and investments in the approach to the Flood Protection Hollandse IJssel storm surge barrier by Rijkswaterstaat. This shift to a system perspective, attracting a higher rating for external coordination by the HHSK between the start and end of the project.

Other improvements were due to a number of factors, examples are:

Belgium (Flanders) – implementation of ISO standards; more coordination due to management change (leadership); Investment management system implemented (government wide);

Sweden – More clarity of the indicators delivered, and clearer view of the problems; the analytical report on the pilot has helped understand the details and costs; greater openness to innovation on the part of the organisation to the ideas of the specialist consultants.

3.4. Fundamental principles for the planning and design contexts of the FAIR framework

The FAIR framework (Figure 3.1) illustrates the important and essential contexts of planning and design for IAM. The framework includes both the assets and the organisational contexts of their management. It is important that the other components for mature and effective IAM are also considered in parallel: the dimensions of performance, risk and cost, together with the competencies of information, engineering and management.

The strategy will produce the adaptive management plan for the assets and the operational (and maintenance) contexts will deliver and maintain the plan requirements.

Interconnecting these is the tactical handshake that will feed information in both directions to inform both strategy as to the need for adaptations and operational practices as to what is expected from the strategic loop.

The following sets out the FAIR framework fundamental principles needed to ensure that the above requirements are encompassed in the AM and in the AM plan processes.

- **Principle 1 – as frequently as possible, re-evaluate the performance, risk and cost, and the AM processes being used.** The tactical handshake connects the strategic framing and initial position with regard to existing and proposed new assets with the operational condition (effectiveness) using evidence about performance. As the assets continue to function, there are time dependencies in this process. Evaluation enables adjustments to be made to the (strategy) implementation plan. The frequency at which the tactical re-evaluation is undertaken is likely to be more often than is the frequency at which strategic re-evaluations are made, see the example in Box 3.1. [this Principle overlaps with Principle 3 below].

Box 3.1 Timing for reviewing strategy aspects of AM

In The Netherlands the flood protection safety standards are expected to be re-evaluated every 25-50 years. However, the mid-long-term plans of the national flood protection programme are provided yearly. In England, the private water companies who are responsible for much of the stormwater systems have to provide five-yearly business plans (known as 'price-reviews' based on AMP) (Black, 2019). However, once 'signed-off', the way in which the strategy in the Water Company business plans is delivered into actual capital or asset maintenance via AM plans, can be modified in response to innovation and information feedback, provided the CBA demonstrates cost-savings, termed 'efficiencies'.

- **Principle 2 – define comprehensive metrics (indicators) and assessment criteria.** Asset owners are continually searching for a way to maximise value/effectiveness from their assets, by finding a balance between the achievement of the desired performance, having control of the risks that occur, and the costs of these measures over the life span of the asset. It is important to set out which indicators will be considered and which criteria are to be used to decide whether performance is as good as possible and even, optimal, including defined and actual performance, what budget is available and which constraints should be taken into account.

- **Principle 3 – ensure that appropriate consideration is given to the temporal and spatial scales.** For the temporal scale, some plans should be valid for the far future (for example where sea level rise is important when maintaining a safe environment). There will also be a need to focus on the current situation and near future only, rather than the longer term, for some AM plans. Spatial scale may or may not be significant as some assets function more or less individually, whereas in other cases the assets are an important part of a network. For example, major dike systems are essentially series systems with little or no engineering redundancy; understanding the difference between component and system reliability is essential for reliability analyses of flood defences (Jongejan et al., 2020); i.e. improving the quality of a single dike stretch in a long or connected dike system, may not significantly decrease overall risks, other than for the dike stretch that was unreliable.

FAIR framework fundamental principles:

1 as frequently as possible, re-evaluate the performance, risk and cost, and the AM processes being used.

2 define comprehensive metrics (indicators) and assessment criteria.

3 ensure that appropriate consideration is given to the temporal and spatial scales.

4 a component of the physical scale above; the management scope; who owns and who operates the assets, individually or adjacent.

- **Principle 4 – a component of the physical scale above; the management scope; who owns and who operates the assets, individually or adjacent.** It is important to decide whether to focus on the assets that are the responsibility of one owner/operator only, or, if it would be beneficial or even essential to include surrounding or adjacent assets, from other owners in the assessment and processes of AM. This may be straightforward for coastal and even pluvial flood risk management, but often stormwater, pluvial, asset systems are dispersed – upstream assets can protect receptors downstream over a catchment for example, and individual property owners may or may not know or wish to manage their own drainage systems to the benefit of others (e.g. Wingfield et al., 2019). This also raises very complex funding issues as to who benefits and who needs to pay, as the latter may not be the same as the former (e.g. Ashley et al., 2020).

There are several considerations that are external to the organisation of AM systems, which may influence tactical assessments, including:

- **Professional drivers** such as actor attitudes to and adoption of, innovative solutions or measures, or new possibilities such as the on-going advance of IT capacity and capability, generally developed in other sectors.
- **Linking opportunities between different functions,** assets and infrastructure domains. This may also apply within an organisation as well as between organisations.

Several of the fundamental principles are illustrated in Figure 3.4. The tactical interactions depend on information from the strategic and operational contexts. In the Figure, the key aspects which could influence the tactical actions are shown for the strategic and operational contexts.

Guiding the **strategic planning and design** loop are:

- **Standards** – requirements e.g. safety standards;
- **Autonomous and semi-autonomous drivers** – the load on/use of the assets could change over time, e.g. increasing sea levels;
- **Societal drivers/policy** (the requirements could change over time by, e.g. aiming for systems that are more sustainable, or part of the circular economy and/or contribute to greater transparency in decision making;
- **Socio-economic drivers** – many of the requirements could change over time by e.g. number of ships passing the asset;
- **System functions & objectives** – which functional criteria must be met, and which (future) objectives and developments are desirable;
- **Reactive processes** – despite strategy needing to take a long term view, it may be necessary to adapt strategy rapidly in response to unexpected or unacceptable events in order to take advantage of opportunities afforded in the policy domain, especially during and immediately after catastrophic events.

It is important to frame strategy in the knowledge that it cannot envisage all possible eventualities (e.g. Butler *et al.*, 2020) and therefore strategy needs to include processes or procedures that are able to react to unexpected events, fed back from and to the operational contexts, through the tactical linkages.

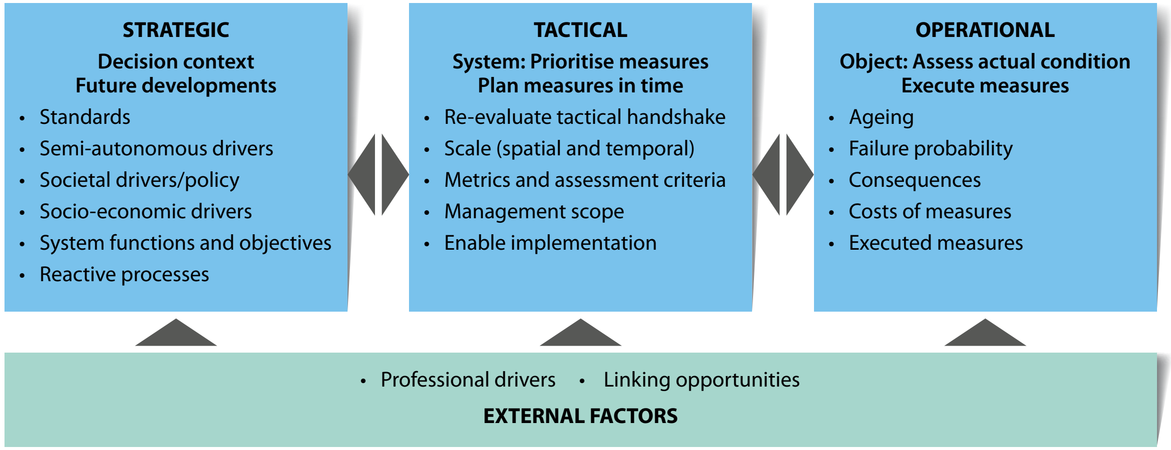


Figure 3.4 Illustration of the fundamental principles that contribute to tactical asset management and the considerations needed from the strategic and operational planning and design contexts (see also Figure 6.1).

Guiding considerations for operational asset management:

- **Ageing** – the change in the asset over time; typically deterioration that influences functionality;
- **Probability of an asset failing** – including assessment of failure modes and fragility;
- **Consequences** – if the asset would fail and type of failure, e.g. partial or catastrophic, significance and impacts;
- **Costs of improvement or replacement** – of the asset, although abandonment may also be considered, e.g. setback of defences;
- **Executed measures** – delivered – as the achieved system/service condition will affect future planning.

Tactical AM outcomes can also be structured using a uniform set of principles and key information.

Typical outcomes of Tactical AM are Mid-Long-Term plans which give information about the prioritisation, programming and coupling of interventions for various and different individual or groups of assets. To make these plans several principles and considerations should be considered. However, facilitating implementation – what comes out of strategy, needs to be enabled as one of the functions of the tactical handshake.

The following Chapters provide greater detail about the components of the FAIR framework, together with evidence from the pilot cases to support this.

4 Strategic asset management

4. Strategic asset management

This Chapter sets out a strategic perspective that comprises the four strategic aspects of the FAIR asset management process (Figure 3.1):

- Identification of threats and opportunities (across the spatial, temporal, knowledge and risk domains)
- Setting of strategic objectives
- Understanding the performance of the asset system
- Developing an adaptive asset management plan

4.1. The strategic context

A strategic approach to flood protection is necessarily a multi-stakeholder endeavour and one that brings together issues of place making (through spatial planning), investment and aesthetics as well as notions of acceptable risk, resilience and ecosystem health (e.g. Sayers, 2017). Asset managers seek to provide flood protection in a way that balances these perspectives through a transparent process of trade-offs relating to life-cycle costs, risk and performance at multiple scales: spatial - from a single asset and to the system of assets - and temporally – from short to long term; a process familiar to all asset managers and reflected in ISO 55000: 2014.

In this context, strategic AM is a continuous process of data and information gathering, analysis, adjustment and the adaptation of policies and assets (including modifying the probability of flooding and its severity as well as the vulnerability and resilience of the receptors threatened) to appropriately manage an ever-changing risk (Sayers et al., 2013). For example, in England there are draft plans for marine and coastal areas[22] that include a flood and coastal management strategy, but also links to other national strategies such as for renewable energy.

The strategic approach developed in FAIR builds upon this definition (and reinforces the recent ISO 14090: 2019) and includes the four major components (numbered 2, 3, 4 and 5 in Figure 3.1) and links through to, and receives information from, the operational delivery through the 'tactical handshake', via component 1. Each strategic component in the FAIR cycle is introduced below.

4.1.1. Performance of the network (of assets)

Good decision-making relies upon an understanding of the behaviour of the 'whole system' (Component 1 in Figure 3.1). This includes developing an appropriate understanding of:

- The **geographic boundaries** of the system, the vulnerabilities to flooding within that system;
- The **external influences** that may influence the behaviour of the system over time, such as sea level rise or development;
- The **hydrological and hydraulic functioning** functioning of the system (during frequently and rarely occurring storm conditions);

22. Draft North East England Inshore and North East Offshore Marine Plan: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/857247/DRAFT_NE_Marine_Plan.pdf

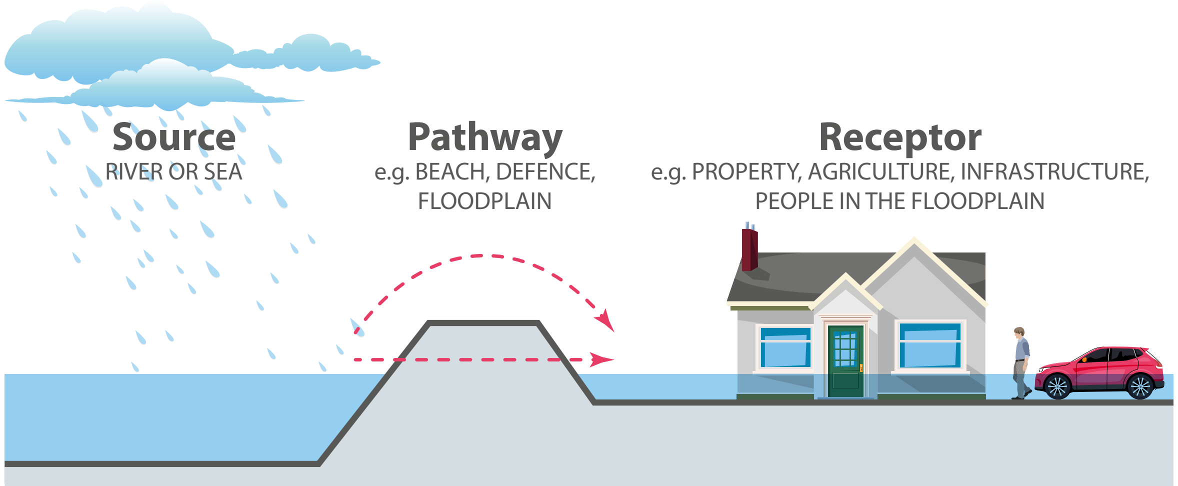


Figure 4.1 The Source-Pathway-Receptor (SPR) framing (Redrawn from Sayers et al, 2002)

- The **performance of the flood protection assets** in response to these loads and future climate change, recognizing the sometimes subtle influences of climate change on asset performance (beyond sea level rise, to including desiccation of surface soils, or sequenced events, Sayers et al., 2015);
- Routine **uncertainties** with the data, models, model structures that may be used to model the performance of the system.

Achieving this understanding can be a daunting task. To aid this process, FAIR beneficiaries have promoted the use of the SPR framework, Figure 4.1, which provides a practical means of disaggregating the basic components of probability and consequence into their constituent components. For example, when exploring the 'whole system' that influences the flood probability, consideration is given to both the probability of the initiating event (the source of the flood such as rainfall or a marine storm) and the probability that flood waters will reach a particular location in the floodplain, taking account of the performance of the intervening system of wetlands, channels, dams, levees, gates, floodwalls and other structures (the pathway of the flood water).

The consequences should flooding occur reflects both the vulnerability of the receptors and the chance that a given receptor will be exposed to the flood when it occurs.

4.2. Identifying threats and opportunities

Defining opportunities and threats is an important part of the continuous on going process of asset management (Component 2, Figure 3.1). Defining these requires consideration separately and in combination, of both external (e.g. climatic, socio-economic) and internal (e.g. asset and asset network functioning) factors. Understanding these opportunities and threats at an individual asset and also system/strategic contexts, enables asset managers to plan ways to optimise investments for the operational contexts so as to simultaneously take advantage of the opportunities (e.g. mainstreaming multi-functionality of services) and minimise the risks from threats cost-effectively (e.g. potential damage, deterioration of the asset, future accelerated sea-level rise (SLR)). Consideration of opportunities and threats in the context of AM, can be categorized in terms of:

1. Domain extent (e.g. Spatial, disciplinary, utility, service, institutional/governance)

2. Temporal extent (e.g. adjacency with other assets, deterioration over time)
3. Uncertainty extent (e.g. reliability and confidence in performance)

a. Spatial domain

Managing assets as part of flood infrastructure systems, entails identification of the physical extent of the AM system. For example, in the FAIR pilot, the city of Hamburg has considered the entire array of automated flood protection gates when seeking to understand the system behaviour/ reliability for flood protection, and hence for targeting maintenance resources effectively. Other domains to consider include institutional/governance, disciplinary boundaries and extents, other services and utilities. This should encompass both institutional/governance domains as well as disciplinary domains when seeking opportunities and understanding threats. Future challenges caused by sea level rise, population growth, public expectations etc., surpass the field of flood management alone, and require trans-disciplinary/utility solutions and multi-functional assets, providing a wide range of potential long-term co-benefits. Therefore, integrated strategies (e.g. blending natural and built infrastructure, Sayers & Smith, 2018) are increasingly being recognized as opportunities, requiring cross-functional collaboration between various institutes, governmental departments, service providers and other stake and shareholder groups.

Problems and threats can only be clearly defined when a broad domain is considered, inevitably increasing the complexity of the system under consideration and difficulties in asset performance analysis. This inclusion of a broader range of stake/ shareholders can often hamper swift/effective decision-making. However, even when pushing boundaries that lead to increased complexity, this can bring new opportunities (e.g. financing arrangements) and new value possibilities (e.g. multiple benefits) can arise, see e.g. Ashley *et al.*, (2020).

b. Temporal domain

Appropriate consideration of both short and longer term asset performance is essential for cost-effective AM. Various time horizons should be considered when planning interventions for AM. Some of the important threats (e.g. climate) are changing rapidly and within the lifetime of many assets. Hence threats will become clear only when a long enough time period is considered, typically 50 to 100 years for a main asset, and even 5 to 10 years for an electrical or mechanical asset (which in any case is likely to become obsolete by then). Effective consideration of asset performance in the face of long-term changes can reduce the threats of maladaptation and also highlight opportunities. For example, many green or nature-based options only start to provide benefits once established after some years. But there is a danger that an excessive focus on the longer term can shift attention away from the need to address current problems, as well as the need for timely interventions, and in view of the increasing uncertainties of external and internal drivers and asset performance into the future, this brings increased uncertainty. This is clearly a threat regarding the need to plan for both short and long term.

c. Knowledge domain

The data, knowledge and information needed for planning asset management have many and varied uncertainties which influence our ability to precisely determine the performance of an asset or attribute risk to specific assets. But not all uncertainties are equally important. Strategic management is most interested in those that influence choice being made. This decision framing underpins the notion of proportionate analyses – where resources are directed to resolving those uncertainties that influence the decision at hand (Sayers et al., 2012). Not all uncertainties are reducible (given limits of knowledge and resource) and some rational doubt will inevitably persist. These remaining uncertainties are most directly addressed by embedding adaptive capacity within the choices made and valuing that capacity (e.g. Brisley *et al.*, 2015).

d. Risk domain

FAIR in part builds upon the 2005, ComRISK2 Project (an EU Interreg funded collaboration involving many of the northern European countries bordering the North Sea) that compared approaches to risk-management, particularly in regard to using 'risk' as a core aspect of the decision making process. For example, it is acknowledged that however extreme a chosen design load, more severe conditions could be encountered (i.e. designing for exceedance). It is also acknowledged that absolute protection from flood hazards is impossible and that risks can only be reduced to a level that is 'as low as reasonably practicable' (ALARP).

The UK's Health and Safety Executive (HSE) 'Reducing risks, protecting people' introduced the concept that risks should be managed to a level As Low As Reasonably Practicable (ALARP) and described 'practicable' in the context of a balance of costs (described as all costs – monetary and non-monetary) and benefits (described as all benefits – both monetary and non-monetary). The HSE also introduced the concepts of 'broadly acceptable risk' (that require no specific management effort); 'unacceptable risks' (that must be reduced unless the costs of doing so can be demonstrated to be disproportional to the risk reduction achieved or it is not technically possible to do so); and 'tolerable risk' (that should be reduced based on a consideration of the cost of doing so and the benefits secured).

This framework is summarized in Figure 4.2 and is instructive in considering how the response to 'risk' is considered within the FAIR pilots (Box 4.1). The triangular shape on the right of the diagram illustrates the 'significance' of the risk - where significance relates to the importance of the risk – i.e. as a system or an asset is managed more effectively it will move down the diagram and the importance/significance of the risk reduces, ultimately moving into the broadly acceptable region.

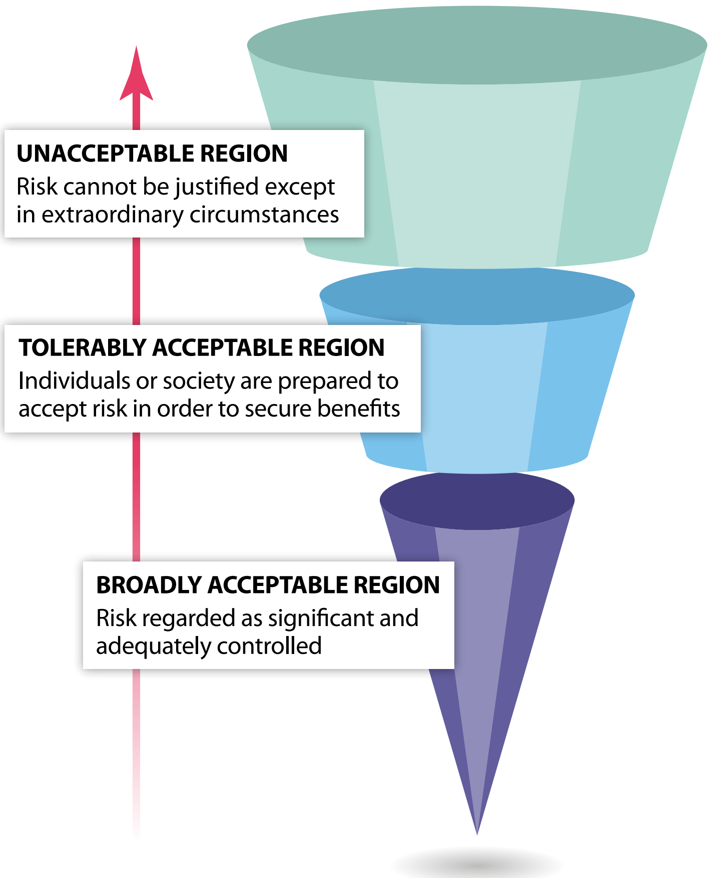


Figure 4.2 The framework of tolerable risk introduced by the HSE in the early 1990s in the UK manufacturing and process industries (Based on HSE, 2001; taken from Sayers et al., 2013)

Box 4.1 Approaches to defining ALARP

Various countries use different approaches to determine what constitutes ALARP. The approaches in England and the Netherlands are compared below (based on Sayers al, 2014):

England: In England flood protection competes with other public investments and typically must achieve a Benefit-Cost Ratio of around 1:5 to compete. The ALARP framework underpins all of the choices made and enables investment to be prioritised locally within a consistent national framework (Defra, 2011a). In the context of flood protection projects, this means that rather than delivering a nationally prescribed flood protection standard, investments are assessed against a counterfactual 'do nothing' and the benefits of costs of 'doing something' compared with this. The 'do something' approach with the largest Benefit-Cost Ratio (that exceeds 1) is first identified. Higher cost strategies – delivering higher standards and greater outcomes for the environment and people – are compared with this solution. An incremental BCR test is then used to select the preferred strategy (with the threshold BCR increasing with the standard of protection provided by each alternative strategy). The available national budget is then rationed to ensure public money enables the many to access a minimum standard rather than a higher standard for a few, based on a simplified priority score that: (i) Allows private funding contributions to increase the priority for national funds; (ii) provides a process that preferentially weights protecting households in deprived areas etc., and (iii) ensures the protection / enhancement of environmental outcomes. This results in a variable standard of protection reflecting benefits and costs (in a broad sense, at least in principle) – this process of determining the relationship between costs to the benefits for society secured, reflects the 'tolerable' region of the ALARP framework. Some dams and other high consequence infrastructures are managed according to the 'Unacceptable' region of the ALARP framework.

Netherlands: In the Netherlands, a national strategy is based on a national assessment based on risk and investment. The 'tolerable' risk is defined using a Benefit-Cost test (BCR>1). This is combined with the definition of an unacceptable risk based on the principle of solidarity and defined as all citizens having a protection standard of 1 in 100,000 against dying in a flood. For this threshold a least cost objective is set. The resulting standards are set out in the Water Act. The standards for the primary flood defences are laid down in the Water Act itself, whereas the regional water system is subject to the standards laid down in provincial regulations and plans. The standards reflect the expected consequences in case of flooding. The standards for the primary flood defences range from 1/1,000 to 1/1,000,000 a year. These standards provide a 'tolerable risk' for all areas protected by primary flood defences. The 'tolerable risk' for those areas is based on two principles: a) everyone should be able to rely on the same minimum level of protection, expressed as local individual risk (LIR), and b) where the expected consequences of flooding are very high, a lower probability of flooding is appropriate, based on societal risk and a social cost-benefit analysis. The standards for the regional water system are less stringent, ranging from 1/10 (for rural areas) to 1/10,000 a year (for urban areas). The differences between the standards are linked to the number of casualties and the scale of the damage / social disruption that would result from flooding.

These will be significant in case of flooding from the sea or the large rivers. The areas outside the primary flood defences are managed according to the 'broadly acceptable region' of the ALARP framework. Many of these areas are regarded as being relatively safe from flooding.

This is because of their high elevation level that has resulted from a process of sedimentation and manmade changes. The Water Act does not prescribe any requirements concerning flood protection for these areas. Generally, new developments are validated against municipal zoning plans and regulations. Some municipalities have now set minimum floor levels in their regulations to protect buildings from flooding.

When considering risks, together with responses to dealing with these for society as a whole, there are numerous ways of sharing the responsibilities for the risks. Insurance is one way of doing this, by spreading the risk across numerous policy holders, such as is done for flooding through various schemes, for example in UK through retail insurers backed by a joint re-insurance initiative between the Government and insurers (Flood Re), in France under the Barnier Fund (Guillier, 2017), and in USA via the National Flood Insurance Programme (Grigg, 2019). Such risk offsets relate to the impacts on the recipients' of flooding, i.e. the assets damaged (Section 1.1) and recompense for this.

FAIR is about the assets that are planned and operated to protect and minimise these impacts. Whilst certain assets, such as domestic appliances are often insured against malfunction, flood protection assets, however, are typically self-insured by their owners (as is typically the case for publically own buildings and other infrastructure). As a result, only the consequences of flood protection asset failures are included in the risks covered by insurance in many countries (e.g. Swiss Re, 2019). There are example of Private-Finance Initiatives that seek to share the risk in the cost of maintaining the performance of flood defence assets, such as the Pevensey Bay Sea Defence scheme[23] in England; the first sea defence project anywhere in the world to be funded as a Public Private Partnership.

4.2.2 Setting strategic asset management objectives and requirements

The strategic context aims to establish the desired role flood protection assets play today and in the future, their performance objectives, the likely investment need (at a national, regional and system scale) in a way that delivers multi-outcomes and that can be appropriately adapted as the trajectory of the future becomes better known (Component 5 in Figure 3.1). Supporting this approach, whilst avoiding an unnecessarily narrow or constraining framing, strategic objectives, based on an understanding of the threats and opportunities, must seek to reflect:

- **Local and national needs:** Strategic objectives recognise that the demands of local communities for protection and the national desire for efficient and equitable investment are not always compatible (Box 4.2). In some cases, it may not be viable (from a national economic perspective) to invest in improving flood protection locally (due to the relative cost and economic value of doing so). Understanding how to leverage local funding and private investment to supplement national sources and to ensure national choices are not simply based on maximum return, but also consider broader issues of social justice and well-being as well as ecosystem health (Sayers, 2017), are common challenges. 'Good' strategic objectives seek to balance these potentially competing demands. As an example, Catchment Partnerships[24] in England are proving effective at focusing local needs with a range of funding partners and even helping to utilise upstream measures to benefit downstream communities (e.g. Wingfield *et al.*, 2019).

23. The scheme is an early example of a nature-based approach. http://www.geographyrocks.org/uploads/2/0/4/2/20422591/pevensey_bay_-_a_case_study_of_soft_engineering.pdf
24. https://catchmentbasedapproach.org/

Box 4.2: Hierarchical approaches to strategic planning in England and the Netherlands

In England – The national strategy is couched in terms of the decision making process set out in Appraisal Guidance associated with a national assessment of risk reduction and investment that enables flood management to compete with other public funds, and delivers a national 'block grant' to the Environment Agency to support local strategies. **Local system strategies:** Alternative strategies assessed using risk and investment and other criteria determine the preferred strategy. An incremental Benefit Cost Ratio (BCR) test is to provide equality of investment, promoting a minimum standard of protection for the many, rather than a higher standard for a few. The preferred strategy at a local system level competes for national funding based on a simplified priority score that: (i) Allows private funding contributions to increase the priority for national funds; (ii) Preferentially weights protecting households in deprived areas. The outcome from such local strategies is a variable standard of protection reflecting benefits and costs within the system.

In the Netherlands – The **national strategy** delivers the defined Safety Standards for each dike section. Based on funding constraints, and matters of safety and risk reduction achieved, a prioritized programme of investment is centrally planned. Preferred system strategies are: a least **whole life cost approach** to delivering the defined safety standard, and regional Water Boards cost sharing on some aspects and opportunities for locally funded enhancements.

- **Align multi-institutional and stakeholder interests:** Physical assets are a potential tangible link between the multiple institutional contexts and stakeholder interests. Strategic asset management recognises this and sets objectives that link across timescales (setting out short-term needs and long term goals) and stakeholders beyond the conventional silo of 'flood protection' whilst balancing cost, risk and performance in the pursuit of multiple outcomes (such as providing appropriate protection to people and economies whilst working with natural processes to promote ecosystem health). This multi stakeholder approach is central to the strategic planning process as illustrated in Helsingborg, Sweden – Box 4.3.

Box 4.3 Integrating flood risks in a city scale planning process – Helsingborg, Sweden

Helsingborg is developing a new master plan with a planning horizon of 2050. An adaptive approach is reflected in general statements and also in the development strategy. The municipality has the opportunity to implement flood defences at a strategic overall scale, being responsible for the harbour, wastewater system, land use and associated infrastructure. In order to do this, the municipality has a need to clearly understand responsibilities and potential benefits of coastal protection, linking different municipal policies regarding management and cost allocations. The harbour and the wastewater system are managed by municipal companies, each having their own budget and investment plan. The work done within the FAIR project has revealed that coastal protection investment planning needs to be spread across all municipal responsibilities in order to be cost effective. The city has already developed investment plans for the inner harbour, which includes raising the level of the quay and walls around the inner harbour area. The results from the FAIR project show that these investments are ineffective unless the future function and configuration of the whole system, i.e. the inner protection, is properly understood. As a consequence the municipality intend now to postpone investments until the risks and opportunities are better understood. Also until there is a defined implementation plan for the inner harbour, including clarity of responsibilities across the municipality. The changed understanding of current and future hydrological and hydraulic functions, performance requirements of future assets, uncertainties related to future major infrastructure projects, as well as sea level rise, informed from the FAIR project, has hence influenced the city's strategic plan processes as well as investments.

- **Set out the requirement performance objectives:** The planning and decision framework will shape the strategy. 'Good' strategies are based on several factors, including a sensible approach to costing – ensuring the use of 'total expenditure' (TOTEX) and avoiding the typical governmental distinction between capital (CAPEX) and maintenance expenditure (OPEX). In FAIR, the German and Dutch beneficiaries are constrained due to governmental differentiation between CAPEX and OPEX funding. In contrast, a strategic approach uses a combination of utility (whole-life benefit-cost test), least-life-cycle cost optimisation (e.g. Klerk et al., 2017) and approaches that value multiple benefits (in addition to core flood protection benefits, e.g. Ashley et al., 2018) and 'fairness' (Sayers, 2017). Regulations and regulatory systems may define, encourage or constrain strategy for infrastructure systems and AM. Increasingly the need to ensure that these are flexible is being recognised, but little has been done so far to ensure that regulatory systems are supportive of, or encourage, innovation (e.g. Altamirano et al., 2015).

- **Funding, roles and responsibilities:** Identifying multiple funding sources (although these may not necessarily be secured) and agreeing roles and responsibilities for taking the strategic plan forward to action are pre-requisites to successful implementation and forming part of any 'good' strategic plan (e.g. Box 4.3).

4.2.3 Measures for the system

The SPR framework – used to understand the performance of the system - also provides a structured means of considering the necessary aspects of the system to include in the system risk analysis, how future changes in different aspects may change this system, and what measures could be taken to intervene on a system level as illustrated in Figure 4.3) which also includes the standard DPSIR (drivers-pressures-state-impact-response) framing.

4.2.4 Developing an adaptive asset management plan

Component 5 in Figure 3.1 focuses on the development of the Plan. In developing the Plan, a strategic process recognizes that the future will be different from the past; but how it will be different is impossible to say. Developing flood protection infrastructure in

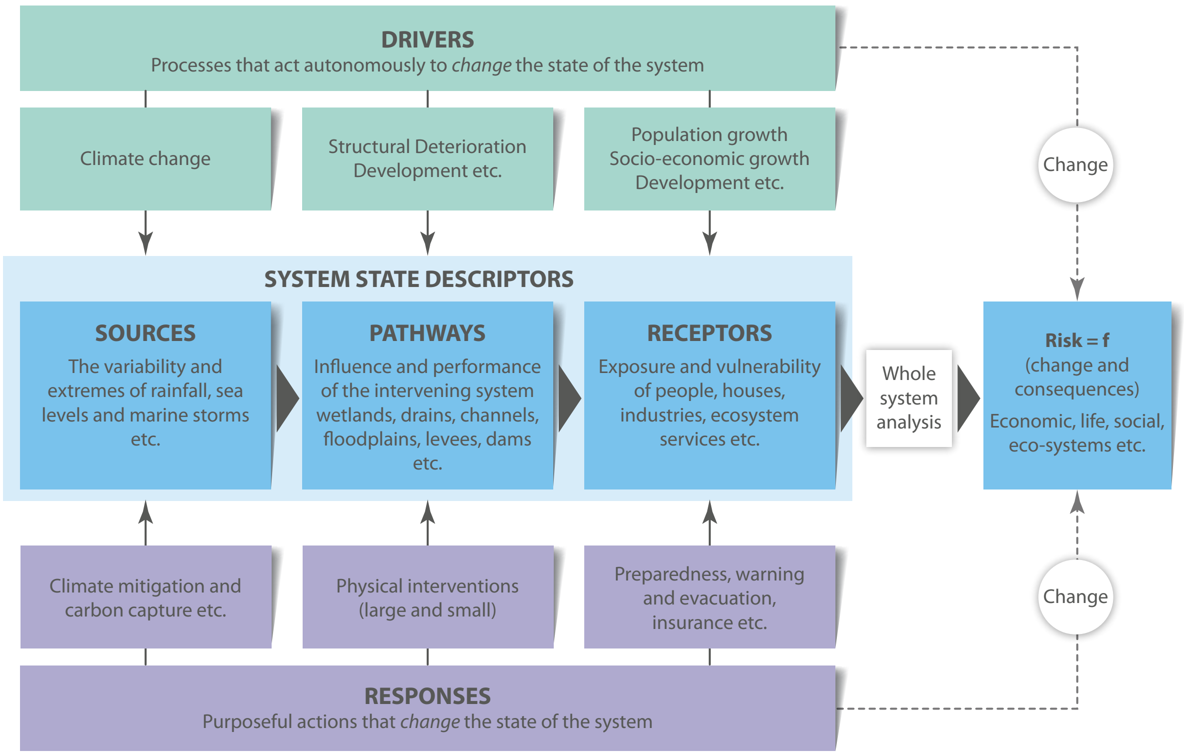


Figure 4.3 Drivers and responses include different aspects of the SPR framework (Sayers et al., 2013)

this context presents several challenges that can only be addressed through a strategic process; how much should be invested today in strengthening and raising assets and where is it possible to delay investment are complex decisions when the climate and socio-economic context has the potential to change (sometimes profoundly) over the life time of the decisions being made. Short-term political realities and varying perceptions of and willingness or otherwise to accept risk, compound these difficulties, and because of this, maintenance and monitoring are typically seen with a lower sense of urgency compared with the excitement of investing in large scale new infrastructure.

Similarly, renewals, renovations or upgrades are often not seen as desirable as new assets. This bias leads to solutions that may be unnecessarily costly or maladapted to the reality of the future as it emerges, and even to decisions that preference 'locked-in' traditional ways of providing new infrastructure (Ashley *et al.*, 2020). This risks 'stranded-assets' in the future when these traditional 'solutions' are no longer fit for purpose (e.g. Lawrence *et al.*, 2018).

Strategy Plans should proactively plan for an uncertain future and can be modified as new evidence and insights emerge. Investments in monitoring and evaluation (assets, the loading conditions and the socio-economic setting) providing the central underpinning of the continuous process of updating both the strategy and operation delivery to ensure flood risks, are well-managed and plans adapted in a timely manner. Two approaches are typically available to represent generically different approaches to future uncertainty:

- **Adaptive** (maximising adaptive capacity by maintaining future optionality and ability to modify the strategy as the reality of the future becomes better known)
- **Precautionary** (based on a priori agreed allowances for future change – for example a sea level rise allowance and then incorporating these allowances within the design process).

A precautionary approach has some utility when the cost of purchasing the required precaution is small and has limited conflicts with other objectives, however, increasingly such an approach is seen as leading to potentially mal-adapted solutions. An adaptive approach is much better and developing the capacity for future flexibility is not simply 'wait and see' but is a process of purposeful preparation and often comes at a price today (e.g. the cost of securing land for future set back of a dike line or strengthen foundations in preparation for future raising). Various tools and techniques are available to help make this case (from visualising adaptive pathways - as decision points McGahey & Sayers, (2008) or potential pathways Haasnoot et al., (2013) - to formally valuing adaptive capacity- - Brisley et al., (2015). Such approaches can be used to underpin the identification of tipping points (such as in the Thames Estuary 2100 studies, Tarrant & Sayers, 2012 – see Box 4.4) and for the basis of the development of longer term planning in Esbjerg Municipality and Danish

Coastal Authority (Box 4.5). Using these tools and approaches can help asset managers balance performance, risk and cost over the short and longer term by maximising societal value and avoiding solutions that may be unsuitable for future conditions (Box 4.5).

In considering the measures to promote adaptive capacity, the role of flood protection should be considered as a support to actions that reduced vulnerability and exposure as a priority (where possible) and where required are implemented in such a way as to maintain room for the river or coastal dynamics in response to sea level rise. Figure 4.4 shows a flow chart to aid the decision process and promote the creation of an adaptive strategy.

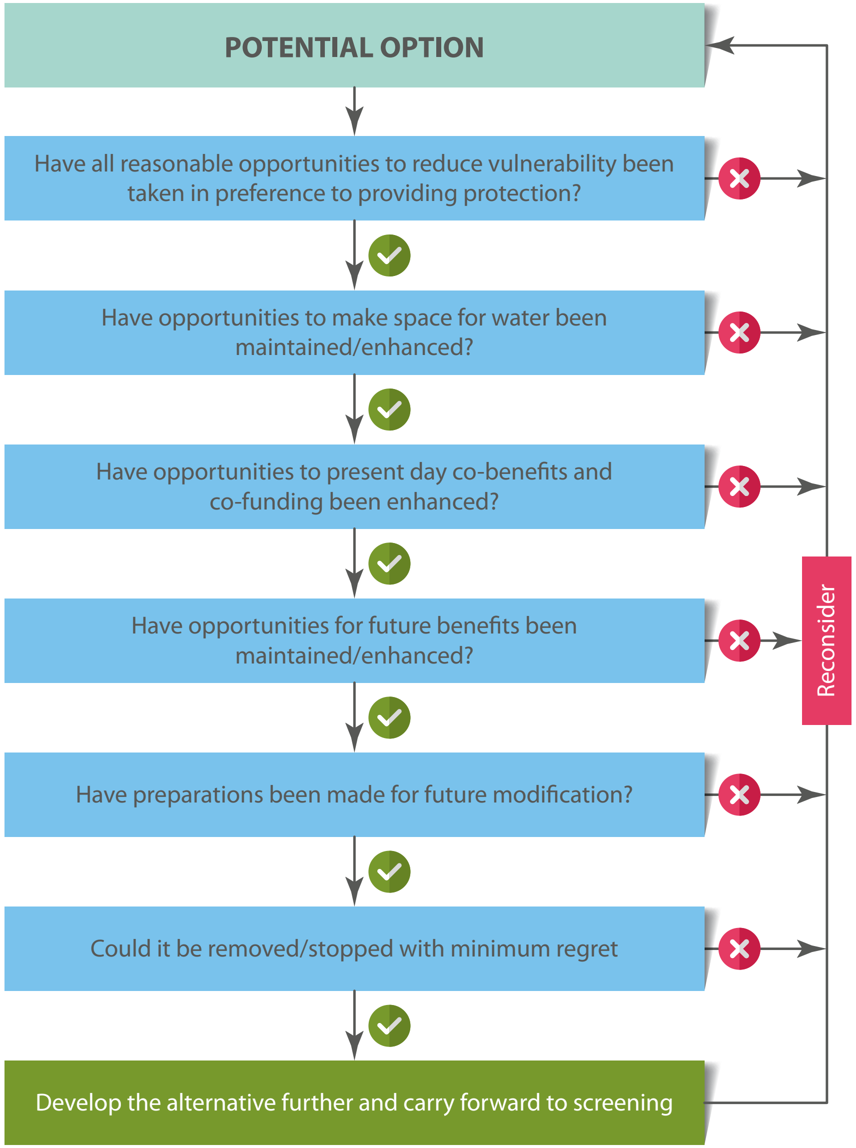
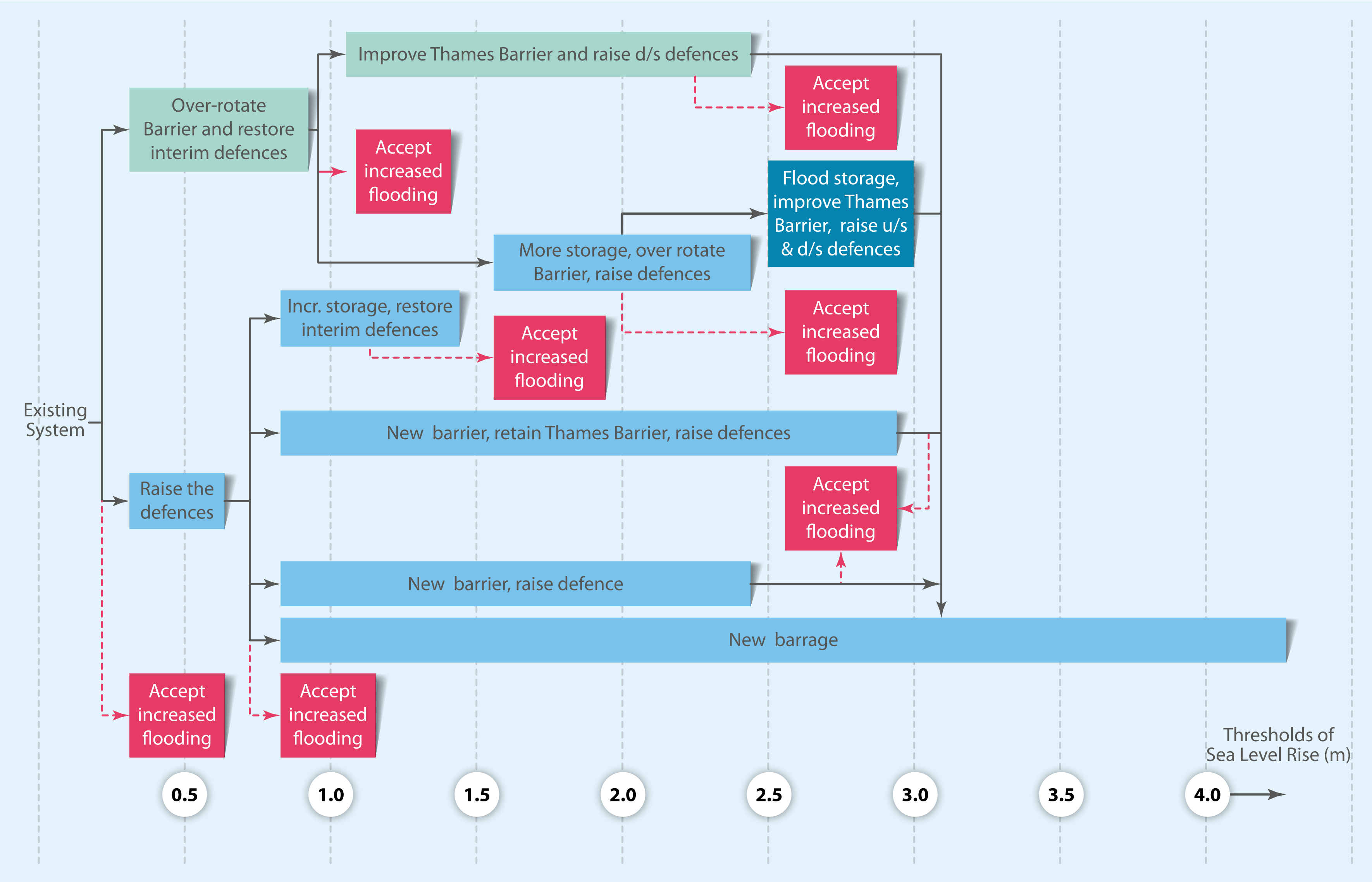


Figure 4.4 flow chart to help guide the development of adaptive management measures (Sayers et al., 2015)

Box 4.4 Adaptive strategy developed for the Thames Estuary, UK

The Thames Estuary 2100 project (TE2100) was established in 2002 with the aim of developing a long-term tidal flood risk management plan for London and the Thames estuary. To reflect this goal of an adaptable strategy, a flexible strategy was developed around the concept of a decision pipeline (McGahey and Sayers 2008), that presents potential actions in the form of a decision tree. The figure below shows the decision tree developed for the Thames Estuary flood defence system, highlighting the choices to be made as sea levels rise. Depending upon the degree of sea level rise that materialises as the future unfolds, the nature of the defence system required may be distinctly different. The decision tree (see below) supported decision makers deciding when and how to invest. In particular it reveals that major investment to improve the defence system is not immediately required. Innovations in the operation of the Thames Barrier (through over-rotation) extends the life of the defence system, enabling potentially high regret decisions regarding the development of a major new barrier to be delayed until more is known.

The TE2100 plan also includes a monitoring and continuous process of re-evaluation. The monitoring process provides the triggers (discussed in Tarrant and Sayers, 2010) for the decisions within the pipeline. For example, if monitoring reveals that climate change is happening more quickly (or slowly) than predicted, the strategy can be reappraised in light of the new information, and options can be brought forward (or put back). Some decisions, once made, require a considerable lead time to implement. This lag time between deciding to act and delivering that action is allowed for in the plan (e.g. the completion of the Thames Barrier took 30 years to plan, design and deliver). The resulting TE2100 Plan sets out a management strategy that can be adapted in response to future change including climate and socio-economic change.



Thames Estuary 2100 Plan presented as a decision tree

Box 4.5 From static/hold-the-line thinking to dynamic planning

Traditionally, Danish asset managers have worked with fixed timeframes following national guidelines and driving operational decisions that typically lead to "hold-the-line" policies, i.e. focused on maintenance of existing measures and not incorporating potential climate change impacts. The processes used include: asset management; flooding mapping; climate adaptation; and river operation, and were divided into separate responsibilities, with actors not working in close cooperation.

New methods such as dynamic pathway planning are now enabling a more strategic approach to be taken, that incorporates multiple aspects of planning at a system level. In the case of Ribe, an SPR analysis has highlighted new possible pathways for how the flood protection systems may respond, based on, among other things: outside pressures on the system (climate change, urban development), planning cycles (local planning, political cycles) and socioeconomic considerations. The possible responses derive from multiple considerations such as moving the economic focus of some areas from farming to tourism, or to services. Also, all significant assets are incorporated in the analyses and therefore they are appropriately included in the planning and decision-making process. Integrated hydrodynamic modelling incorporating sea levels, river discharges, groundwater levels and precipitation are becoming key components in the planning toolbox, and a common understanding of the performance of all assets are important prerequisites of any future work.

A workshop, facilitated under the auspices of FAIR, undertook a review of alternative adaptation pathways for existing and future flood defences. This included front-line staff and managers from the municipality, as well as from DCA. Options as well as limitations in the flood mapping were considered and this instigated discussion and development of alternative pathways. This has initiated a detailed study to develop an adaptive climate plan for the flood defences for the Ribe area – the strategic context in the FAIR framework.

The discussion at the workshop, further studies and plan development is intended to be presented to policy makers before the FAIR project ends by mid 2020. The detailed measures to be used (FAIR framework, operational context, Figure 3.1) have not been defined, but the process initiated above is already improving the way in which the future plans for assets are being formulated. This included qualitative assessment of the options' ability to deliver desired outcomes, the likely costs, the potential for negative 'side effects'.

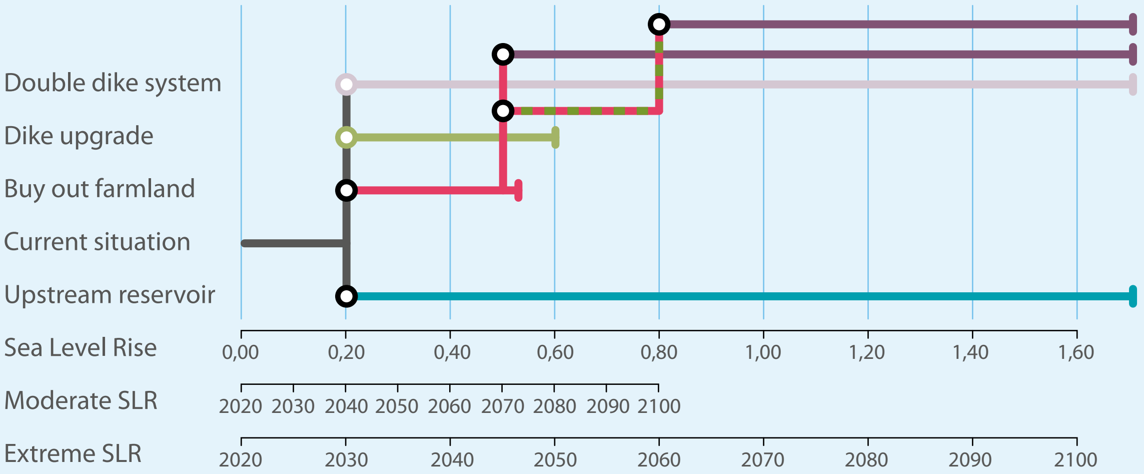
In 2013 Danish municipalities were required to prepare climate adaptation plans that integrate erosion and flood protection within their long-term strategic planning process (including urban development, wastewater management and environment). Despite not being required to revise the plans, the importance of doing so is widely recognized and many municipalities continue to work with national organisations to reflect better evidence on present and future risks and potential adaptation options within local planning decisions

Within Ribe, Ejsberg Municipality are considering the long term approach to flood protection. One central issue is the sustainability of the existing dike line as sea level rises. Initial workshops have started to explore potential adaptation pathways as illustrated below. This will be further explored and developed in the coming years.

Colour	Action or pathway	Target effects	Costs	Side Effects
	Current situation	○	○	○
	Double dike system	✓✓✓	✗✗✗	○
	Dike upgrade	✓✓	✗✗	○
	Upstream reservoir	✓	✗	○
	Buy out farmland + Dike upgrade	○	○	○
	Buy out farmland + Double dike system	✓✓	✗✗	○
	Buy out farmland	○	○	○
	Buy out farmland + Dike upgrade + Double dike system	○	○	○

Key

- ✓✓✓ Very beneficial
- ✓✓ Beneficial
- ✓ Somewhat beneficial
- ○ Neutral
- ✗✗✗ Very detrimental
- ✗✗ Detrimental
- ✗ Somewhat detrimental



Map generated with Pathways Generator, © 2015, Deltares, Cathago Consultancy

5 Operational asset management

5. Operational asset management

This Chapter sets out an overview of Operational Asset Management (OAM) before providing details on four key aspects:

- Defining the measures for assets, using requirements from strategy passed through the tactical handshake and refined for each asset.
- Design and construct procedures, undertaking of detailed design and planning actions for each asset and system, also delivering information for the strategic context via the handshake for the long term strategic planning and management of assets.
- Monitoring, maintenance and operation, including data collection about the assets, their performance, maintenance and operation.
- Assessing the performance of assets by observation and prediction of the long term functioning and reliability.

This chapter also addresses the aspects of **bridging the gap between design and construction** and maintenance and **operation** early in the planning phase, which may significantly reduce Life Cycle Costs of FRM assets.

Further to the description of the main components, the feedback to the tactical AM is addressed.

The components of operational AM (Figure 3.1) and the associated aspects are further explained here.

5.1. The Operational Loop

In FAIR, we take the broad view of the operational perspective which goes beyond mere maintenance. In the FAIR approach, operational asset management encompasses all activities that ensure the individual assets and asset systems continue to perform as required and when required. OAM also provides many of the data building blocks that strategic planning relies upon. Within FAIR this broad remit is considered in the context of four aspects (as set out in Figure 3.1 right hand loop): (A), Measures for assets; (B), Design and construct; (C) Monitoring, maintenance & Operation; (D) Performance of assets.

In implementing the strategic plans, OAM takes account of governing health and safety and environmental legislation, such as the Machinery Directive 2006/42/EC for mechanical and electrical assets, and seeks to adopt best practice in Data and Information Management (see section 5.2) whilst continuing to inspect, repair, and even protect from vandalism (see section 5.4) and taking a lead during flood events to operate moveable barriers, and contributing proactively to event communication.

The operation of a flood protection asset is normally managed by the respective operating authority or private owner (the operator) which, in most cases within the EU, is a public authority. However, the public authorities in the North Sea Region represented in FAIR handle operation and maintenance very differently, ranging from contracting out all measures to performing inspections and repairs themselves, supervising every inspection, to just assisting and giving advice. In general, a trend to build in-house competences can be seen in contrast with the downsizing and budget cuts for maintenance that were or are happening in many public institutions in the North Sea Region. A detailed analysis of existing maintenance and operation strategies for flood protection assets in the North Sea Region is given in Jordan *et al.* (2019).

Each of the operational components (A-D in Figure 3.1) is detailed in the following sections.

5.2. Measures for Assets

The requirements derived from the strategic context via the tactical handshake, contribute to the setting of the context for the decisions on the types of flood protection assets to be used in Component A of the FAIR framework and also for the continuing use of existing assets.

In this component of the FAIR framework, the overall management of the assets and the measures to be adopted are defined. This may include the following key tasks:

- For 'on demand' assets such as gates, sluices, pumping stations: Ensuring the protection of assets through the implementation of the relevant Machinery Directive e.g. 2006/42/EC:
  - Making the Declaration of Conformity for the flood protection asset
  - Ensuring the asset safety, i.e. ensuring that all safety measures have been undertaken to make the asset safe
  - Ensuring the operational safety, i.e. ensuring that all elements of the asset function properly, as per design
  - Ensuring the safety at work for operators
- For all assets: Data and Information management, which includes the following activities:
  - Documentation of asset location and function
  - Documentation for inspections and monitoring records
  - Documentation of the asset characteristics and features (type, dimensions, capacity etc.)
  - Documentation of the status of assets (available, standby etc.)
  - Documentation of performance of assets as a result from the monitoring process
- For all assets: Flood preparedness for extreme events (preparatory measures such as training, contingency planning and organisation)

These activities are usually undertaken by the operators and are aligned with the requirements derived from the strategic context (Component 5 of the strategic loop). They should be formalised and auditable (see for example, EA, 2014).

There are a variety of flood protection assets that can be considered for the selection of specific measures. These range from dikes, sluices, dams, flood gates, storm surge barriers, stormwater networks, pumping stations and increasingly, nature-based assets - NBA or their combination (refer also to Section 1.1).

The requirements encompass technical, environmental, societal and economic dimensions, emphasising the importance of the multifunctional approach. The synergies and conflicting issues are analysed related to e.g. the environment and ecology, mobility, economy (such as tourism, agriculture), spatial and landscape planning, social/political or cultural matters (e.g. heritage sites). As these requirements can change over time, it is important to regularly monitor the societal (political) changes, economic changes and / or conflicting requirements. However, these always need to be grounded back to the strategic contextual specifications. An example of the multifunctional design and interconnectivity between operational and strategic contexts, via the tactical handshake that has been developed in FAIR is given in Box 6.2 for the FAIR Pilot Middelkerke, Belgium.

Here, the enhancing of the primary function of the assets for flood protection has been used as a chance to enhance the economic and tourism value that can be supported by changes to the asset, and consequently in developing a multifunctional system which is partly funded by the Flemish Government (flood protection) and the local government (architectural upgrades).

Many structural flood protection assets, for example, grassed dikes, rely on vegetation to function effectively and therefore require the management of vegetation as part of maintenance. Furthermore, following the trend to develop and deploy nature-based assets (NBA) as a part of flood risk management strategies, maintenance strategies may need to be adapted in the future to support the needs of these NBA based systems. This again confirms the need to have an adaptive approach in AM and align its strategic and operational perspective as already presented in Section 3.

5.3. Design and construction of assets

For component B in the FAIR framework, the functional requirements such for the flood protection assets, given in Section 5.2 are implemented in the design procedures. These are given as hydraulic (i.e. provision of the design flood protection level), environmental, economic, or may consider a wider range of issues such as enabling drainage of the land behind a dike, or securing better traffic flows.

General approaches for planning and design of individual assets are defined in national or international codes, standard specifications or technical rules. In some countries, recommendations of technical associations have a status similar to standards. Practices in the different NSR countries vary. In general, the key technical steps of the planning process include (e.g. referring to US Army Corps of Engineers, 2002):

- Review of local specific problem (type of floods, vulnerabilities, current and projected risks, etc.)
- Definition of design parameters (e.g. water levels, wave conditions, currents, soil properties) for flood protection assets, based on return periods of events / necessary safety levels and / or acceptable risks
- Functional design of flood protection
  - Definition of functional requirements
  - Definition of defence line
  - Selection of construction (dike, dune, revetment, wall, etc.) or combination of different structures
  - Application of functional requirements to construction(s)
  - Functional analysis / check of functionality
- Constructional design of flood protection
  - Definition of structural requirements
  - Application of national design codes
- Cross check of functionality, constructability und operational requirements
- Selection of the final option

Box 5.1: An example of the design procedure for the FAIR pilot in Middelkerke, Belgium focusing on the definition of design parameters.

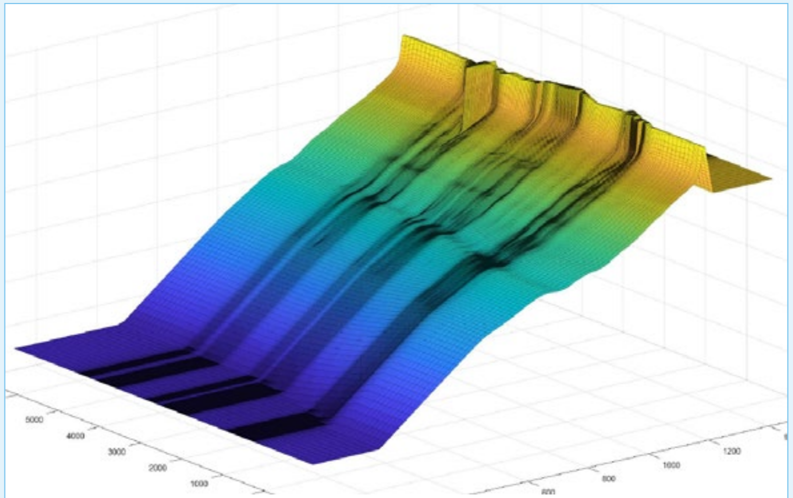
Review of local specific problem: For the pilot site in **Middelkerke** a detailed and extensive design was carried out for the new sea dike and dune. A combination of advanced methods was used to determine the performance of the measures.

Definition of design parameters: A computer model of the environmental and hydraulic aspects of the North Sea was used to predict the sea level and the wave height regimes during storms at the coastline in Middelkerke. This model was validated with extensive measurements by a network of monitoring devices in front of the Belgian coast and in the coastal ports (https://www.afdelingkust.be/en/flemish-hydrography).

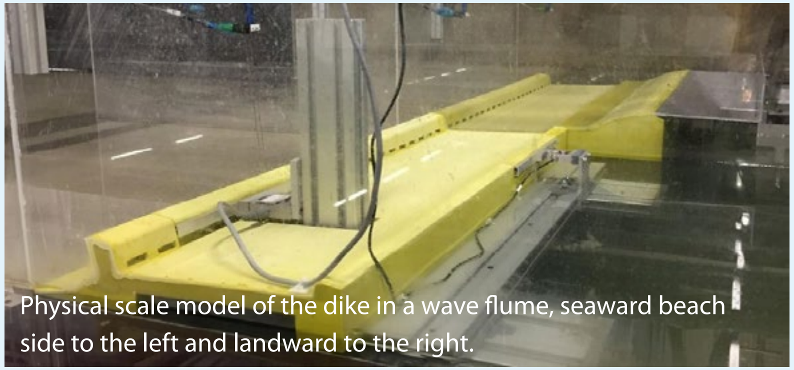
The Flemish minimum safety level is a storm event with a return period of 1000 years. A sea level rise of 42 cm by 2070 (life span of the structure) has been included in the water level estimates.

After determining the boundary conditions, the erosion of the beach during the storm was estimated using a computational numerical model (XBEACH[25]). This model can be used to determine the behaviour of the beach during a storm. The beach will erode due to the incoming waves. This will lower the beach and result in higher waves at the toe of the dike and the dune.

Another numerical model (SWASH[26]) was used to estimate the wave conditions at the toe of the dike. The waves will transform from deep water conditions to breaking waves at the toe of the dike. With these calculated wave conditions at the toe of the dike, a series of physical scale model tests were then carried out using a laboratory wave flume to determine the overtopping of the sea wall and the forces acting. The structural calculations and design of the final protection options were undertaken using these force estimates. The dune was also modelled with the same numerical model for the beach erosion and the wave transformation.



Results from modelling of the beach erosion during a storm (XBEACH) – the vertical axis (unscaled) shows elevation, the left hand axis is distance alongshore (m) and right hand axis, the distance perpendicular to the defences (m).



Physical scale model of the dike in a wave flume, seaward beach side to the left and landward to the right.

25. Developed by Deltares, Netherlands: https://oss.deltares.nl/web/xbeach/
26. Developed by TU Delft, Netherlands: https://www.tudelft.nl/en/ceg/about-faculty/departments/hydraulic-engineering/sections/environmental-fluid-mechanics/research/swash/

Although the design parameters, principles and functional requirements vary for different local conditions and contexts, these share some key underlying requirements and principles, which are at the core of FAIR and have been addressed in the activities of the FAIR pilots. These are:

- **Multifunctionality** i.e. the requirement to enhance the value of the flood protection assets to include further functions and benefits, such as economic (e.g. tourism), ecological or social. An example is the promenade in the harbour area of Hamburg, which has been raised and enforced to meet the highest standards on the dike safety, as it is an asset of the primary dike line (see also Kron & Muller, 2019). This upgrade has been used as an opportunity to enhance its value in terms of the social and economic benefits (tourism, leisure). Another example describing the upgrading of the primary dike line in Belgium is given in Box 6.2.
- **Bridging the gap** between design and construction of assets, and maintenance, monitoring and operation of assets; i.e. creating an active exchange and cooperation between these components. This is to ensure that design flaws or errors, which become apparent during the operation or maintenance of an asset, are not repeated in the design of new assets and improvements can be incorporated in future designs and planning. In the design phase, the involvement and the interests of the asset owner[27] should be paramount. The assets selected should fit into the already operational asset portfolio, rather than creating unique and possiblly complex infrastructure, unless absolutely necessary. Therefore the asset owner should deliver a clear specification of demands upfront, for example to ensure the efficient maintainability by utilising uniform construction elements comparable with those already existing, or for ease of maintenance.
- An example of the bridging of the gap procedure for the FAIR pilot in Hamburg is given in Box 5.2.

Box 5.2: Closing the gap between planning processes and operation - adaptive design of Flood Protection Gates in Hamburg (Components B to C, Figure 3.1).

In order to bridge the gap between planning and design and O&M, FAIR partner LSBG in Hamburg (responsible for planning and operation of flood protection assets) has a specific agreement between planning, construction and maintenance units. This agreement regulates the cooperation between affected parties and describes a way in which all sides benefit - in a form that is standardised for all flood protection facilities. The agreement regulates, for example, the form in which assets are handed over from planning or construction to maintenance. Which documents and records are handed over to ensure smooth operation? What does further cooperation look like? These are only examples of the numerous aspects that are specified in the LSBG agreement. The agreement also ensures that employees from maintenance and operations are involved in the planning of new assets from an early stage and are present at planning meetings. Thus, the planning and design of new flood protection assets or the repair of existing assets, benefits from the long-time know-how of employees who work with and on the assets every day.

- **Long-term perspective** of the designed measures; i.e. considering all relevant drivers and challenges for the future development and the associated uncertainties, as given in section 1.1 or Box 1.1. Adaptivity (**adaptive design**), resilience and robustness, have emerged as explicit criteria for strategic decisions, which are then included in the operational loop for the planning and design of assets.

27. The asset owner will enure that societal interests are paramount for any FP assets.

Included in the planning and design should be due regard to the inclusion of adaptive asset management, where the design process should actively implement flexibility and adaptability requirements, but at the same time maintain service performance and robustness (see also Section 1.3). Putting the design of assets into a longer-term perspective, the objective is to expand their lifespan or reduce the overall costs of use. Also, the operational behaviours can change, responding to the adaptability requirements – for example, the Thames Barrier rising sector gates are now being over-rotated to provide a higher crest level than was originally designed for in order to provide a longer useful life and save on replacement costs[28] (see also Box 4.4).

There are a number of approaches being used in the design process for individual or groups of assets as outlined below, which vary across the NSR countries involved in FAIR.

For **reliability-based design** (e.g. Buijs, et al., 2004), the design details for the flood protection asset are specified usually by minimising the costs for the construction to achieve the defined protection for a given flood probability. Where multi-functionalities are expected, a cost-benefit assessment may be used. General approaches for the planning/design of individual assets are defined in national or international codes, standard specifications or technical rules. The specified flood probability to be managed will be defined in the strategic context of the framework in Figure 3.1, in compliance with the relevant regulations or standards, passed to the operational context via the tactical handshake.

In **risk-based approaches** the flood probability used for the design is obtained by comparing the cost of protection measures with the resulting risk reduction (probability of occurrence multiplied with the potential damage) the measures will provide. A set of possible design options is created and compared based on the final risk where tolerable risks and residual risks have to be taken into consideration. The risk-based approaches require a full risk and damage or loss assessment along the source-pathway-receptor path (Chapter 4 and Oumeraci, 2001 or 2005).

In **life-cycle cost (LCC) optimal design** the main cost-based criteria are analysed with the objective to find the solution connected to the minimum cost over the life-cycle, whilst meeting the performance requirements. Life-cycle-costs include: i) planning and building costs; ii) operational costs including maintenance, monitoring and inspection costs (e.g. EA, 2017); iii) cost of environmental impacts; iv) repair and replacement costs; and v) decommissioning costs. These can be divided into four categories: planned; unplanned costs; cost of ownership; and cost of usage. Life-cycle cost assessment is aimed at the selection of the most suitable and economic solution from possible alternatives, fulfilling the desired requirements (functions and required safety standards for the asset at the network level) of a construction. Also consideration of any buildings' environmental impacts should be part of the LCC design process.

5.4. Maintain, Monitor and Operate

Maintenance and monitoring of dikes, embankments, flood-protection dunes and walls as well as physical operation of FRM assets during storm events including the operation of 'on demand' flood protection assets (Component C, Figure 3.,1) are frequently seen as the basic and most important tasks of the operation of assets in FRM. Sometimes, and especially in the absence of extreme events, the operations are simply delivered as maintenance.

28. https://www.bbc.co.uk/news/magazine-26133660

Independent of the type of asset there are three main approaches to a maintenance strategy in coastal engineering (Glimm *et al.* 2009; DIN EN 13306, 2018). With the *Corrective Maintenance Approach* an asset or a unit is being replaced when there is a failure or damage occurs. When following the *Predictive Maintenance Approach*, depending on the expected wear and tear, maintenance measures are planned and initiated in a timely intervention before a failure occurs. The *Condition-based Maintenance Approach* schedules regular inspection to gather information about the degree of wear of single units of an asset. Further, a risk based inspection approach requires a detailed analysis of the probability and consequences of failure, both quantitatively and qualitatively. The focus is therefore on the critical assets that carry the most risk to fail. Thus the objective of this strategy is to determine the most economic use of maintenance resources to minimise the risk to failure, or to lower it to an acceptable level. Table 5.1 gives an overview of the advantages and disadvantages of the three strategies. A combination of the advantages of these maintenance strategies is required to organise maintenance efforts for flood protection assets as economically as possible. For maintenance scheduling, priorisation and works, FAIR builds on the above mentioned concepts within a risk based priorisation framing.

A Europe-wide accepted **maintenance** standard, where basic steps and approaches of maintenance are defined, has not yet been implemented. However, there are initiatives to develop an EN on Maintenance Engineering, such as the initiative of the Standards Norway to be led by CEN/TC 319, and the working group WG 14 Maintenance engineering (Working Programme, CENELEC, 2019[29]).

Nevertheless, in FAIR the approach to maintenance takes into account accepted maintenance concepts and approaches. Several international as well as national standards of relevance are available for maintenance applicable to AM for FRM. For example, ISO 16646:2014 Maintenance – Maintenance within Physical Asset Management, supports ISO 55001:2014 (Asset Management) in ensuring AM requirements are met (Nagyova & Pacaiova, 2018). ISO 9001:2015 Quality Management Systems sets out the need for and essentials of a risk-based approach. Various NSR countries have general maintenance guidelines or norms of their own. For example, in Germany the standard 'Fundamentals of Maintenance' (DIN 31051:2012-09)[30] defines maintenance as: *"a combination of all technical, administrative and management actions during the life cycle of a unit, which serves to restore or maintain its' functioning condition so that it can perform the required function"*. This comprises four basic measures (adapted here for FRM):

a) servicing - measures that extend or maintain the desired lifespan;

b) inspection – measures to assess the actual status of an asset to derive necessary consequences;

c) repairs – measures to restore the functioning of a failed asset;

d) upgrade – measures to increase the reliability/maintainability/safety of an asset without altering the original function.

The main goal of maintenance is to preserve (maintain) or improve a defined target state of the asset in order to ensure desired functionality (protection level) over the complete operating life of the asset.

Europe-wide there are no commonly defined standards for flood protection asset maintenance that are applied within FRM.

29. https://www.cencenelec.eu/news/brief_news/Pages/TN-2018-090.aspx
30. Replaced by DIN 31051:2019-06

Nevertheless, there are several national standards. For example, in the Netherlands the *"Flood defence system inspection manuals"* (STOWA, 2012[31]) and in the UK the Condition Assessment Manual (EA, 2012) and inspection guide (EA, 2014). In addition, there are numerous guides related to monitoring flood protection assets, including CIRIA (2013) and Wallis *et al.* (2012). Most of the manuals and recommendations describe a range of measures from the simplest walk-over (make a visit) to the use of contemporary sophisticated instrumentation.

Within FAIR, Jordan et al. (2019) analysed the maintenance practices implemented for FP assets in the NSR (Appendix B) and concluded that maintenance strategies for coastal protection generally fall into one of the following generalised maintenance strategy categories (DIN EN 13306; Glimm, *et al.*, 2009), and Table 5.1:

- corrective maintenance strategy – repair and / or replacement of part after failure;
- preventive maintenance strategy:
  - predictive maintenance strategy: replacement of a part is scheduled prior to failure before the minimum lifetime of the part is reached;
  - condition-based maintenance strategy: regular inspection ensures determination of deterioration, damages, illegal activities, etc., or parts and actions (repair, replacement, etc.) for parts are defined to ensure the intended status is available.

Commonly for flood protection assets, the preventive strategy is a combination of the predictive and the condition-based strategies, applied for effective maintenance planning. Nevertheless, in practice all of the above approaches may be used within maintenance processes.

Strategy	Advantages	Disadvantages
Corrective maintenance	• Optimum use of the life span of the asset/ element of an asset • No costs for preventive planning • Low administrative effort	• Only possible, if the asset does not always have to be available • Looming damages are not detected • Possible high follow-up costs from damage
Predictive maintenance	• Avoidance of high follow-up costs from damages	• Severe planning effort (extensive data collection) • Technical life span rarely fully utilized
Condition-based maintenance (risks included)	• Flexible adaption of inspection intervals • Optimised use of the life span of an object • Collection of data/information on degree of wear • Plannable costs in the long-term	• Often considerable costs for inspections

Table 5.1: Maintenance strategies in coastal engineering, advantages and disadvantages (modified after Jordan, et al. 2019, adapted from Glimm et al. 2009 and DIN EN 13306, 2018)

31. STOWA 2012-14 Inspection Manuals For Flood Defense Systems, ISBN 978.90.5773.542.4, Directorate-General for Public Works and Water Management, Ministry of Infrastructure and the Environment, Ammersfoort, 2012

The organisation and responsibilities for the maintenance of assets varies around the NSR (Jordan *et al.*, 2019; Appendix B), finding that in the Netherlands, Belgium and England[32] the main responsibilities are centralised. Corporate governmental bodies and agencies, such as Rijkswaterstaat (NL), MDK (B) or the Environment Agency (England and Wales), are responsible for the flood protection assets throughout the respective countries. Only the responsibilities for smaller, local assets like river dikes are dispersed amongst several other organizations; e.g. the Dutch Regional Water Authorities. Centralised approaches ease the compliance with nationwide, uniform standards and methods, but can also risk the danger of losing track of the comparatively smaller assets and measures.

The Scandinavian countries in FAIR have a long history of decentralised governance. In Denmark and Sweden, local municipalities or even private citizens, are responsible for local flood protection. National authorities like the Danish Coastal Authority or the NVE (NOR) only give advice, provide knowledge and regulations, or assist with inspections. A decentralised approach has strengths in the coordination of maintenance measures and in problem solving between different parties involved in maintenance. But there is also a risk in adding responsibilities to municipalities or even private landowners, without ensuring sufficient resources and knowledge are in place.

The German approach represents a mix of centralised and decentralised governance. There is no nationwide institution which is in charge, but rather one main institution for each of the Federal states along the German coastline, e.g. the LSBG in Hamburg.

The different responsibility structures for maintenance requires a specific approach and organisational structure to ensure maintenance and operation where for practical purposes a **maintenance strategy**, underpinned by specific **maintenance plans** (manuals) for individual assets, has to be developed (as stated e.g. in CIRIA, 2013), implemented and documented with respect to the performance of the specific flood protection asset within the network. Practical maintenance distinguishes between flood protection assets with on demand flood protection assets with moveable parts (e.g. stop-locks, flood protection gates or storm surge barriers) and flood protection assets without moveable parts (e.g. dikes, walls or dwelling mounds). Regular inspections of the FRM assets are necessary which may also include an operational test, especially if the asset consists of moveable parts. Formalised documentation of the inspection and the results of the inspection are essential. Observed deviations from the target state need to be recorded and assessed. Necessary actions need to be initiated. Regular inspections form the baseline to assess whether or not the asset is providing the required functioning (Section 5.5 / Component D in Figure 3.1) and to support necessary servicing and / or repairs.

Hamburg re-defined the Federal States' maintenance strategy (Box 5.3) within FAIR. Through standardization of maintenance processes and the direct link of the maintenance operation to the documentation and assessment of the maintenance costs, the necessary budget was reduced by 5% without reducing the safety and therefore the protection level in the flood prone areas (see also Fröhle *et al.*, 2018).

32. This applies to coastal flood risk management. Arrangements for stormwater and watercourses differs in England and Wales.

Experience gained from the analyses of the maintenance approaches in the FAIR partner countries showed clearly that planning implementation and maintenance and operation of FRM assets are frequently separated between the various coastal protection organizations. Hence, the communication between the planners and the operators is often limited and there is a gap between planning and operation (Box 5.2). Nevertheless, the analyses showed that a good communication of experiences in both directions is necessary and that therefore an institutionalised link and information exchange between components B and C of the FAIR framework (Figure 3.1), early in the planning phase is recommended (closing the gap between planning and operation). Through communication, this leads to more maintenance friendly assets with potential cost reductions for both construction and maintenance. Based on experience with operation and maintenance, Hamburg will in future install fewer complex and more standardised, flood protection gates; where estimates show that LCC will be reduced significantly (>10%). In addition, planning helps to provide direct requirements for the maintenance needed.

Box 5.3: The Hamburg Maintenance Concept – the FAIR Approach

Assets, which are in round-the-clock operation (24/7), require a different maintenance strategy than those which are used only a few hours per year. For this specific case, the LSBG and TUHH developed an adaptive Maintenance Concept. The overall objective was to increase the reliability of the assets as well as reducing the maintenance costs. Furthermore, the quality of the maintenance can be sustained or even enhanced. A constant asset availability is LSBG's top priority. A well-thought-out maintenance concept, which explains the basic strategy as well as the schedules, gives the responsible people more confidence in their actions. Through standardisation, the technical framework for this can be simplified. This adaptation facilitates the easier operation and an improved long-term understanding of the assets by the operational staff.

A holistic view of the entire LCC is an essential aspect of the maintenance strategy. Important feedback from the maintenance organisation is gathered for future asset designs, in order to contribute to sustainable planning and operator concepts. The permanent improvement process is based on the goal of providing optimised and application-oriented systems.

The maintenance concept developed from this describes the structure for the maintenance of the facilities in delivering the objectives. This is intended to serve as supporting guidance for all maintenance services.

As a result of the planning and construction phase, a large amount of data and information (plans and drawings, defined cross-sections, safety levels, design considerations, intended uses, etc.) are available, which is necessary for the operation and **monitoring**. Over time, uses and requirements may change and rights of access to information may be granted to third parties and / or internally.

Monitoring of the status of flood protection measures is an integral part of the maintenance process. For this, regular comparatively low-effort checks are mostly more effective than rare high-effort campaigns. In most NSR countries one to two yearly expert surveys are performed for the flood protection network to analyse the status of the flood protection assets. The results of these surveys are documented and compiled and measures to ensure the safety of the assets defined. This includes practical works for rehabilitation of assets, administrative measures and / or optical measures.

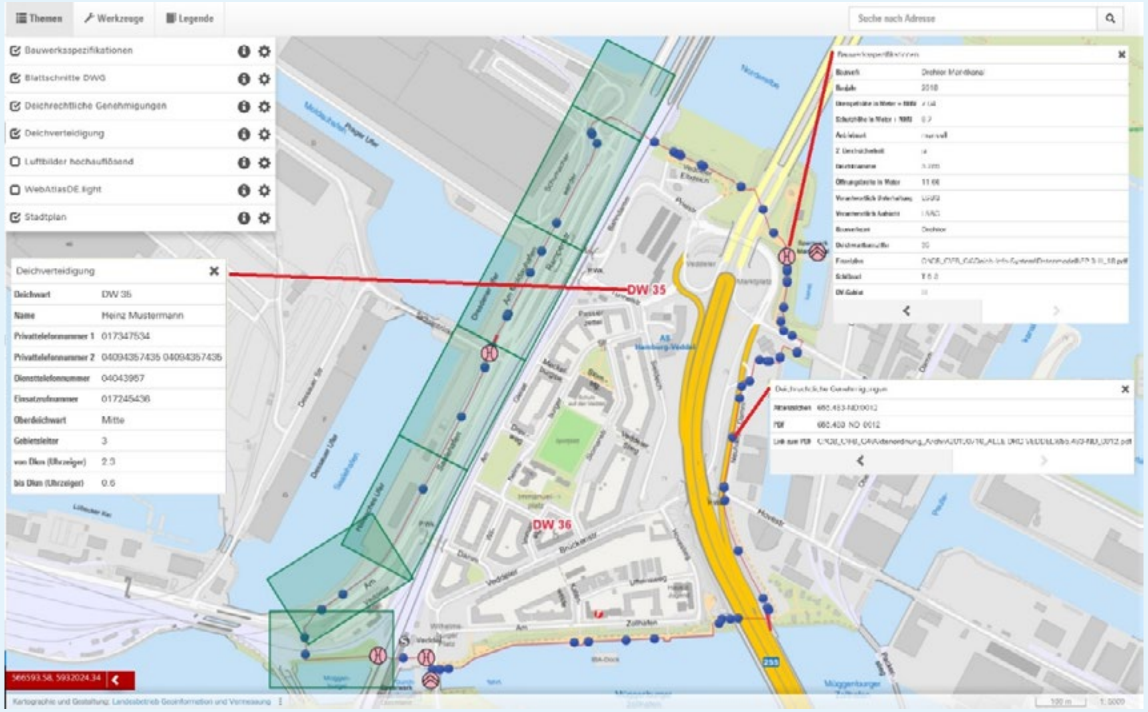
In addition to the monitoring of the status of the flood-protection asset, the frequency and intensity of loads on the asset have to be monitored. This includes water levels, currents and waves as well as ice conditions and other mainly site specific loads. Specialised governmental authorities (from State scale to local scale) are usually responsible for the measurement networks. Examples of gauging networks can be found[33]. Comprehensive data portals are available in some countries[34].

Managing the data and making the data available for maintenance and operation processes is a key task (Section 5.2). All available information on assets and on loads should be compiled into data bases and managed effectively in order to provide the right information to the right person when necessary. An example of an information management system implemented within the FAIR project is shown in Box 5.4. The maintenance processes can be further optimised through a direct link to the maintenance personnel.

Box 5.4: Dike Information System (DIS) of the FAIR Hamburg Pilot

In Hamburg a central module for the presentation of all relevant data of the flood protection facilities - the **Dike** Information System (DIS) - was developed within the FAIR project. Its goal was to provide the official supervisory authorities, planners, constructors and maintenance staff with a tool that allows them to work comprehensively.

The most important aspects were to determine the data structure, to avoid redundancies, and to convert the data itself into a digital and georeferenced form, since it was often only available in paper form. The application is web-based designed. Information is thus available in the office but also on the dike, out in the field or at any other location.



33. e.g. https://www.pegelonline.wsv.de/gast/start
34. https://www.bsh.de/DE/DATEN/daten_node.html;jsessionid=51E06E62813EA2F7D722D9E817448A1F.live21301

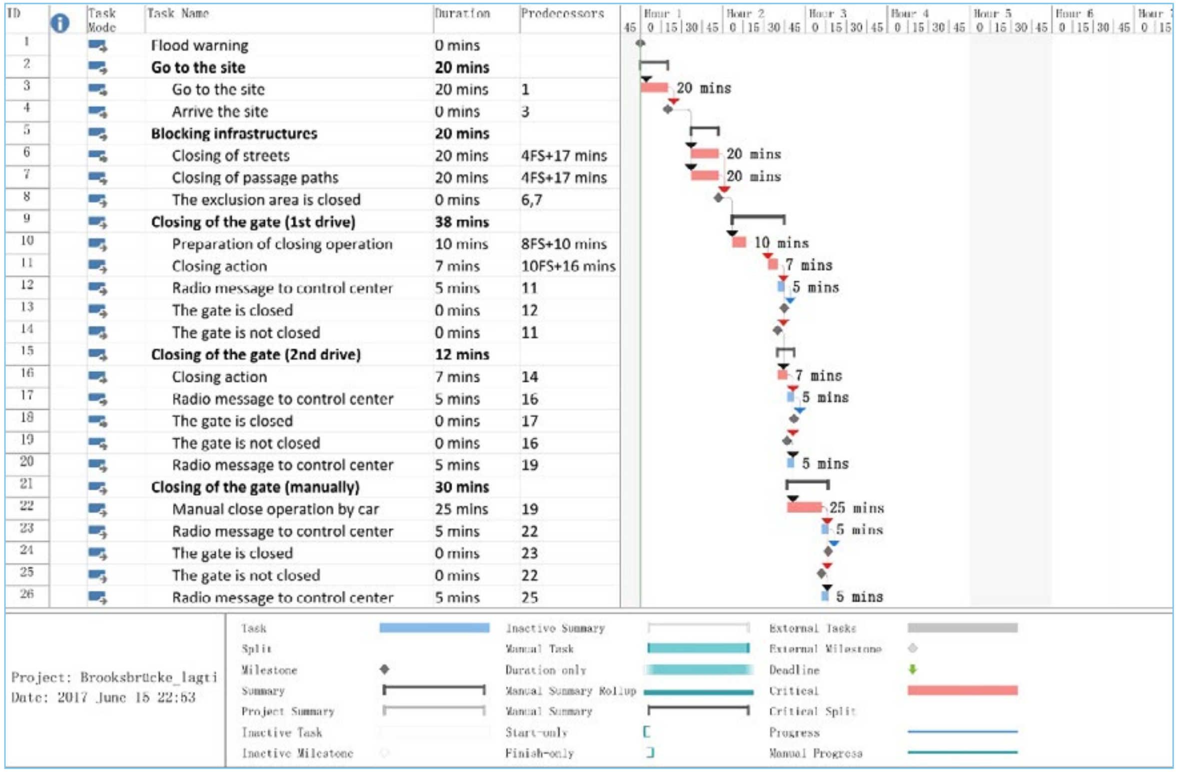
The city of Hamburg is currently developing a system for maintenance management that will include all assets from e.g. school buildings, cycle paths, parks and … flood protection facilities. The information from DIS is of available to this application.

This programme led to significant optimisation of the work. The process enables integrated work at one workstation without asking, searching and collecting information at different locations. This saves a lot of time and helps to reduce errors because all information is available. Importantly, the direct availability of the data enables decisions to be prepared more clearly and better. This makes it easier to avoid costly, less than optimal decisions.

The process is being further developed. The data design was chosen in such a way that other applications (as front-end) can also be based on it and use the non-redundant data. With this development and the support of the FAIR project, the digital mode of operation in the flood protection of the city has been significantly improved and cost savings made.

Besides the day to day **operation** of FRM assets, the assets have to be in place (functioning) when needed. This requires regular maintenance for assets without moveable parts and installation and implementation plans to ensure emergency preparedness of the defence line. In addition, the flood protection assets have to be robust and resilient (maintained) during flood and storm events and any unavoidable inundation has to be handled by pumping or otherwise.

Within FAIR, the operation of flood protection gates has been analysed in detail in order to define the critical path for this procedure and to improve preparedness.



ID	Task Name	Duration	Predecessors
1	Flood warning	0 mins	
2	**Go to the site**	**20 mins**	
3	Go to the site	20 mins	1
4	Arrive the site	0 mins	3
5	**Blocking infrastructures**	**20 mins**	
6	Closing of streets	20 mins	4FS+17 mins
7	Closing of passage paths	20 mins	4FS+17 mins
8	The exclusion area is closed	0 mins	6,7
9	**Closing of the gate (1st drive)**	**38 mins**	
10	Preparation of closing operation	10 mins	8FS+10 mins
11	Closing action	7 mins	10FS+16 mins
12	Radio message to control center	5 mins	11
13	The gate is closed	0 mins	12
14	The gate is not closed	0 mins	11
15	**Closing of the gate (2nd drive)**	**12 mins**	
16	Closing action	7 mins	14
17	Radio message to control center	5 mins	16
18	The gate is closed	0 mins	17
19	The gate is not closed	0 mins	16
20	Radio message to control center	5 mins	19
21	**Closing of the gate (manually)**	**30 mins**	
22	Manual close operation by car	25 mins	19
23	Radio message to control center	5 mins	22
24	The gate is closed	0 mins	23
25	The gate is not closed	0 mins	22
26	Radio message to control center	5 mins	25

Figure 5.1 Critical path analysis of the performance of a flood gate in the Hamburg pilot. The red bars indicate the critical path in the operation of the gate (LSBG / TUHH)

For this, a stepwise analysis of the asset operation has been carried out, identifying the critical processes, based on their duration and on the factors that can impact on their optimal or designed performance. An in-depth analysis of the asset performance (here for flood gates) has been undertaken in Hamburg. All processes and actions before, during and after the operation have been analysed, and each allocated the expected duration and the agreed tolerance level based on the expert opinion and experience gained in operating the gates. From this, it has been possible to assess the critical path (Figure 5.1) and address the possibilities to overcome unwanted impacts for the operational context, and at the same time providing suggestions for the redesign of the gates.

5.5. Performance of assets

The assessment of the performance (Components D and 5 in Figure 3.1) is a core element in bringing together the asset (operational) and the network (strategic) oriented management of flood protection via the tactical handshake (Chapter 6). Understanding and verifying that the performance is as required, defined by pre-defined criteria and indicators, is decisive in deciding whether to adopt an asset as part of the AM programme. Also, the asset performance assessment will show if there are improvements needed to the AM process. This Component is a continuous and long-term part of the operational AM process and it may require changes in established practices by the various actors involved.

Performance analysis of assets is based on the asset condition and on the targeted protection level in combination with the protected values, and should ideally also include the performance related to multi-functionality, adaptability, cost effectiveness and possible extended lifetime of the FRM asset.

There are no standardised approaches for the assessment of the performance of assets defined as yet in the EU and the NSR countries. In general, the performance against defined criteria are analysed and assessed by:

- On site analysis of asset performance
  - Experts / experts group opinion on expected asset performance based on subjective / descriptively objective asset condition analysis (e.g. CIRIA (2013), STOWA (2012));
- Objective assessment of asset performance utilizing indices based on quantitative testing of asset condition against defined criteria or deterministic models (physically based or empirical);
- Probabilistic assessment of asset performance (input quantitative tests);
- Risk based assessment of asset performance (probabilistic assessment and consequences).

All approaches rely on information and data generated in components A to C in Figure 3.1, where a strong link to experiences gained in C, for maintenance, monitoring and operation is in place.

'Asset health' has emerged as a concept that is being used extensively for defining the condition of an asset, if for example, there are cracks in a dike (e.g. Klerk et al., 2019). There are various definitions of 'asset health' which *"needs to consider not only the physical state of the asset but also the role and importance of the asset in ensuring that service performance targets and (customer) expectations can be met."* (CH2M, 2017)[35]. In England, 'asset health' is being used in association with asset resilience as the key aspect of the water service sectors' ability to deliver reliable and resilient water and wastewater services to current and future

35. https://www.ofwat.gov.uk/wp-content/uploads/2017/09/Targeted-Review-of-Asset-Health.pdf

customers. In the latest business planning round (2019)[36], the private sewerage undertakers in England had to define their *"Asset health performance commitments"*, for a range of asset types, including stormwater assets (Black, 2019). This concept is also being used for natural assets (EU, 2019), especially to engage communities in monitoring the asset condition.

There are a number of other methods used to analyse and evaluate the performance of assets. The risk-based or reliability centred approaches to maintenance and inspection take a qualitative and/or quantitative risk assessment focusing on the critical elements and processes related to the asset performance (such as dikes, walls, gates) and operation. The main approaches are outlined below.

The on-site analysis of the asset conditions based on expert surveys, including functional tests (where necessary) is the current typical way of analysing the asset condition for a specific site. Within this process, experienced surveyors examine an asset and consider the condition based on individual objective requirements or on defined condition levels, as e.g. given in a Condition Assessment Manual (EA, 2012). The results of the surveys and the actual status are documented and measures to ensure the safety of the assets are defined (Section 5.4).

The on-site analysis of the asset conditions, linked with quantitative criteria, is based on an initial assessment. Critical assets are identified and considered for further analysis

Quality characteristics		Excellent Grade: 1	Good Grade: 2	Moderate Grade: 3	Poor Grade: 4
Grass cover density	Ground Cover [%]	> 75	60 – 75	45 – 60	< 45
	Size of the uncovered area [cm²]	< 32	32 – 64	64 – 96	> 96
Rooting	Root Length [m/5dm³]	> 900	750 – 900	600 – 750	< 600
	Root Weight [g/5dm³]	> 14	12 – 14	10 – 12	< 10

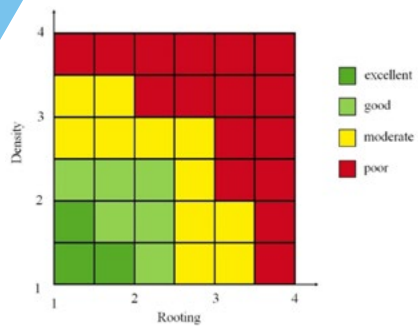


Figure 5.2: Condition assessment: 'grid' method used to assess the condition of the grass cover applied to a coastal dike in Hamburg and the corresponding evaluation matrix with the quantitative criteria for the assessment of the condition of the sod. The condition of the dike sod is determined as a function of the grass density and the root penetration.

36. https://www.ofwat.gov.uk/outcomes-definitions-pr19/

Quality classification/grade	Limits (kN/m2)	Rating
1	> 70	Perfect
2	55 - 70	Good
3	45 - 55	Moderate
4	35 -45	Poor
5	< 35	Very bad

Figure 5.3: Condition assessment: example onsite method to assess the shear stress within a coastal dike as part of the dike inspection procedure

Right: Quantitative evaluation of the shear stress. This method is a part of the maintenance toolkit that is currently being developed as a support to the current inspection procedure.

based on previous experience and the available knowledge of the maintenance and operational assets as well as on documented examples available in publications. In risk-based approaches, the objective (quantitative) criteria are developed or applied in order to assess the conditions of the elements. For coastal dikes in Germany, the following elements are critical: (1) gaps and cracks in structures; (2) condition of the grass sod and; (3) susceptibility to erosion of a dike (Jordan *et al.*, 2020). Quantitative criteria have been further developed to assess the criticality of a dike condition for these elements. An example of the approach developed for the grass sod on the dikes in Hamburg is shown in Figure 5.2. Figure 5.3 illustrates a method to analyse the shear stress within a dike and how this is related to the dike condition.

Automated (smart) analysis of asset condition assessment is evolving rapidly in some NSR countries, where attempts have been made to analyse the individual asset condition from sensor based measurement networks, including loads and behaviour of the infrastructure. These technical approaches are still part of research programmes. Examples are the LiveDijk[37] project in the Netherlands and the EarlyDike[38] project in Germany.

The different methods available for the assessment of performance have varying degrees of complexity (from inspection to risk based approaches) and can be selected depending on the degree of risk involved, or based on the protected values; i.e. increase complexity and effort of assessment where higher asset values are to be protected. For example, the Ministry of Infrastructure and the Environment and Rijkswaterstaat (RWS) in the Netherlands have launched a risk-driven approach named **RAMSSHEEP**[39] which has been used for AM for highway projects **(box 5.5)**.

37. https://www.ijkdijk.nl
38. http://mdi-de.baw.de/earlydike/
39. https://www.semanticscholar.org/paper/Applying-RAMSSHEEP-analysis-for-risk-driven-Wagner-Gelder/4715e8fcda2f4473fef50d8806c1630a161049a7

Box 5.5: RAMSSHEEP approach to performance assessment of assets

RAMSSHEEP – Reliability, Availability, Maintainability, Safety, Security, Health, Environment, Economics and Politics to assess the performance of assets which protect high risk areas. RAMSSHEEP is based on a well-developed method of analysis that provides an indication of the performance reliability (quality) of the functioning of an asset. This is defined by the Reliability, Availability, Maintainability and Safety (RAMS). The RAMS analysis can be seen as a risk concept that is used to define the primary performance of all the functions of an asset or asset system. A RAMS analysis can be used at every stage of the life cycle for the entirety of the infrastructure in The Netherlands: road network, major waterways and main water bodies, but is also usable for individual components within a network.

Within the NSR a variety of the generally applicable approaches are in use, most utilising an on-site method of analysis of performance of assets, where the complexity of the approaches is adapted to the protected values and/or the risks in the protected areas.

Information and knowledge of performance and the development of the performance of FRM assets generated during the assessment need to inform the maintenance process to provide the foundation for improvements to support the extension of asset life span and / or optimise life cycle costs.

5.6. Feedback to and from the Tactical context – via the tactical handshake

The FAIR project framework (Figure 3.1) has been designed in a way that there is effective interconnection between the **strategic** and the **operational contexts** via the **tactical handshake** to ensure that the requirements defined in the strategic adaptive asset management plans are properly fulfilled in the performance of assets, individually, as well as in combination with other assets. It also ensures that the information gained from the operational context about the performance of individual and collective assets is effectively fed-back into the strategic planning process loop.

The operational AM receives the main requirements from the strategic AM via the tactical handshake relevant to the planning and design of the individual assets (see also section 5.2 i.e. step A of the operational loop).

The key information from the operational AM feedback to the tactical asset management is related to the actual condition of an asset (e.g. condition of grass on a dike section and its change over time) and the performance of an individual or groups of assets. Using multiple feedbacks for the range of assets in use, the strategic plans can be adapted accordingly (box 5.6).

As explained in Chapter 4, it is important to emphasise here that the operational and strategic AM are usually operating at different spatial and temporal scales and their effective cross-communication is required to make decisions at the appropriate scale to inform the existing and future strategy. For example, when deterioration of an asset is occurring more rapidly than expected for numerous assets, it will be necessary to decide on whether to revise plans for the strategic, tactical or operational contexts or continue with the originally planned maintenance. Here the operational AM supports this decision making using the asset data collected and also from the experiences and expertise of the operational staff (also refer to section 6.4 on organisational challenges).

In FAIR, the importance of the constant exchange and communication between different contexts has been highlighted in the pilot projects. The asset owners and operators are in process of modifying individual operation and maintenance strategies and concepts to ensure that these include adaptive planning, and effective functional links between operation and the strategic planning context by strengthening the tactical handshake. The change has been noticeable in that there is stronger communication within and between the strategic planners and the operational providers, as in the example of Hamburg above. Here, the key planning and maintenance actors are communicating more intensively in the planning process for new asset designs and for upgrading existing assets. Both sets of actors have acknowledged the benefits of this improved communication, and it is likely to become established as routine.

Box 5.6: The pump house IJmuiden

The pump house regulates the water discharges in the Western part of the Netherlands. It has been operational since 1975. It originally had 4 pumps each with a capacity of 40 m3/s (total 160 m3/s). Next to the pump house there are sluice gates with a maximum capacity of 700 m3/s. The pump capacity is needed to prevent the salinization of the inland water and groundwater. Saline intrusion can be stopped by positioning the inlets to the pumps at the base of the canal (salt water is denser) and thus pump this water back to the sea. In 1998 after an extreme rainfall event causing severe problems in the water systems, it was decided to extend the pump house with 2 new pumps, each with a capacity of 50 m3/s. The 260 m3/s total capacity was considered sufficient to cope with the predicted sea level rise (leaving limited capacity to discharge any surplus water by gravity) and more extreme precipitation to be expected by climate change up to 2050. The surplus pump capacity with the 6 pumps, helped to implement a more efficient maintenance programme. Rijkswaterstaat could also maintain any of the pumps during the winter as there were always 5 of 6 pumps available. The extension of the pump house was operational in 2005. However, already by 2015, the regional water authorities frequently required Rijkswaterstaat to have all 6 pumps available because heavy rainfall was expected.

From an operational performance monitoring perspective, the question raised is if the strategy as used for estimating the maximum needed pump capacity (260 m3/s) was still valid and should be reconsidered. The strategy division of RWS is carrying out a survey to determine how best to face the challenges of the coming decades. Is a new increase in capacity required for the pump house, despite it being only halfway through the originally designed lifetime expected for the 2015 expansion?

6 Tactical asset management

6. Tactical asset management

This Chapter sets out what tactical asset management comprises, which includes:

- How the tactical context helps to 'translate' (or link) the strategic plans to establish the boundary conditions in space and time for the components in the operational context. In this 'translation' from strategic to operational delivery, prioritisation and programming are key elements.
- How the tactical context ensures that knowledge about the performance of the assets (operation) as part of the overall system, is presented in an appropriate way to help the asset owner or operator to develop an adaptive asset management plan. This link from operational to strategic processes, includes the translation of performance of single assets to system/ network performance.
- The five primary components of the guidance used in translating strategic planning into operational processes and vice versa comprise:
  - Re-evaluating the tactical handshake
  - Getting the right temporal and spatial scales
  - Enabling implementation: incorporating challenges of cross-utility and multi-functional use
  - Use of appropriate metrics and assessment criteria
  - Looking beyond the immediate management scope

6.1. The tactical context

The tactical context of the FAIR framework (Figure 3.1, centre) links the strategic and the operational loops with information and communication constantly flowing between these: i.e. via the tactical handshake (Section 3.2). This comprises: (i) from left-to-right in Figure 3.1 – communication from the adaptive plans developed as part of strategic asset management (component 5) in delivering structural or other measures for assets to be dealt with in the operational asset management process (component A); (ii) from right-to-left, aiming to ensure that actual operational asset performance is taken into account in the recurrent strategic (re-)analysis based on information about the network performance (i.e. from component D to 1).

Figure 6.1 illustrates the flow of information between the two loops of AM, showing details of what this comprises, and how the tactical context of AM links the strategic and operational contexts. Importantly, this ensures the 'translation' of actionable information and plans between the different spatial and temporal scales: while operational asset management tends to look at shorter time horizons and smaller systems (albeit typically in much more detail), strategic asset management is more concerned with longer term adaptation to developing threats and arising opportunities.

The tactical link translates the metrics from one loop to the other in Figure 3.1. While strategic asset managers might use network state or performance indicators as main assessment criteria, these are of only limited actionable value when, for example, maintaining the moving parts of a particular asset. Tactical asset management should ensure that relevant assessment criteria from both of the loops are translated in an actionable way, such that strategic and operational actions are aligned and synchronised in terms of aims and objectives. This also concerns the assignment of the relative importance to different performance indicators, such as cost and multifunctionality.

Overall this reciprocal translation ensures an alignment of management scope and facilitates the implementation of strategic measures in an operational context, and the feedback from operational performance to strategic objectives and plans. These two components are further explained in Sections 6.1 and 6.2 in terms of the AM process.

The value of the tactical handshake is illustrated through the five aspects presented in the central box in Figure 6.1 which are used in translating strategic planning into operational processes and vice versa, as explained below.

Re-evaluate the tactical handshake: Here the term 'evaluate' is used to refer to the process of doing/making the tactical handshake. The handshake needs to be made recurrently, i.e. re-evaluated semi-continuously to ensure that the information such as policy and strategy is translated into delivery in operation, and that feedback is given regarding the operational feasibility of policies, and the progress with their implementation. These re-evaluations can trigger the need to reconsider strategies or adapt operation.

Scale (temporal and spatial): The strategic considerations are typically based on a larger spatial and temporal scale than the individual operational interventions. The translation in the tactical handshake here includes aggregation (operational to strategic) or specification (strategic to operational).

Metrics: A major factor in the success of the tactical handshake is whether the metrics (and associated organisational processes) used for translating strategic to operational decisions are fit-for-purpose and vice-versa.

Management scope: A major challenge in the tactical handshake is that strategic and operational contexts of AM may be the responsibility of different organisations (or branches within an organisation) and may receive funding from separate sources. Managing diverse operators or funders is an important part of the tactical handshake.

Enable implementation: Typically flood protection assets are multi-functional. This means that different performance requirements might hold, and different methods of assessment are prescribed. For instance, any building at or in the vicinity of a levee has to satisfy the building regulations specified in the Eurocode(s) or other standard(s). Hence, the tactical handshake should align and point to these (often) different requirements and desires from different functions.

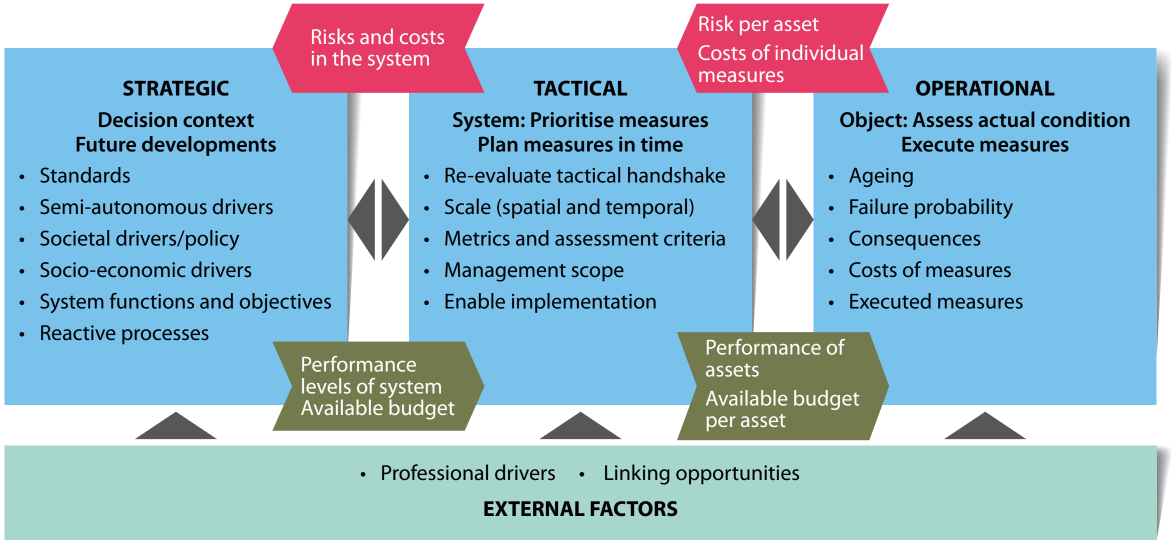


Figure 6.1 flow of information via the tactical handshake (modified from Figure 3.4)

6.2. From strategic to operational

In the FAIR framework a typical example of tactical asset management, considering the framework in Figure 3.1, the link from strategic to operational, is the translation of an adaptive plan at system level to defined measures for assets (5 to A in Figure 3.1). In this, the strategic plan is translated into asset-specific measures, such that potential constraints in terms of budget or capacity are dealt with using an assigned prioritisation. It is possible that the strategic plan might not be practically feasible immediately (if done properly, this is taken into account in the plan). This is one of the core tasks of the tactical handshake: to align strategic goals to deliver actual measures in the operational process that fit the available resources.

In this 'translation' from strategic to operational delivery, prioritisation and programming are key elements. In Chapter 4 it was explained how many investment and policy decisions in (water) infrastructure management have significant and often long-term consequences. Moreover, decisions made now will contribute to meeting long-term objectives. Thus, it is crucial that when making reliable decisions now, that these need to be aligned with long-term goals, subject to increasingly uncertain drivers of change and dynamically changing and competing demands on and for infrastructure systems. Faced with an often deeply uncertain future (e.g. due to climate change), there is a need for more than the traditional prediction or scenario-based decision methods to help evaluate alternatives and make decisions, thus adaptive planning is needed (e.g. Sayers *et al.*, 2012). Several examples of this approach are available in the 14 cases in the ROBAMCI project (Heijer, 2020). This project showed that utilising tactical asset management can lead to some 5-20% reductions in AM costs, of which a major component is achieved by better aligning decisions with performance, cost and risk over longer periods of time. More information on the intervention planning tool used in ROBAMCI is given in Box 6.1. A second example in the translation from strategic to operational contexts is the FAIR pilot case Middelkerke, Box 6.2, where the requirements defined from strategy were refined for individual assets. Another illustration of the added value of the approach used in the Middelkerke pilot was to combine different budgets in order to serve more functions than the reduction of flood risk only.

Box 6.1 The ROBAMCI-tools

Intervention planning with ROBAMCI Tools: ROBAMCI developed tools for Risk and Opportunity Based AM for Critical Infrastructure (Klerk & Heijer, 2017). The tools may be used in conjunction with other assessments to derive planning and cost estimates for alternative intervention strategies. These intervention strategies provide the starting points for assessing specific intervention characteristics, such as (prescribed) maintenance frequency of individual assets. For every strategy, an optimal intervention plan can be determined in order to control the risk. The optimal strategy and corresponding prioritisation and planning process can be selected with the aid of the ROBAMCI tools.

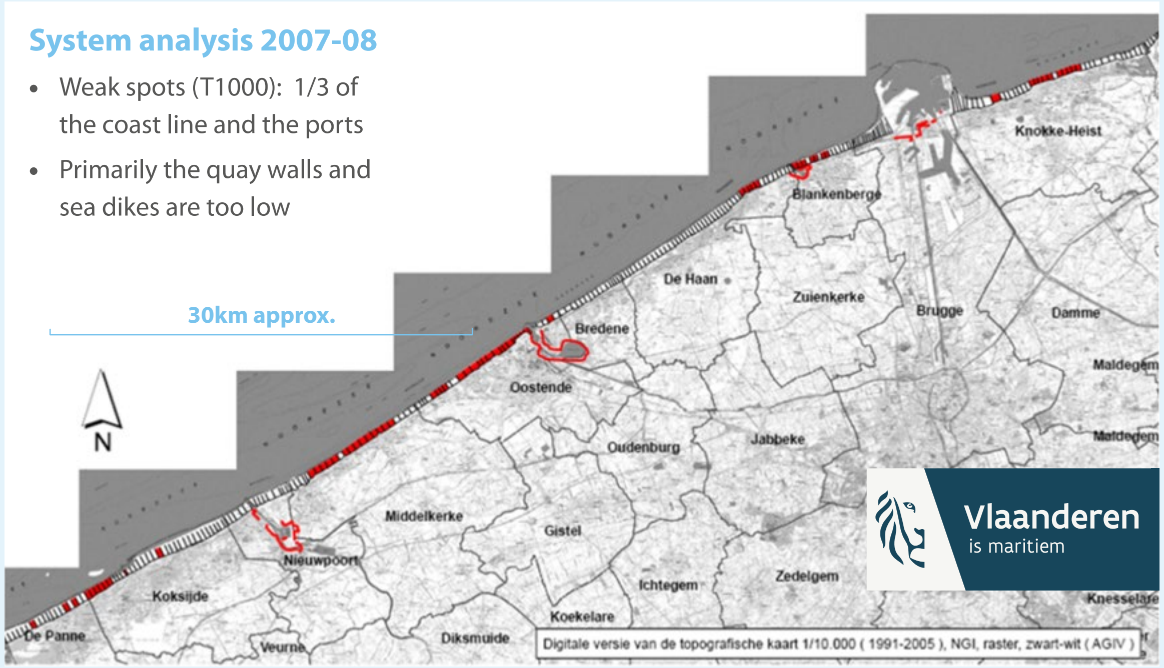
Box 6.2 Pilot Middelkerke

Measures for assets: requirements defined from a strategy can be refined for each asset

In Belgium the masterplan coastal safety prescribes a 6 yearly assessment of the entire coastline. The desired safety level is for a storm with a return period of 1000 years. In the 2008 assessment, one third of the coastline was found to be vulnerable. Four coastal pilot projects were allocated to address these weakest defences. The pilots led to different rehabilitation projects (see Figure below).

For each project a cost benefit analysis was carried out and different options were assessed. The cost benefit analyses and the variants were reviewed with the various interested parties, as the general funding is provided by the Flemish government, supported by funding from the local municipality for any architectural upgrades. For Middelkerke, the most cost-beneficial option was for a heightening of the beach, where the municipality proposed an expansion of the dike for tourist and economically beneficial reasons. The final selected option is for widening of the sea wall, with most of the funding from the municipality.

For the other coastal projects, the preferred solutions were determined in a similar way, although, the specific requirements varied locally. For some projects, the extra cost of heightening the asset was marginal compared with the overall investment costs, and thus a lot of extra safety was achieved with little extra investment. For some of the other existing assets it was found beneficial to invest in an increase in life span; e.g. a storm surge barrier built for 100 years.



Overview of the initial weak spots along the Belgian coastline.

6.3. From operational to strategic

In the FAIR framework, a typical example of tactical asset management, considering the framework in Figure 3.1, the link from operational to strategic processes, is represented by the translation of performance of single assets to system/ network performance (D to 1 in Figure 3.1). This, and other aspects, should ensure that asset performance is assessed properly at a network level; e.g. a dike ring or series of dike sections will fail when one section fails (e.g. Jongejan *et al.*, 2020). Whereas a pumping station consisting of say, 9 parallel pumps may still perform adequately if one of the pumps is defective. The analysis of the performance over time of a single asset (D in Figure 3.1), such as over a dike length, can be observed and understood using the information from the operational loop in the FAIR framework (Chapter 5). This enables a forecast to be made of the deterioration rate of the asset in terms of probability of failure, or risk (e.g. Klerk *et al.*, 2019 and Chen & Bahari, 2019).

Of particular importance is that the operational asset performance assessment includes all aspects relevant for determining the network performance. So for a dike ring area, it should include all possible modes of failure for every section and component. Otherwise the information is incomplete and strategic asset management may be focused on issues of only secondary importance. The time horizon of the performance assessment is of importance, as performance assessments typically have time horizons e.g. <12 years, but strategic plans typically extend far longer than this. This disparity should be addressed in this component, either by changing requirements for the operational performance assessment, or by translating the monitored results into a longer term prediction of network performance.

A performance analysis can be carried out using different levels of scrutiny, ranging from simple rules to simple or more advanced fragility curves, as illustrated in Figure 6.3, or even advanced reliability analysis using e.g., Finite Element Models. The level of scrutiny should be tailored to the intended use in a strategic context and be proportionate to the scale and complexity of the assets being managed.

The analysis of the performance over time of a network of assets (1 in Figure 3.1), based on the information of the performance of an individual asset, can be made using a variety of approaches and models, such as used for the Dutch flood defence assessment, described by (e.g. Jongejan *et.al.*, 2020).

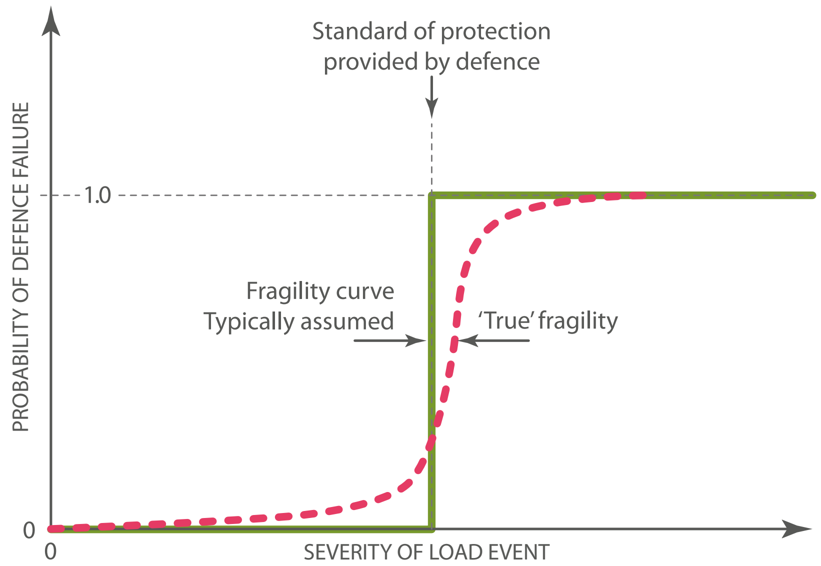


Figure 6.3: Example of a simple (green) and more advanced (red) fragility curve that also takes into account uncertainty. Such curves relate probability of failure to a given load event and can be derived by both expert assessment and advanced reliability calculations.

An example of a typical project where the effective translation from operational to strategic processes is underway[40], is the pilot Watersafety Hollandsche IJssel outlined in Box 6.3. A system-approach is being applied, where costs and benefits between dike and barrier improvements are considered together as a means to reduce whole life cycle costs. This leads to lower overall investments in flood defences by taking more effective system measures, mainly due to a more comprehensive system analysis, where it is clear that network performance could be enhanced more effectively by integrally planning conjunctive measures for both the storm surge barrier and dikes, compared with managing the two asset groups individually. An analysis of network performance is a pivotal part in this analysis.

One of the biggest challenges of this FAIR project pilot was thus to 'break free of the silo'. In this case the two main responsible organizations were both aiming to reduce flood risk, and were planning separate measures in the same at-risk flooding system. Bringing them together into a coordinated approach is allowing them to choose the overarching goal of maximising benefits to society, in preference to what might have been considered to be their more narrow organizational interests[41]. This pilot demonstrated that there are also financial challenges in the need to connect budgets across sectors/operators (funding for dikes may need to be transferred to funding for storm surge barriers or vice versa). Both of these budgets are provided separately by the Dutch Flood Protection Programme and they are normally strictly demarcated. The transfer from one budget 'pot' to another has not been done before in the Netherlands, but in this case is proving extremely cost-beneficial.

Box 6.3 Pilot Flood protection Hollandsche IJssel (HIJ)

Dikes along the river Hollandsche IJssel are operated by the regional water authority (HHSK), but they no longer meet the statutory standard. The Hollandsche IJssel river can be isolated from the main river (Nieuwe Maas) by a storm surge barrier (operated by Rijkswaterstaat, RWS) thus controlling hydraulic loads on the dikes.

Part of the Dutch Delta programme, and pilot of the FAIR programme was to make an integrated flood risk management plan for the entire river of the Hollandsche IJssel. HHSK and RWS worked together on this plan.

The main outcome is in the improvement of the reliability of the storm surge barrier which in turn, decreases the expected hydraulic loading conditions on the dikes; thus reducing the need for investments in dike reinforcement, although additional investment in the barrier is needed to achieve this. By optimizing investments in dikes and storm surge barriers conjunctively the life-cycle cost of achieving the statutory standards for the coming decades is being significantly reduced.

In 2017, the dikes of HHSK were assessed on their performance (**component D of the FAIR Framework, performance of assets**). The conclusion of this assessment was that there was more urgency in beginning a dike reinforcement programme. This was due to the introduction of new legislation and revised standards (based on national flood-risk assessments), and the incorporation of the failure rate of the storm surge barrier into the enables models. Under the new standards, the height of the dikes was inadequate, despite their on-going stability. The cost for these (and future) dike reinforcement measures also had to be better assessed.

40. This is, and needs to be, a semi-continuous process carried out regularly

41. This does not mean that each organisation does not aim to maximise societal benefits in their individual activities; rather the coming together is allowing a new set of options and opportunities to emerge that are even more beneficial to society.

By carrying out a broader system study on the entire river of the Hollandsche IJssel (**component 1 of the FAIR Framework, performance of the network**), HHSK and RWS together, determined that by reducing the failure risk for the storm surge barrier, this could significantly simplify the dike reinforcement needs of HIJ, at the same time reducing the costs of (future) dike reinforcements.

The Hollandsche IJssel is a unique and complex defence system, with numerous factors playing a role for flood protection:

- High water levels from the sea (with the influence of the Maeslantkering Storm Surge Barrier and with potential sea level rise in future);
- High water from the river (with potential higher discharges in the future),
- Regional water discharge at the Hollandsche IJssel;
- Wind, causing waves at the Hollandsche IJssel;
- Land subsidence (also beneath the dikes).

This complicated system and array of influential factors, made understanding of the system performance difficult and model analysis imperative. The SPR Framework (1 and 4 in Figure 3.1) was used to develop a mutual understanding of the system performance. The optimal solution required that the short-term strategy as well as the extant operational choices would have to be adapted. Including updating of the models used to calculate the hydraulic loads on the dikes.

This pilot demonstrates how important the tactical handshake has been between the operational and strategic contexts. This is an especial challenge, as the handshake is also between two organizations, HHSK and RWS and their stakeholder groups, such as the Ministry, other waterboards, the flood protection programme (HWBP) and others.

RWS is asset owner of the storm surge barrier and HHSK is asset owner of most of the dikes along the HIJ. To deliver the determined asset investments, legislation still has to be updated, for example the standard for the storm surge barrier will be updated with the evaluation of the new legislation around 2030. In addition, the financial and budgetary aspects of delivery have also to be aligned.

6.4. Organisational challenges

The tactical handshake provides the link to ensure there is effective communication between strategic planning and decisions, and operational activities; i.e. activities that benefit the objectives set in the strategic context. In turn these strategies are informed by the flow of information in the other direction. The practical success of the tactical handshake depends upon the capacity to understand and direct two-way information flows and 'translate' these into a comprehensible form. Throughout the NSR there are a variety of approaches used, which often lead to what appear to be challenges and even dilemmas for operators. In FAIR the challenges have been explored using a questionnaire completed by the asset owners/operators in the project. Below, in Sections (a) – (f) these are highlighted and recommendations as to how to address them for effective AM are provided, based on the FAIR operators' responses in the context of the five basic principles of the tactical handshake, introduced in Section 6.1.

a. Re-evaluate the tactical handshake

In practice, the tactical handshake needs to ensure the fit from strategic plans and objectives into specific asset investment programmes. For example, in the Netherlands, the Flood Protection Programme for dike reinforcements, and in the UK similar tactical programmes, have been utilised for decades (e.g. Defra/EA, 2011). In general, such programmes are re-evaluated annually and a new investment plan published, which will typically look forward into the future beyond simply the next year. In Sweden (Helsingborg) the re-evaluation frequency of the long-term flood risk management plan is 4 years, while the short-term AM plan that is used for delivering projects is 5 years. In the UK the investment programme fixes funding for 6 years and has a general outlook (pipeline) for 15 years. The Flood Protection Programme in the Netherlands is similar.

Important in the re-evaluation of the tactical handshake is to ensure stable funding is available for a defined and confirmed period for delivering projects, whilst being flexible enough for adjustments to cope with new insights as these arise from the strategic context, or due to issues with implementation that arise from the operational activities.

b. Get the right temporal and spatial scales

Typically, the tactical handshake has to accommodate (sometimes changing) strategic planning decisions, execute these into practice, and evaluate their effectiveness without having to immediately revisit the strategic information. This means that strategic decisions are preferably translated into robust operational actions that have only a limited chance of being evaluated as ineffective later on (sometimes referred to as 'no-regret' solutions), even if circumstances change. Strategic plans are often catchment-wide or for coastal reaches, whereas individual projects are usually of smaller, localised scale.

Translation of this scale (catchment strategy) into a local context via the tactical handshake is therefore an important component of effective AM. This is often found to be a challenge, especially organisationally. For many areas there are multiple actors with different responsibilities and different strategic goals, who each have limited budgets. Even if responsibilities are based within a single organisation, there are often multiple internal silos[42], maintained by different budget streams or responsibilities that may appear to conflict or to have differing priorities. This is an example of ineffective boundary setting – usually the boundary being too focused on the mission of the silo at the detriment of the overall organisation's mission.

c. Enable implementation: incorporate challenges of cross-utility and multi-functional use

Different functions often have differing responsible actors, also in terms of funding sources or allocations. For FRM projects, the funding of non-FRM benefits in projects is often left to others than the flood risk management authorities. In the UK and the Netherlands such benefits (and assets) must be covered by other sources, such as private contributions or other government budgets (Ashley et al., 2018). Aligning these funding sources with strategic and operational plans via the tactical handshake is often difficult, but is not impossible, although it may lead to apparent additional on-costs for the specific project under consideration.

42. 'Silo' is a term commonly used to denote a single area, domain or focus. 'Silo thinking or mentality' is a term defined in numerous publications to refer to sectors within an organisation that are e.g. reluctant to share information with other parts of the same organisation. However, 'silo' may also refer to an unwillingness to engage with others across or beyond an organisation.

Usually the overall benefit value will, however, outweigh the added on-costs, when considered in terms of the overall societal benefits.

In such cases, the tactical handshake needs to map the different utilities and functions, clearly showing who is interested, who benefits and who pays. This added analytical complexity is a significant challenge in allocation of resources, especially as funders typically do not understand the need to do this beyond their own immediate interests (e.g. Ashley et al., 2020). It is incumbent on everyone engaged in AM for flood protection to fully understand the need to maximise the value of investments, beyond the immediate 'problem', and to promote the mainstreaming of adding functionality and value to 'clients'. Professionals need to ensure that they are equipped to do this (e.g. Hargreaves et al., 2019).

d. Use appropriate metrics and assessment criteria

The use of various and different metrics to assess the value and benefits from AM investments can cause confusion, disagreement and misunderstanding. In many applications different ways of assigning priority and value are used by each major stakeholder. For example, some operators use (multi-dimensional) benefit-cost ratios to prioritise projects. In some countries (e.g. Denmark and France) the prioritisation is mainly based on politically decided funding, which is not dependent on the amount of investment needed, or in the case of France, on the most at-risk areas. Where there are multiple utilities involved, this can lead to at best confusion, at worst, complete failure to deliver effective flood protection.

Whole Life costs and benefit approaches (or formal AMP) are not always used for planning and operating flood protection measures (e.g., Denmark, Germany), and often any maintenance costs are included but based on very approximate estimates defined in tactical planning (e.g. Netherlands). Frequently the maintenance costs and the strategic planning are not the responsibility of the same organisation (see also the next section), leading to confusion and non-commensurate metrics being used.

Overall, as called for by CIRIA (2013) and others, any metrics need to be standardised and formalised in an agreed by all players, format. There are many standardised systems in use, such as PAMS in England and Wales (EA, 2009) and the flood protection standards as part of the Dutch Water Law.

e. Look beyond the management scope

A challenge in AM decision making is to properly account for benefits that might not directly benefit the asset owner (see 6.4b). In the Netherlands and Belgium, LCC is required for planning flood protection projects, whereas a major part of the construction costs are funded by the national government, the maintenance costs are borne by the asset owner. Thus, asset owners tend to prefer projects with high construction cost over alternatives with lower up-front cost, but higher maintenance cost, even if the LCC is lower. A similar arrangement is used for aspects of the FRM AM in England and in Norway. This split in scope is one of the major difficulties for tactical AM as this often constrains an asset owner to a 'preferred' solution that is more convenient, despite it being less beneficial or more economic to society as a whole. The tactical handshake challenges the various adverse preferences which should be exposed and dealt with in a joint effort by the relevant actors.

7 The FAIR framework in action

7. The FAIR framework in action

The framework is defined and illustrated in Chapter 3, Figure 3.1, and the components explained in Chapters 4, 5 and 6. This Chapter illustrates how the use of the framework leads to tangible and valuable results for AM for flood protection, via:

- Use of a standardised logic chain assessment
- Examples of beneficial use of the framework for each of the three contexts of strategic, operational and tactical
- A summary of the overall benefits arising from the FAIR project and framework usage.

7.1. Assessing the value from the application of the FAIR framework

This Section introduces the approach used in FAIR to assess the beneficial effects that will result from the application of the FAIR framework. The effect on flood risk reduction in the NSR delivered through the FAIR pilots will be limited, because the pilots are relatively modest in scale. The real value of the various pilots is in demonstrating the potential for the framework to help deliver at least a 5% cost reduction, a 5% increase of asset lifetime and assets with multifunctionality (i.e. at least two functions) of service provision. The pilots provide a proof of concept, which validates the FAIR framework and therefore justifies use by other asset owners in the NSR. In this way, the FAIR project can be expected to have a major overall effect on flood risk reduction in the NSR. The assessment approach, therefore, distinguishes between different levels of results, specifically the outputs, the outcomes and the beneficial effects. In various approaches to evaluating results such as these, there are different definitions of these terms, used together[43]. Here, the following definitions apply:

- **Outputs** refer to the improved approaches, methods and guidance for AM of flood protection infrastructure, provided in this End report. An example of an output is the Source-Pathway-Receptor (SPR) framework, given in Figure 4.1. The FAIR outputs enable usage by the asset owners in the context of the pilots, but also facilitate wider uptake (beyond FAIR).
- **Outcomes** are the improvements in existing practice, learning or other insights from the usage of the FAIR outputs. This typically means that an asset owner does something differently (behavioural change) or something better (a change in maturity). For example, when an asset owner in FAIR bases a policy change on the evidence obtained from the pilots, such as has happened in the Helsingborg pilot. Other asset owners (beyond FAIR) can replicate and benefit from these improvements and learnings achieved through the pilots.
- **Effects** relate to the broader, longer-term benefits from applying the FAIR framework. These effects are typically detectable only after a period of time (2 – 10 years). An example is the reduction of flood risk in a region as the result of a policy change.

43. e.g. https://northsearegion.eu/media/1441/23-indicators.pdf

In FAIR, this will not be evident until a period of time has elapsed after the project completion.

Together, the three terms provide a logical sequence of evaluating results, as illustrated diagrammatically in Figure 7.1. This figure provides a systematic approach to analyse the relationship between outputs and outcomes, and between outcomes and effects. Using this approach, FAIR has illustrated the positive effects that result from applying the FAIR framework (see next Section). In some instances, more than one outcome may be required for a positive effect to result. Similarly an outcome may produce more than a single effect.

Figure 7.1: Approach to assess the value from the application of the FAIR framework (examples shown).

7.2. Summary of the benefits from using the framework

It was explained in Section 7.1 how the utilisation of the processes defined and embodied in the FAIR framework provide the means to not only save costs, but also to ensure that assets and associated AM processes are planned, delivered and managed as optimally as possible for facing the coming changing challenges in flood risk management. Tables 7.1, 7.2 and 7.3 are based on evidence from the FAIR pilots and demonstrate how the utilisation of the processes in the FAIR framework result in outputs that contribute to the three Project Result Indicators, or efficiency, of asset management for flood risk management (Section 2.2) . Some additional evidence is also provided from the ROBAMCI project where this shows complementarity with the FAIR framework.

Table 7.1 Examples of FAIR outputs, consequent outcomes and impacts – for the strategic context

Outputs from FAIR		Outcomes in FAIR due to these outputs		Beneficial effects
Output description	**Information in End report and Pilot reports[44]**	**Outcomes through piloting in FAIR**	**Outcomes through communication and wider uptake**	
1. Application of the **Source-Pathway-Receptor SPR framework**, as a practical means of including the essential components of probability and consequence in strategic planning. Example from FAIR: **Esbjerg Municipality**	Figure 3.1 left hand loop, components 1 and 4. Also 5 after response plan formulated. Section 4.1 and Figures 4.1 provide details of the SPR framework.	The use of the SPR framework has led to an improved understanding by asset owners of the constituent components of flood risk.	Better informed planning and decision making by asset owners.	Better return on investment from flood protection asset management planning through enhanced understanding of where best to target risks.
	Municipality has used the SPR framework to better structure the approach to managing the assets for the Ribe polder and to identify the aspects to include in the system risk analysis. See Box 4.5.	Informed discussion between the Municipality and DCA on which aspects to include in the computer model for Ribe polder.	Groundwater was not part of the original DCA model. However, the SPR analysis helped to demonstrate this was important.	As this pilot project is still in the planning stages, definitive estimates of return on investment are not yet possible.
2. Use of a **whole system framework** relating the drivers and responses influencing the risk to the SPR (above). Providing a structured means of considering how future changes in different aspects may change the systems, and what assets could be used/ enhanced to respond to challenges. Example from FAIR: **Helsingborg**	Figure 3.1 left hand loop, components 1 and 4. Also 5 after response plan formulated. Section 4.2.2 includes information on the need to take a whole systems approach aligning with other stakeholders.	Use of the whole system framework has led to better planning by asset owners due to an improved understanding of the behaviour of the 'whole system'.	Integration across infrastructure and service provision/providers has helped identify opportunities for timely and synergistic interventions.	Sharing of costs across service sectors/domains brings added value from utilising windows of change in one sector to effect better performance in another sector.
	The Municipality used the whole system framework to identify and when possible quantify, aspects of flood risk related to societal and technical functions for the city centre. See Box 4.3.	With an improved understanding of the whole system, the Municipality was able to focus on promising asset investments, including (e.g.) how to integrate improvements in the sewerage system as a complementary component of a broader strategy for coastal protection.	Closer and new partnership working across municipality departments; opportunity sharing and identification. Also with external organisations.	Not yet quantifiable economically, however, synergistic planning will bring significant efficiencies.

44. See separate individual pilot reports on each of the FAIR beneficiary projects.

Outputs from FAIR		Outcomes in FAIR due to these outputs		Beneficial effects
Output description	**Information in End report and Pilot reports[44]**	**Outcomes through piloting in FAIR**	**Outcomes through communication and wider uptake**	
3. **Adaptation planning** is an approach to proactively plan for an uncertain future, where the strategy plan can be modified as new evidence and insights emerge.	Figure 3.1 component 5, is where the plan emerges to be conveyed to the operational loop context. Note that all aspects of the AM process need to be adaptive (including policy). Details are provided in Section 4.2.4.	Adaptation planning has provided asset owners with the means to avoid sunk assets, lock-in to inflexible asset use and maladaptation. Also supporting autonomous adaptation planning. Allows asset owners to buy time to better understand future uncertainties as they develop, for example by intensifying maintenance on assets to extend the life time.	Adaptation planning has provided the means to balance performance, risk and cost over the short and longer term. Approach maximises societal value and helps avoid asset management planning that may be unsuitable for future conditions.	Reduction of life cycle costs of flood protection infrastructure – through better targeting of investments; Increase in the number of functions of flood protection infrastructure – through collaborative planning and connecting investments. Extension of asset life time to narrow down uncertainties – by intensified maintenance;
Example from FAIR: **Esbjerg Municipality**	Municipality and DCA used adaptation planning in a workshop with participation of staff and managers for Ribe Polder. See Box 4.5.	Municipality and DCA obtained further insights into the consequences of alternative adaptation pathways under different scenarios. It also provided an overview of other planning processes that can interact with flood asset management or provide synergies.	On-going discussions are being continued based on adaptation pathway planning with politicians/policy makers of the City Council.	At this planning stage, relative cost efficiencies cannot be quantified. However, synergies are expected from (2) above and by planning adaptively, changes can be addressed more cost-effectively.
Example from FAIR: **Helsingborg**	Municipality has developed an adaptive strategy with measures at different time scales related to large multifunctional infrastructure assets. The implementation can be moved forward or backward in time to respond adaptively. See Box 4.3.	The insights from adaptation planning have led to a review about planning ahead. From this, decisions made to defer some flood protection measures to achieve better cost efficiency.	Expanding the time frame to allow adaptation planning, hence deferring asset investments, provides the time and means to integrate flood protection with other development planning.	The municipality has deferred some measures, which leads to a higher benefit-cost ratio in the discounting process.

Table 7.2 Examples of FAIR outputs, consequent outcomes and impacts – for the operational context

Outputs from FAIR		Outcomes in FAIR due to these outputs		Beneficial effects
Output description	**Information in End report and Pilot reports[44]**	**Outcomes through piloting in FAIR**	**Outcomes through communication and wider uptake**	
1. **Guidance on maintenance strategies and importance of a whole system approach**. Strategy advantages and disadvantages are highlighted.	Figure 1.1 shows the performance over the life of an asset when different maintenance and adaptation strategies are adopted Figure 3.1 right hand loop, components B and C. Chapter 5, Sections 5.3 and 5.4.	Supports asset owners in developing an asset maintenance approach that includes the portfolio of assets and the interacting systems.	Through a standardised approach, asset maintenance efforts can be better focused. The approach provides insight into whole system interactions, and helps to understand where to intensify maintenance in order to extend the life time of the whole system.	Maintenance costs, as part of the Life Cycle Costs, can be reduced. The lifetime of the whole system can be extended by intensifying the maintenance of a single asset or couple of assets.
Example from FAIR: **Hamburg**	LSBG, the operator have reviewed the flood protection gate maintenance and monitoring processes, based on the guidance (Box 5.2 in Chapter 5).	An inventory was made of all assets. Development of a standardised conceptual and practical approach to asset operation, maintenance and monitoring, which included potential multi-functionality.	Benefits for asset day-to-day maintenance. Raised the potential for multi-functional use of assets and led to wider acceptance among staff.	Maintenance costs for the gates expected to be reduced by some 3- 5% per year. Potential for multi-functional operation will increase the functionality of flood protection infrastructure in Hamburg.
2. Taking account of the **importance of the feedback loop from the maintenance to the design and construction**, helps to improve the design of flood protection assets.	Mainly from C to B in the right hand loop of Figure 3.1. Chapter 5, Sections 5.3 and 5.4.	Supports asset owners by highlighting the need to organise regular, standardised and institutionalised exchange and interaction between maintenance and design/ construction processes.	Ensures mutual benefits of closing the gap between planning and operation are understood and acted upon, demonstrating the need for all players to carefully consider if communication is comprehensive enough.	Efficiencies are much more likely from better communication between maintenance (maintainers) and designers and constructers.
Example from FAIR: **Hamburg**	As part of the FAIR review, LSBG observed that there was a gap between the maintenance and the design and construction within the same institution. (Box 5.2 in Chapter 5).	The gap has been addressed due to better understanding from FAIR.	LSBG now stimulates active participation of the maintenance department in planning and design of new assets or renovations.	As the design of assets has been improved, investment and maintenance costs can be reduced significantly (>5%) and costs of operation may also be reduced longer term.

Outputs from FAIR		Outcomes in FAIR due to these outputs		Beneficial effects
Output description	**Information in End report and Pilot reports[44]**	**Outcomes through piloting in FAIR**	**Outcomes through communication and wider uptake**	
3. Promotion and illustration of different ways to **assess the performance of assets**, ranging from simple in-situ technical inspections to comparatively complex methods.	D and C for right hand loop of Figure 3.1. Chapter 5 Sections 5.4 and 5.5.	Asset owners/operators introduced to the wide variety of methods available to assess performance. Stimulates asset owners to incorporate new (more appropriate) ways of performance assessment and updated assessment criteria into their processes and procedures.	Contributes to the need to ensure that there is effective and ongoing cross-group dialogue and engagement.	Through a better performance assessment maintenance efforts can be reduced and planned more efficiently over the asset lifetime.
Example from FAIR: **Hamburg**	LSBG found that maintenance and operation of assets is an evolving process that needs review, revision and enhancement. (Box 5.3 in Chapter 5).	LSBG revisited existing maintenance procedures and techniques and tested new ways of performance assessment on some of their flood protection assets (e.g. grass covered sea dikes).	This necessitated ongoing dialogue and enhanced cross-group working.	A higher maintainability and operability of assets can be achieved, thus costs can be saved and the life span of certain parts or whole assets extended.

Table 7.3 Examples of FAIR outputs, consequent outcomes and impacts – for the tactical context

Outputs from FAIR		Outcomes in FAIR due to these outputs		Beneficial effects
Output description	**Information in End report and Pilot reports[44]**	**Outcomes through piloting in FAIR**	**Outcomes through communication and wider uptake**	
1. Enable implementation: **incorporate challenges of cross-utility and multi-functional use**	Section 6.3(c) components D to 1, and 5 to A, link respectively in both loops of Figure 3.1, although promotion of cross and multifunctions is most likely to originate from the strategic planning.	Giving an overview of all functions of the flood defences should become a component in the procedure for asset rehabilitation projects.	This overview should be made by the relevant asset owners and could be combined with stakeholder analysis.	Creates support and benefits for all stakeholders and reduces lifecycle costs by pooling investments from different functions.
Example from FAIR: **Middelkerke**	MDK found that it is important to integrate flood defences into the surrounding areas. This can be realised by incorporating extra functions when designing the infrastructure for coastal safety.	MDK now seeks to incorporate extra functions across utilities for all the coastal safety plan projects. This necessitates not just building walls and concrete barriers, but integration into the surroundings.	MDK has put architects and urban planners in charge of the design, rather than traditional coastal defence engineers.	Due to the usage of a dune instead of a hard sea dike the investments costs can be reduced by 26 - 38%. There are also at least two extra added functions because of the dune: nature, recreation, biodiversity and tourism. The dunes will last for a long time; they are prone to erosion, but won't degrade in the same way as a concrete structure.

Outputs from FAIR		Outcomes in FAIR due to these outputs		Beneficial effects
Output description	Information in End report and Pilot reports[44]	Outcomes through piloting in FAIR	Outcomes through communication and wider uptake	
2. Use **appropriate metrics and assessment criteria** between strategic and operational contexts.	Section 6.3(d), and component 5 to A and D to 1 in Figure 3.1, link the strategic and operational loops, but need shared metrics in order to communicate.	The managers of the subsystems should establish a common set of metrics in order to communicate information and approaches used for AM for the entire system. Units and criteria need to be suitable for all of the assets in the system.	Results, plans and procedures, decisions etc., will be supported by all personnel within and beyond one organisation. i.e. legitimisation through the common 'language'.	Reduction of life cycle costs of flood protection infrastructure – through better aligning/ legitimising decisions between players.
Example from FAIR: **ROBAMCI**	The ROBAMCI method and tools derive planning and cost estimates for alternative intervention strategies, based on the same metrics for cost, risk and performance, and applied in different cases. See Box 6.1	With the method applied in the ROBAMCI pilot case[45], it was possible to compare measures for improving different functions and to present the joint results using the (agreed) criteria.	The translation of information for strategic starting points in relation to operational interventions promotes communication on the most effective cross-functional interventions.	By using tactical AM this can lead to some 5-20% reductions in costs, of which a major part is achieved by better aligning decisions with performance, cost and risk over longer periods of time.
3. Look **beyond the (immediate) management scope**	Chapter 6, Section 6.3, especially 6.3(e), explains the need to take as broad a perspective as possible in the tactical handshake. In Figure 3.1, components 2 and 4 in the left hand loop need to be used to inform local asset management in the right hand loop.	Before starting with a project at (local) asset level, asset owners should ensure communication with the strategic context ensures proper understanding of what are potential challenges, opportunities, risks and measures to be taken.	This check should be done with all relevant asset owners, not only in the primary responsible organisation.	Reduction of life cycle costs of flood protection infrastructure – through better targeting of investments; Increase in the number of functions of flood protection infrastructure – through collaborative planning and connecting investments.
Example from FAIR: **Flood Protection Hollandsche IJssel**	By using a broad system approach on the entire river of the Hollandsche IJssel, HHSK and RWS together found out that the reduction of failure risk of the storm surge barrier HIJ could significantly simplify the dike reinforcement plans of KIJK. See Box 6.2 and 6.3.	By looking beyond the management scope for KIJK, HHSK was able to incorporate assets from other asset owners into the analyses.	Intensive cooperation was needed and started up because of FAIR, working together on a system analysis, and taking a broad view on possible measures, such as using the flood plains, and improving the storm surge barrier.	The original costs of the dikes were reduced substantially: life cycle costs of 5%. That is: €30M savings on an amount of €600M. There is also an increase of life span of the dikes, because of using the flood plains. This may in turn result in multifunctional dikes: when heightened, the flood plains may be of use for nature.

45. Heijer, den F. et al., (2020)

7.3. Summary

The examples presented above in Tables 7.1, 7.2 and 7.3, from FAIR, supported by additional evidence from the ROBAMCI project, illustrate how the various aspects of FAIR have come together to help to deliver more effective, efficient and practical AM for flood risk management infrastructure assets. Although the pilots are from the NSR, the illustrations, showing outputs, outcomes and results, are readily applicable to other cases where flood risks are manifest and likely to be increasing. These support the use of the framework in Figure 3.1 as a means of focusing asset owners and operators on the various components of best practice AM.

What is new, is the inclusion of the need to be adaptive, not only in the day-to-day management of assets, but also in the entire approach to AM. The Tables in Section 7.2 provide a guide only to where and how the use of the framework can save on costs, prolong the life of assets or produce added functionality, due to the limited scope and scale of the FAIR pilot projects and also because many benefits will only fully manifest over periods of time beyond the termination of FAIR. The Middelkerke case for example, is expected to deliver additional functionality, as yet to be fully planned and realised. The Hamburg pilot, however, focused on day-to-day operation and maintenance of the flood protection gates has already shown how cost savings can be made in planning and carrying out routine AM activities. Whereas the Danish Ribe Polder pilot is in the earliest planning stages, for which FAIR has shown how these plans can be as efficient and effective as possible, ensuring the project will ultimately not go down a pathway of maladaptation or of inappropriate asset investments. Together, the results from FAIR will ensure that all players (stakeholders and shareholders) are engaged in the effective planning and delivery of adaptive AM responses to the increasing flood risks across the NSR.

8 Challenges

8. Challenges

In the context of flood management, an adaptive AM approach aims to optimise the performance (i.e. value) of flood protection infrastructure at the lowest total cost to the asset owner or operator, whilst providing the best value to society as a whole. However, in reality, a compromised approach is often employed, including accepting sub-optimal performance or using cost-effectiveness as a measure. This is because there are several key challenges for the adoption of an adaptive AM approach throughout the NSR, which are explained and addressed in the FAIR Policy Brief:

- The institutional context for AM is often fragmented
  - (relates to Policy Brief Recommendation #1, Break Free of the Silo);
- Funding is constrained, especially for maintenance and monitoring
  - (relates to Policy Brief Recommendation #1, Break Free of the Silo);
- Strategic planning and operational processes are often misaligned
  - (relates to Policy Brief Recommendation #2, Mind the Gap);
- Decisions taken today may not account for long-term implications
  - (relates to Policy Brief Recommendation #3, Prepare for change);
- Innovation is not consistently embedded in standard practice
  - (relates to Policy Brief Recommendation #4, Make space for innovation);.

8.1. The institutional context for asset management is often fragmented

Flood defences are often just a part of infrastructure with multiple functionalities, such as a sea wall integrated into a boulevard or a dike with a road on the top. AM of this infrastructure is often fragmented, because functionalities such as flood defence, transportation and planning urban development are usually the responsibility of diverse organisations. Furthermore, the institutional responsibilities and sources of finance for different assets and for the various contexts and components in Figure 3.1 are fragmented. For example, dikes may be owned and maintained by private parties (e.g. Denmark) or by local/regional authorities (e.g. Sweden), whilst strengthening measures are (partially) funded by the national government (Table 2.1). Where there are fragmented institutional arrangements, this presents a range of challenges to AM.

For example, the Flemish government only finances basic flood protection and needs the support of local stakeholders to realise upgrades of the flood defence system.

46. A perspective on the future of asset management for flood protection - A Policy Brief from the Interreg North Sea Region FAIR project

Figure 8.1 New sea dike Middelkerke (courtesy: Afdeling Kust)

Alignment of views and ambitions of stakeholders is needed to achieve a financially feasible design. This required an innovative design to integrate the flood defence, as a wave stilling basin into the boulevard of Middelkerke, as shown in Figure 8.1 (see separate project report).

The FAIR case studies in Denmark (Table 2.1) have demonstrated how a lack of information about the system can hamper the ability to carry out an appropriate system analysis. In this case, inadequate information about the performance, dimensions, location and ownership related to dike history and development posed challenges to strategic and tactical AM activities, such as the flood risk assessments and priority setting of interventions, despite Denmark responding to the Floods Directive requirements (Jebens *et al.*, 2016). However, thanks to the FAIR project, the Danish pilot project has made significant progress as explained in Box 4.5.

The numerous stakeholders in the scheme is a challenge in the FAIR case in Helsingborg (Sweden), Table 2.1. Local communities are responsible for flood defence AM. However, the resources and capacity of these communities to adequately manage flood defence assets are inadequate. Recognising this challenge, the County Administrative Board Länsstyrelsen Skåne, has taken an active role in disseminating knowledge and experience related to flood defence AM into the communities.

The Policy Brief Recommendation (#1) for this challenge is to 'Break free of the silo' and to 'Align multiple planning processes within and beyond flood management'.

8.2. Funding is constrained, especially for maintenance and monitoring

Flood defence assets are ageing across NSR countries. Large investments are therefore required to improve these flood defence systems to contemporary standards and there are already significant adaptation deficits due to lack of vision and prioritisation. Financing streams are primarily directed at renewal and strengthening works to reinforce the weakest links in flood defence systems. Although maintenance and monitoring have in the past required less relative funding than does capital asset investment, available budgets for these activities are typically seen as less important, and in some cases, optional. In future, greater priority and investment focus may be needed in the operational context in the NSR, especially where the assets are multifunctional.

Limited budgets have triggered, for example, the Hamburg "Agency of Roads, Bridges and Waters" (LSBG) to seek better ways of cost efficient maintenance for its moveable floodgates. Adequate performance of the floodgates is required to meet the legal flood safety standards. Past experiences have shown that the reliability of the system depends on the capacity of the operating staff with regard to failures of automated gates when under pressure, especially during challenging weather conditions. These experiences have motivated LSBG to explore the relationships between the complexity of systems, reliability and life cycle costs (see Table 7.2 and Kron & Muller, 2019).

Disincentives for optimising life cycle costs can occur when funding sources for different life cycle stages are fragmented. For example in the Netherlands, finance for measures to strengthen flood defences is shared amongst asset owners (regional waterboards - 50%) and the national government (50%), whilst the asset owners need to cover the costs for maintenance and monitoring. This provides a disincentive for asset owners to invest in measures that require relatively high maintenance costs and sophisticated monitoring programmes to acquire more in-depth insights into flood defence performance, beyond the scope of strengthening works.

Given the moves to use more nature based assets (NBA), the responsibility for monitoring performance and asset condition, and also for maintenance, has shifted in many jurisdictions. For example, in England, nationally leading NBA stormwater management measures in Sheffield have to be maintained by those responsible for parks and open spaces, whilst the performance monitoring for the flood defence effectiveness remains with the Lead Local Flood Authority. Both are within the same municipality, but in different departments and with different budgets. The flood department had to find a way of diverting funds from traditional flood risk management to the budgets of the Parks department.

The other major issue with NBA is that these may or may not be defined as 'assets' – there is an open question as to when and if a nature-based system is 'infrastructure'? One definition suggests that if the NBA serves a function that is equivalent to a grey infrastructure system, then it is infrastructure and therefore an asset. However, there is much confusion on the part of the traditional flood defence asset providers and operators. In England, the sewerage undertakers have defined NBA for stormwater as 'sewers' (Water UK, 2020) in order to be able to include these as 'assets' in their inventories.

This is important, as being private companies, their ability to raise loans depends on their asset inventory (Loftus et al., 2019) and this skews their approach to the selection of and management of assets (Ashley *et al.*, 2020).

The Policy Brief Recommendation (#1) for this challenge is as for 8.1 above, to 'Break free of the silo' and to 'Align multiple planning processes within and beyond flood management'.

8.3. Strategic planning and operational processes are often misaligned

Strategic planning is reliant on continuous learning in terms of changing system conditions and infrastructure performance. For example, forecasts and scenarios are considered to anticipate to uncertain future conditions and system performance (e.g. Butler *et al.*, 2020). Operational performance is typically task oriented and is therefore more straightforward in terms of clarity of scope, needs and direction. 'Regret' investments can only be avoided when strategic and operational perspectives closely interact via the tactical handshake. Unfortunately in many organisations the strategic and operational components interact poorly, if at all.

For example, the FAIR case study in the Netherlands (Table 2.1) demonstrated that institutional fragmentation can lead to sub-optimal decisions for upgrading flood defences if inter-connections within an organisation and outside the organisation are inadequate or willfully ignored. In FAIR it was found that the flooding of the Hollandsche IJssel can be mitigated through upgrades in a storm surge barrier in the river (responsibility of the national government) and/or dikes along the river (responsibility of the regional waterboard). Closer alignment in FAIR has demonstrated that this can lead to the most cost-effective and beneficial co-interventions in existing assets (Box 6.2 and 6.3).

In Helsingborg, Sweden (Table 2.1), as in every urban area, flood management needs to be effectively integrated into overall city planning. For this, a clear strategy is required in order to be proactive and be able to plan and build an appropriate storm surge protection over a long timescale. The case study demonstrated how such a strategy should be based on a risk and impact assessment, in order to get an overview of the investments that may be required in the short and long term. In addition, the costs and socio-economic benefits of the measures need to be assessed to inform decision making.

The Policy Brief Recommendation (#2) for this challenge is to 'Mind the gap' and to 'Link strategic planning and operational processes through a tactical handshake'.

8.4. Decisions taken today have long-term implications

Change is inevitable but predicting the future is impossible. Developing flood protection infrastructure in this context presents several challenges: How much should be invested today in replacing, strengthening and renovating assets? Should we delay investment? These complex decisions become even more difficult when the long-term choices (that take account of future uncertainties in climate and socio-economic contexts) clash with short-term political realities and varying perceptions of risk. In response, large-scale infrastructure investments, renewals or upgrades are often preferred over maintenance and monitoring.

This 'bias-to-build' is attractive to politicians but can lead to infrastructure that may be unnecessarily costly, maladapted, regrettable or 'stranded' as the reality of the future unfolds.

There is a need for actionable tools to incorporate uncertainty in decision making processes. For example, to avoid regret as a result of the renewal of dikes and sluices in the Ribe polder in Denmark (Table 2.1), it was considered vital to integrate climate change predictions into the protection standards (Box 4.5). However, the lack of such standards in Denmark has created a need for a thorough system analysis, using flood scenarios and maps, as well as performance analysis of existing assets before commencing any new capital investments of asset renewal works.

The Policy Brief Recommendation (#3) for this challenge is to 'Prepare for change and to 'Develop strategies that are flexible and assets that can be modified'.

8.5. Innovation is not consistently embedded in standard practice

Whilst available budgets are typically insufficient for maintaining flood protection assets to the required standard, innovation is needed that will help to develop new approaches that are effective in terms of life cycle cost, flexible enough to respond to new insights, compatible with landscapes and land use, and to ensure public acceptance. Although the pilot cases in FAIR have demonstrated various technological and process innovations, it has been concluded by the FAIR Policy Learning Group that these, and possible, innovations are not consistently embedded in standardised AM working processes across the NSR. For example, how best to acquire and use data about asset performance? New ideas and techniques are developing rapidly around the concept of Big Data, but many asset operators still lag behind even rudimentary data collection regarding asset condition, let alone seizing the opportunities from upcoming innovations.

These challenges are considered further in Chapter 9, where the way forward is considered including how AM and AM processes can be (i) delivered better today using extant knowledge; (ii) delivered in a way fit for the future and the knowledge requirements for this to come about.

The Policy Brief Recommendation (#4) for this challenge is to 'Make space for innovation' and to 'Accept that new approaches attract risk but managing, rather than avoiding, risks can lead to innovative solutions'.

9 Way forward

9. Way forward

This Chapter brings together the findings from FAIR to illustrate the way to ensure that assets, as well as the process of AM, are adaptive in flood protection planning, management and operation of infrastructure across the NSR. The following Sections summarise the implications of the findings from the FAIR project described above, especially the Challenges in Chapter 8 and resultant policy recommendations. Beginning with an overview of the current status of AM planning and processes in FRM as found in FAIR, future perspectives are considered signposting the best way to ensure that FRM assets, and the supporting AM process, are fit for the future.

This chapter focuses on three questions:

- What is the current approach to AM for flood protection infrastructure?
- What should be improved in this approach in order to address the current challenges?
- What needs to change to make these improvements?

9.1. Where are we now?

There are a variety of perspectives on maximising the value (to society) from FRM assets via AM processes across the NSR as found in FAIR. Some pilot cases and operators illustrate highly structured and integrated approaches to AM (See the Maturity Section 3.3), whereas others take a more individualistic approach to managing single assets. AM is changing, as traditional approaches to AM for FRM have only rarely needed to consider adapting the asset or adapting the AM process itself. This is because the rate of change of the flood risk drivers has been relatively slow compared with the lifetime of the assets, and societal needs have been relatively stable over time. This approach is no longer valid, as the drivers are now changing much more rapidly as explained in ISO 14090: 2019. This also compels the need to look at the balance between capital investment in new assets and revenue required for continuing operation over the lifetime of an asset (i.e. LCC) within the context of whole-life value.

As stated in various places in this Report, there has been a tendency to preference capital investments in traditional infrastructure assets, like coastal barriers, so building up a valuable asset portfolio, with less interest in providing revenue for long-term maintenance and monitoring of performance.

Numerous funding arrangements have, and continue to, skew these investments, so that Capex (Capital expenditure) dominates to the detriment of the essential Opex (Operational and maintenance expenditure). The emergence of investment planning based on Totex (Total expenditure) funding arrangements is now facilitating the optimal balance between Capex and Opex to be determined for a particular asset or group of assets. This is essential, as the need to adapt to cope with the future challenges requires the ability to invest in the appropriate combination of Capex and Opex as well as the option to abandon the asset, or at least let it decay naturally.

Traditional assets are now increasingly being used in combination with nature-based assets (NBA), as it is now understood that there are significant opportunities to get more value from assets and the AM process by designing and operating these to deliver more than a single function. This can be across other domains, as there is an understanding that taking a 'natural capital' approach:

> *"By understanding nature as an asset, it is possible to define the diverse "flows" of services those assets provide"*[47].

This can give the foundation for including NBA as assets alongside traditional grey infrastructure, in a hybrid arrangement (e.g. Kapetas & Fenner, 2020). The need to shift focus to include and account for NBA is becoming an essential component of best practice flood protection AM.

AM processes will need to continue to evolve in order to facilitate adaptation of both the assets themselves and the process of AM, in order to cope with the changing drivers and at the same time take advantage of the opportunities adaptation can bring. It is now understood that the opportunities to get more out of AM and assets by designing and operating these to deliver more than a single function, including across other domains, such as recreation or place-making, is an essential component of best practice AM. A life cycle (LC) approach to AM is essential, for which asset performance is considered not only at the design stage, but also regularly throughout the lifetime.

Looking at opportunities to create flexibility in assets' and asset systems' roles has become much more relevant in the context of climate adaptation. A LC approach, aiming at keeping options open as far as practicable, such as being used for the Thames Barrier in London (Box 4.4), provides opportunities to adapt or otherwise intervene to ensure that the expected service is maintained whatever the challenges.

9.2. What can we improve further?

Notwithstanding the heterogeneity of the NSR, FAIR has demonstrated that asset managers face common challenges for improving AM and AM processes in order to effectively deal with flood risks and ensure maximum value (societal benefits) from their assets. The project has highlighted essentials for further improvements as shown in Table 9.1, linked to the Maturity dimensions, Policy Brief and the Knowledge Agenda.

47. Natural Capital is the Stock of natural assets which provide benefits to people in the form of tangible things which are typically marketed and less tangible services (such as air purification, recreational settings and flood prevention). [Defra (2020). Enabling a Natural Capital Approach: Guidance – January. Crown copyright, London]

Table 9.1 Further improvements in AM and AM processes as identified in FAIR

Maturity dimension (Section 3.3)	Essential aspects for managing assets for FP & FRM	Examples of links with the Policy Agenda (Chapter 8)	Examples of relevant links to the Knowledge Agenda (Section 9.2.1)
Asset management decisions	Ensure flood risks are managed appropriately in time and space at a system scale (from catchment to coast).	Recommendation #1: Align multiple planning processes within and beyond flood management	Gap A Question 1. How can we better know where assets are, their condition, and measure asset performance and deterioration, and therefore better understand asset dynamics over time?
External coordination	AM needs to integrate with and across the various domains: e.g. flooding, water resources, transport, public health and welfare etc. in devising and operating assets in a reflexive[48] way (i.e. learn by doing).	Recommendation #1:	Gap D Question 5. How do we engage relevant key stakeholders in AM as shareholders, thus creating innovative financing opportunities and (better) sharing of risks?
Asset management decisions	Use natural landscape features as legitimate nature-based assets (NBA), in concert with traditional infrastructural responses.	Recommendation #4: Accept that new approaches attract risk but managing, rather than avoiding, risks can lead to innovative solutions'	Gap B Question 3. How do we take robust and adaptive decisions now with uncertain and changing information about the future?
External coordination	Assets are implemented and managed so as to be integrated, multi-valued, multi-functioning and adaptable (hence to provide as comprehensive a service as possible; to bring maximum value to society as well as to the asset managers/ owners).	Recommendation #3: Develop strategies that are flexible and assets that can be modified.	Gap E Question 6. How do we engage with society in the way needed to ensure that assets are delivered and managed in the best way?

48. In this context reflexive means learning by doing and continually reflecting and altering how assets are managed to fit changing drivers (both internal and external). See for example: Westling E L., *et al.*, (2019).

Maturity dimension (Section 3.3)	Essential aspects for managing assets for FP & FRM	Examples of links with the Policy Agenda (Chapter 8)	Examples of relevant links to the Knowledge Agenda (Section 9.2.1)
Processes and roles	AM and the AM process is standardised, comprehensive, multi-valued and adaptable, and demonstrably fit (auditable) to deliver the required services (standardised systems such as ISO55000:2014 should be adopted).	Recommendation #1: Align multiple planning processes within and beyond flood management	Gap C Question 4. How do we manage our organisation(s) to efficiently translate AM policy into actions?
Operational context	Embed adaptive capability within asset design and management choices: beyond the traditional realms of uncertainty in accordance with ISO 14090: 2019 (This includes transformational change, as well as incremental adaptation).	Recommendation #3: Develop strategies that are flexible and assets that can be modified	Gap B, Question 3. How do we take robust and adaptive decisions now with uncertain and changing information about the future?
Tactical context	The policy-making and implementation of plans from policy, correspond with the FAIR framework or an equivalent (Figure 3.1, including the tactical handshake between strategic and operational contexts).	Recommendation #2: Link strategic planning and operational processes through a tactical handshake.	Gap C Question 4. How do we manage our organisation(s) to efficiently translate AM policy into actions?
Processes and roles	The organisational process for AM need to include social and economic aspects (as well as technical).	Recommendation #1: Align multiple planning processes within and beyond flood management.	Gap A Question 2. How can we translate Big Data on all aspects of AM into good quality and valuable information for decision making?

Maturity dimension (Section 3.3)	Essential aspects for managing assets for FP & FRM	Examples of links with the Policy Agenda (Chapter 8)	Examples of relevant links to the Knowledge Agenda (Section 9.2.1)
Internal coordination	Address the strategic, tactical and operational contexts include the organisational, legal and financial elements that each has to manage, (as often these constrain what can and cannot be done).	Recommendation #1: Align multiple planning processes within and beyond flood management.	Gap C Question 4. How do we manage our organisation(s) to efficiently translate AM policy into actions?
Culture and leadership	Reform any and all aspects of AM and the AM processes where needed to improve functionality as shown in the FAIR framework.	Recommendation #4: Accept that new approaches attract risk but managing, rather than avoiding, risks can lead to innovative solutions.	Gap D Question 5. How do we engage relevant key stakeholders in AM as shareholders, thus creating innovative financing opportunities and (better) sharing of risks?

9.2.1 The FAIR knowledge agenda

Several topics have been identified in the FAIR project by the beneficiaries as considered important to shape the future direction of AM for FRM infrastructure and for which knowledge is lacking. These are derived from the Policy Brief and the pilot projects and are shown linked with the former in Table 9.1. These topics can be used to help focus future AM project development activity in Europe and beyond. A separate report[49] accompanies this End Report in providing further details of the knowledge agenda. Here the contents are summarised in Table 9.2 and structured around the key terms illustrated in Figure 9.1. The separate report relates the knowledge agenda to the Challenges in Chapter 8, using examples from the FAIR beneficiary pilots.

AM begins with an understanding of what the assets are, where they are, what condition they are in and how they perform. Historically, many assets have been built and forgotten; as those responsible have changed over the asset lifetime. Now, and especially since the advent of digital systems, asset knowledge can be collected readily, stored and catalogued in shared databases.

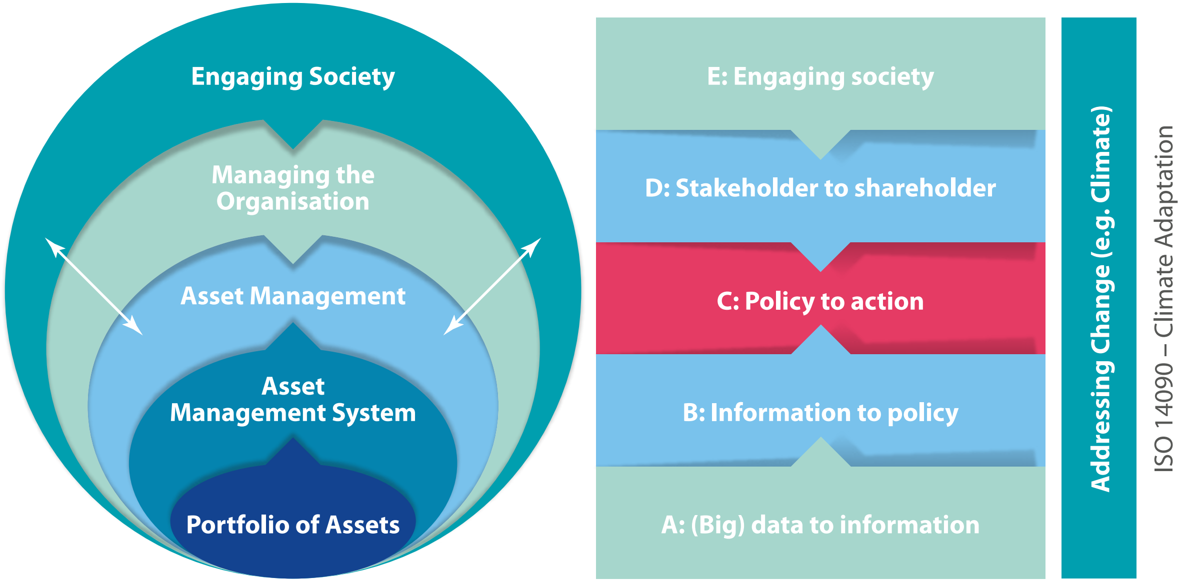


Figure 9.1 Left: Asset management key terms, derived from ISO 55000:2014. Right: the categories that have been defined for the FAIR knowledge agenda.

49. Adaptive asset management for flood protection – A knowledge agenda for 2020 and beyond.

Table 9.2 Knowledge agenda – topics identified as of the most significance in the FAIR project

Gap	Question	Brief description
A. From (big) data to information	1. How can we better know where assets are, their condition, and measure asset performance and deterioration, and therefore better understand asset dynamics over time?	Relates to knowledge required to determine what data has to be collected and how it has to be interpreted such that it yields the required information both on assets and the socio-economic system these assets serve. Often the location and nature of the asset is uncertain. Relatively little is known about the performance and deterioration of various types of assets under specific conditions and pressures. Standard recording systems are needed and profiles of asset performance and costs over time are required that also show the effects of interventions.
	2. How can we translate Big Data on all aspects of AM into good quality and valuable information for decision making?	Few FAIR beneficiaries are as yet using (big) data from multiple disciplines and sources in ways that can best help with asset management. Multi-disciplinary challenges require data analyses that are fit to combine these different data sources. This integration between domains is a future challenge to be addressed.
B. From uncertain information to AM policy	3. How do we take robust and adaptive decisions now with uncertain and changing information about the future?	Every FAIR beneficiary struggles with the uncertainties when looking to the future, whilst accepting the need to live with uncertainty and build it into decision making for asset planning, design and operation. Even with monitoring, (big) data and real-time systems, there are continuing and important uncertainties in planning AM.
C. From AM policy to action	4. How do we manage our organisation(s) to efficiently translate AM policy into actions?	Organizational and institutional arrangements for FRM have been established historically, with many of these in the NSR set up prior to the realisation that climate and other drivers are changing faster than the lifetime of individual assets. These arrangements may need to be reconfigured in a way that allows them to be more efficient and effective and open to change, adaptation, or even fundamentally reformed.
D. From stakeholder to shareholder	5. How do we engage relevant key stakeholders in AM as shareholders, thus creating innovative financing opportunities and (better) sharing of risks?	AM should focus on multi-functionality to address the multi-sectoral challenges beyond flood risk that climate change brings. This requires collaboration with a much wider group of stakeholders than in the past, each of whom will have a variety of different interests. Shareholders are a special type of stakeholder – who have a share in the creation of the plan and in the responsibility for delivery and maintenance.
E. Engaging Society	6. How do we engage with society in the way needed to ensure that assets are delivered and managed in the best way?	Effective and mutually beneficial engagement with communities is more important than in the past, especially to help people to understand the need for FRM measures and the need to use and maintain these in response to climate change. There is no clear way to effectively engage communities, despite there being a large volume of documents, guidance and research findings on the topic.

9.2.2 Potential for improvement of organisation and policies (See also Table 9.1)

Appropriate and effective organisations, institutional arrangements and governance structures are required to deliver integrated and adaptive AM. The maturity assessment undertaken in FAIR (Section 3.3) shows that there may be grounds for reform for some operators. Policies and strategies are only effective if these are delivered within the operational AM sphere (connected by the tactical handshake, as set out in the FAIR framework, or through an equivalent process).

It is imperative that policies are devised and set in place that are fit for the purpose of effectively managing risks, now and in the future. With this in mind, the FAIR project has derived policy recommendations gleaned from the FAIR work activities, categorised into four main areas (see the FAIR Policy Brief[50]):

- Align multiple planning processes within and beyond flood management (integration and cross-domain);
- Link strategic planning and operational processes (using e.g. FAIR framework);
- Develop flexibility and adaptive capacity within flood protection (and in the AM process itself);
- Make space for innovation.

Each of these has sub-recommendations and best practice examples of instruments to facilitate uptake in the FAIR policy brief.

9.2.3 Potential for improvement of best practices

Best practice AM as a process, needs to include, as set out above, strategic and cross-sector life cycle and whole life approaches informed by: data collected from monitoring and observation turned into information and hence knowledge, about state and performance of assets; clear policies and rules related to societal requirements for renovation, adaptation, replacement and abandonment; leadership and defined unambiguous responsibilities for action; incentivising rewards for each actor in the AM process chain.

9.3 Delivery of adaptation in practice

As the world grapples with an uncertain future, the FAIR project beneficiaries recognised that there is no 'silver bullet' to aid in moving towards effective adaptive and integrated asset management for FRM.

From a workshop jointly convened by the FAIR project and the Environment Agency (England and Wales)[51], there was a general consensus on the urgency of the issues to be addressed and what is needed to make real progress.

Building upon the four Policy Recommendations from the FAIR project (above) these included several common priority issues to be addressed:

- **Adaptation is more than simply modifying a flood defence asset** – it is a process that requires innovative, whole system, longer term thinking. Achieving this relies on recognising:
  - 'Our world is changing faster than our thinking' – we need to catch up;
  - Adaptation is a 'people thing' – including individuals, communities, politicians, planners and engineers;

50. https://northsearegion.eu/media/8638/aw_interreg-policy_a4_web.pdf
51. Oxford, February 2020 (Sayers, 2020)

- Uncertainty is driven by more than climate change alone – development (local and remote), funding, societal preferences; all have implications for the choices we make;
- Change starts with you (us)! Flood risk management practice is in a pivotal position (although not always leading) to influence change - we must 'break free of our silo' – we all have to reach out to influence change.

- **Prerequisites for progress**: To make progress in flood and coastal risk management we must be better at:
  - Envisioning and visualising the future – creating and using storylines are powerful vehicles in supporting buy-in to alternative (better) courses of action;
  - Addressing the hard choices – marginal system or asset adaptation is easy, but making hard choices (such as realignment, or investing significantly more today for future flexibility) is more difficult, but these choices must be made;
  - Recognising adaptation as a purpose – adaptation is 'not kicking the can down the road' (i.e. can be deferred, or passed on to someone else) – we must take responsibility for the future today;
  - Accepting adaptation is 'not a free lunch' – how much are we willing to pay for future flexibility/reduced lock-in?
  - Avoiding the potential trap of 'paralysis by analysis': We have many of the tools needed to understand asset and system performance. We have much information – much of which is not being used effectively. New data are not always needed (sometimes it may be) – but we can make good decisions with the information we have.

9.3.1 Delivering adaptation is a continuous process - you can't get 'adaptation done' - adaptation is an ongoing process. How do we get there?

This Section summarises what is needed to address the four policy recommendations in the FAIR policy brief and the various knowledge gaps highlighted in this report. It contributes to the list of issues that emerged from the Oxford workshop in Section 9.3 above.

Although there are numerous initiatives to bring together the various domains of societal need, especially in relation to climate hazards and related infrastructure interdependencies – including the management of flood risks as one component – into an integrated strategic approach (Dawson *et al.*, 2018), as yet only a few case examples have been developed and few have been implemented. In particular domains, attempts are being made to deliver adaptive and flexible assets that provide multiple benefits and a range of services, by taking an integrated approach, which in the urban domain is founded in effective land use management (e.g. CIRIA, 2019). The science and knowledge in this area continues to be developed and lessons learnt.

These initiatives need also to be complemented by appropriate supportive frameworks, including facilitating governance, leadership, unambiguous responsibilities for action, incentives and vision.

52. Pilot Helsingborg - A Practice Brief from the Interreg North Sea Region FAIR project

a. What does it mean for policy makers / politicians?

The needs are for:

- Political structures that support and reward those who are willing to pursue innovation and adopt an integrated / cross sectoral approach; i.e. risk takers. An example from FAIR on the courage to innovate, is the pilot for Helsingsborg Municipality[52], where (experimental) failure was not penalised but rewarded. Sometimes failure may only lead to lessons learnt; other times it can inform cost savings or improved outcomes;
- Appropriately linked flexible budgets that are broader than silo focused funding for individual infrastructure sectors;
- More effective engagement of stakeholders, where feasible as shareholders; i.e. reward recipients for investments;
- Leadership for change, e.g. to provide strategic oversight and importantly to drive innovation forward.

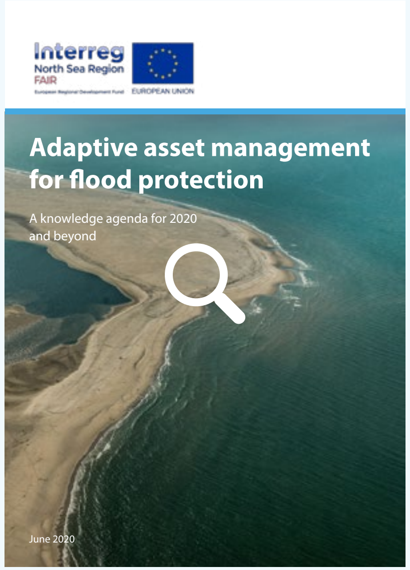
b. What does it mean for practitioners?

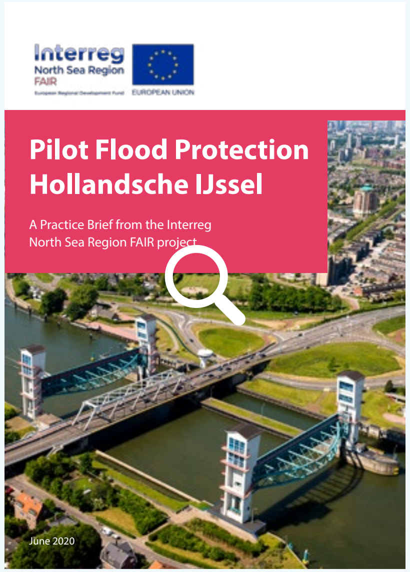
The needs are for:

- Promotion of accelerated learning, via e.g. engagement in a community of practice that supports learning from best practitioners and learning and innovating together;
- More effective spanning and connection of disciplines across the entirety of AM for service provision and risk management;
- Better Engagement with, funding and direction of research to address needs; e.g. on the needed transformational change (strategic planning);
- Practice to better inform theory, by for example, monitoring asset performance and making best use of observed data (e.g. on failures or near-failures), to disseminate information about the wide range of asset failure risks.

Further reading and references

Further reading





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Appendix

Appendix A - Maturity Analysis

Table A.1 The 5-point scale and the 7 maturity indicators of Volker et al. (2013) as used in FAIR.

Maturity indicator	Asset Management Decisions	Information Management	Internal Coordination	External Coordination	Outsourcing activities	Processes and roles	Culture and Leadership
Optimized	Life cycle costing is embedded in strategic, tactical and operation decisions and forms the basis of the evaluation of risks and opportunities.	Assets information that is: collected once and used many times, up to date and readily available is used by all stakeholders.	Departments coordinate their asset management at strategic, tactical and operational contexts. Departments have an active role in drawing up and optimisation of the framework.	Prioritisation and planning are undertaken in collaboration with the other asset owners and wider stakeholders with a legitimate interest in the assets.	A combination of internal expertise is maintained with respect to programming and execution with some activities and assets outsourced where necessary to deliver added value through innovation in planning, financing and execution.	Clearly defined and understood and supported by a continuous process of structural evaluations and internal/external auditing, to drive improvement.	AM is an integral component of the organisational culture. Management is open to new AM approaches and employees are pro-active when it comes to proposing improvements.
Well Managed	All risks for objects and network-level components are systematically prioritized. The evaluation of risk-management decisions on a tactical and operational level is supported by cost calculations.	Data is being used to generate management reports which are frequently updated to incorporate new insights. Asset information is available integrated and is being reported.	Departments coordinate all their infrastructure management internally and work for the most part within the set up framework. Departments communicate common bottlenecks related to the framework back to the board (management).	The water authority prioritizes their own maintenance , but coordinates the planning of maintenance of network-level components with other asset owners and end users.	Some activities and assets outsourced to private sector parties and managed through operational standards expressed with performance criteria. Added value focused largely on execution.	Clearly defined and understood relying upon an ad hoc process of interviews and internal audits to drive improvement.	AM is generally considered as one of the most important organizational principles. All employees are familiar with the basic principles of AM and there is a broad variety of AM trainings available.

Maturity indicator	Asset Management Decisions	Information Management	Internal Coordination	External Coordination	Outsourcing activities	Processes and roles	Culture and Leadership
Standard	A systematic prioritization of the most important risks and risk management decisions is available for critical objects and network-level components.	Static and dynamic data of all relevant objects is stored in databases according to standard procedure. Data on asset performance is accessible any time.	Departments coordinate tasks internally and solve problems within the budget framework.	The water authority informs other asset owners and end users about the scheduled maintenance of objects and network-level components. On an operational level coordination is limited.	The water authority uses its knowledge of the market by using their own portfolio planning for maintenance on an object and network level, to coordinate with the private sector parties while reflecting the content.	Clearly defined and understood relying upon an but discrepancies between strategic, tactical and operational contexts exist.	AM is one of the organizations targets, but the is no formal route for employee driven innovation and few employees given the opportunity for AM specific training.
Repeatable	A couple of risks and risk management decisions are prioritized in an ad hoc manner.	Information of a few objects are stored according to comparable methods. The importance of standardized Asset-databases is acknowledged.	Departments solve problems themselves within the set budget framework and coordinate internally on an ad hoc basis.	The water authority informs both end users and other asset owners on the execution of maintenance of objects (before and after maintenance).	The water authority outsources preset activities on object and network level to private sector parties.	There is a shared view of processes and roles of asset management but these are not clearly defined and described.	AM is promoted by ambassadors across the organization, bringing attention to AM where considered to be needed.
Ad Hoc	No attempt to make an inventory of and systematically prioritize risk management decisions.	Knowledge of objects are known on the work floor. Information is decentralized maintained in own database.	Departments solve problems internally within the set budget framework.	The water authority operates autonomously and informs end users on the maintenance of objects (before and after maintenance).	The water authority outsources preset activities on an object level to private sector parties.	There is no shared view of processes and roles within asset management.	There is no specific attention towards AM and particular AM skills.

Table A.2 The 5-point maturity levels and definitions linked to the 3 decision contexts in the FAIR framework (The components 1-5 and A-D were finally categorised into the 3 contexts after these assessments were made, and are different in the final framework)

Level of maturity	**Strategic** **1-3**	**Tactical** **4, 5 & A**	**Operational** **B-D**
Relevant steps in framework	*1. Threats & opportunities* *2. Objectives & requirements* *3. Measures for system*	*4. Adaptive plan* *5. Performance of network* *D. Performance of assets*	*A. Measures for assets* *B. Design & construct* *C. Monitor & maintain*
Optimized	A long term vision on system development is present, and a consistent method is applied in order to continuously translate this vision into a well-defined asset management strategies, based on cost, risk and performance as indicators.	There is a continuous evaluation of asset performance that informs network performance. Long term plans are updated both following significant changes in network performance and periodically. These long term plans translate to optimized planning for measures, of which the performance is measured by the main AM indicators.	Performance of assets is reported using a standardized method, based on generally defined performance indicators that are used for all similar assets. There is a continuous evaluation of performance, optimized implementation of measures is realized based on the main asset management indicators.
Well Managed	All decisions for long term investments are evaluated using a consistent method based on a small number of the well-defined AM indicators. Performance indicators are specifically defined.	Long term plans result in asset interventions based on general and measurable performance indicators. Asset performance is translated to performance of the network, but doesn't automatically instigate a re¬evaluation of the long term vision and/or plan.	Performance of assets is measured using quantitative and measurable performance indicators. The performance is monitored continuously and plans are periodically updated and executed based on the most recent insights.
Standard	Decisions on long term investments are made based _ on ideas but not a vision, a consistent decision making method is available but only uses the main asset management indicators in a generalised manner (often qualitative only).	There is a standardized method for translating long term planning to asset interventions. This uses the main AM indicators in a qualitative way. The measurement of performance is also mostly qualitative.	Maintenance plans and plans for interventions on an asset level are common practice. A standardized method for determining performance is used as input. Interventions are based on these plans, but there is no continuous monitoring of the performance of the implemented strategy.
Repeatable	Long term decisions are transparent but not made using a consistent decision making method. The main asset management indicators (performance, risk and cost) are not used.	Long term strategies translate into asset decisions. However there is no relation between performance and performance requirements defined on a strategic level. Reporting of performance of assets is not done in a standardized way.	Interventions are based on daily issues and qualitative decisions. These decisions are made transparent integration of planning of larger interventions and maintenance plans are scarce.
Ad Hoc	Long term decisions are taken at an ad hoc basis, based on daily issues. The basis for these decisions is not transparent. Performance is not measured or evaluated.	There is no clear relation between long term decisions and decisions for specific assets. The performance of assets is not translated into performance of the network, so any long term decision disregards the actual performance of the network.	Performance of assets is not measured. Interventions are based on daily issues. There is no connection between maintenance, larger interventions and performance.

Appendix B – Survey and questionnaires used in Chapters 5 and 6

Two assessments have been carried out to review the aspects of the FAIR framework described in detail in: Chapter 5 for the operational context; and Chapter 6 for the strategic handshake. These have been undertaken by means of questionnaires and semi-structured interviews by members of the scientific team of FAIR.

B.1 Survey on maintenance processes and strategies (summarised in Jordan *et al.*, 2019)

Semi-structured interviews were conducted by TUHH between April 2018 and January 2019 with seventeen representatives of organisations with responsibilities for assets for flood protection. The interviews included multiple persons from NSR countries where appropriate and also representatives from (7) organisations other than the FAIR beneficiaries, in order to get a complete picture of the maintenance processes being practiced in NSR countries. Hence, interviews were also conducted with Norwegian and English asset owners/operators. Those interviewed were experts and responsible organisation representatives. No attempt was made to randomise those selected for interview, as it was necessary to ensure willingness to participate from personal recommendations.

Questions covered strategic maintenance aspects such as responsibilities, legal framework, funding or organizational structure. The operational aspects considered actual maintenance processes such as servicing, inspection, repairs and upgrade.

The interviews were informed by the questions in Table B.1. The detailed sub questions are not shown.

Table B.1 Main questions included in the interviews on maintenance processes and strategies

Main topic	Sub topic (each had a number of sub questions)
1. Strategic perspective	1.1 Organisation
	1.2 Sensitivity & Conflict potential
2. Operational perspective	2.1 Basic data
	2.2 Maintenance process
	2.3 Sensitivity & conflict potential

B.2 Survey of asset owners on current asset management and investment policies

The survey aimed to collect information to guide the Asset Owners in identifying the challenges, barriers and gaps they face in developing more adaptive Asset Management. An online questionnaire was devised by Deltares. Individual questionnaire responders were self-selected within asset owner/operator organisations. Eight individual questionnaires were completed by FAIR beneficiaries and also representatives from Norway and England. For the Netherlands, both RWS and HHSK completed separate questionnaires. The main questions are shown in Table B.2.

Main topic	Sub topic (each had a number of sub questions)
A. National context	Context within which asset management takes place
	Challenges and barriers to be overcome
	Overview of tools and data used
	Decision processes
B. Case study	Setting the scene
	Specific barriers and challenges to be overcome
	Overview of tools and data to be used
	Decision process
	The relationship of AM to board planning issues

Picture references

Reference supplied by Bart for the picture in box 5.6: https://beeldbank.rws.nl, Rijkswaterstaat / Rens Jacobs

Afsluitdijk1: https://beeldbank.rws.nl, Rijkswaterstaat / Jan Wessels

Afsluitdijk2: https://beeldbank.rws.nl, Rijkswaterstaat / Jan Wessels

Dike1: https://beeldbank.rws.nl, Rijkswaterstaat / Harry van Reeken (Dike near the Linge river)

Dike2: https://beeldbank.rws.nl, Rijkswaterstaat (location is Texel)

Dunes1: https://beeldbank.rws.nl, Rijkswaterstaat / Jeroen Mies (location is Ameland)

Housebehinddike: https://beeldbank.rws.nl, Rijkswaterstaat , Ruimte voor de Rivier / Ruben Smit

Houtribdijk: https://beeldbank.rws.nl, Rijkswaterstaat / Harry van reeken

Project1: https://beeldbank.rws.nl, Rijkswaterstaat , Ruimte voor de Rivier (near Westenholte)

Project2: https://beeldbank.rws.nl, Rijkswaterstaat / Jan Wessels (Afsluitdijk)

Project3: https://beeldbank.rws.nl, Rijkswaterstaat / Jan van den Broeke (afsluitdijk)

River1: https://beeldbank.rws.nl, Rijkswaterstaat , Ruimte voor de Rivier / Ruimte voor de Rivier

River2: https://beeldbank.rws.nl, Rijkswaterstaat , Ruimte voor de Rivier (IJssel river, Deventer)

River3: https://beeldbank.rws.nl, Rijkswaterstaat / Harry van Reeken ((Waal River, Haaften)

River4: https://beeldbank.rws.nl, Rijkswaterstaat , Ruimte voor de Rivier / Gemeente Nijmegen (Waal river, Nijmegen)

Sandmotor1: https://beeldbank.rws.nl, Rijkswaterstaat / Joop van Houdt

Sandmotor2: https://beeldbank.rws.nl, Rijkswaterstaat / Joop van Houdt

Ship: https://beeldbank.rws.nl, Rijkswaterstaat / Jeroen Mies (Rijkswaterstaat vessel)

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A perspective on the future of asset management for flood protection

A Policy Brief from the Interreg North Sea Region FAIR project

February 2019

Marken Vuurtoren, Courtesy Rijkswaterstaat

Summary

FAIR[1] brings together flood protection asset owners, operating authorities and researchers from across the North Sea Region (NSR) to share the policy, practice and emerging science of asset management.

Despite the diverse character of the NSR, asset managers face common challenges across the region. FAIR identifies four priority policy recommendations that respond to these challenges. Addressing these policy challenges will be a prerequisite to ensuring flood protection assets are fit for purpose in an uncertain future.

The four FAIR recommendations:

1. Break-free of the silo: Align multiple planning processes within, and beyond, flood management;
2. Mind the gap: Link strategic planning and operational processes through a tactical handshake;
3. Prepare for change: Develop flexible strategies and asset designs that can be adapted to meet changing requirements in future;
4. Make space for innovation: Embrace and manage risk to support the development of innovative solutions.

Background

Collectively EU Member States invest an average of €3 billion per year on flood protection infrastructure[2]. But a combination of climate and socio-economic change is increasing the annual average damage caused by flooding. Complex and difficult decisions will need to be taken in response to these threats, especially in coastal regions, as rising sea levels challenge the sustainability of existing policies and plans[3]. An improved approach to the planning, design and management of new and existing flood protection assets will be central to addressing this challenge.

Significant new ideas and methods are being developed to ensure best value asset management options are identified for both existing and new infrastructure. However, their alignment with socio-economic policies and supporting governance systems is often neglected[4].

FAIR recognises these challenges and identifies four priority policy recommendations to progress flood protection asset management. This Policy Brief presents the drivers behind these challenges facing the NSR and elaborates the four policy recommendations supported by good practice illustrative examples from across the FAIR partnership.

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[1] https://northsearegion.eu/fair/

[2] Acteon (2018) Investment Needs and Innovative Financing Mechanisms for Flood Protection. Report for OECD, Paris highlights that between 1971 and 2015, flood damage increased by seven times worldwide.

[3] Committee on Climate Change (2018). Managing the coast in a changing climate. Authors Russell, Jacobs and Sayers.

[4] Rijke J., et al., (2012) Fit-for-purpose governance: A framework to make adaptive governance operational. Environmental science and policy 22(2012) 73 – 84.

South coast, England – Courtesy Sayers and Partners

Recommendation 1: Break free of the silo

The challenge: The institutional context for asset management is often fragmented

As a multi-stakeholder endeavour, flood protection brings together issues of place-making through spatial planning, investment, aesthetics, acceptable risks and many more. Flood protection asset management balances the perspectives of stakeholders and trades-off issues of cost, risk and performance at multiple scales (from a single asset to a system of assets that act in combination to provide flood protection). Asset managers will recognise this context which is also reflected in ISO 55000[5].

The demands of local communities for flood protection and the national desire for efficient investment are not always compatible. In some cases, it may not be efficient (from a national economic perspective) to invest in improving flood protection locally due to the relative cost and economic value of doing so. To avoid making planning choices based solely on maximising national investment returns, broader issues must be considered, including social justice and well-being, and ecosystem health[6]. Understanding the role of, and opportunity for, leveraging local funding and private investment to supplement national sources is also an important consideration.

The institutional context within which these challenges are responded to is crucial for flood protection assets planning, promotion and management. With a few exceptions, like Helsingborg Municipality, Sweden (see right), no single organisation is entirely responsible for asset management throughout all its stages. In most countries, roles and responsibilities are dispersed amongst many organisations. Consequently, any mismatch between responsibilities and available capabilities and resources can undermine the provision of fit-for-purpose flood protection. A self-assessment of asset management approaches used by FAIR partners points to the strengths of a decentralised governance model for coordination and problem solving between the different departments of an organisation. But the same survey also highlights the risks of adding responsibilities to municipalities without sufficient resources or knowledge to deliver[7].

[5] ISO 5500 provides a useful overview of asset management, its principles and frameworks applicable to all organisations
[6] Sayers, PB. (2017). 'Evolution of Strategic Flood Risk Management in Support of Social Justice, Ecosystem Health, and Resilience'. Published by Oxford Research Encyclopedia: Natural Hazard Science.
[7] Gersonius et al. Asset management maturity for flood protection infrastructure: a baseline across the North Sea region. Proc. International Symposium on Life-Cycle Civil Engineering (IALCCE 2018).

The policy recommendation: Align multiple planning processes within and beyond flood management

There are many complex and interacting planning processes and actors that influence effective asset management (often with centralised processes delivered by dispersed, localised operators).

Well-aligned asset management is dependent on having a coherent strategy in place to link flood asset planning, delivery and operation with broader planning objectives. In many cases, strategic oversight by a responsible authority or process lead will be required to provide the bridge between these multiple planning processes and flood asset management. Without this oversight opportunities for efficiency savings can be missed and the successful delivery of flood management undermined by uncoordinated local choices.

Illustrative examples

Sweden, integrated city planning, Helsingborg: The municipality of Helsingborg leads the coordination of all aspects of city planning. This enables a simultaneous consideration of major investments in regeneration of the seafront and harbour area (including green space and beach access) and improvements to flood protection standards. Plans are also adjustable in response to resources and changing needs.

England, strategic oversight and local delivery: Following widespread flooding in 2007, arrangements were put in place to enable more effective working between the main agencies involved in managing risks. The Environment Agency[8] was given the responsibility of strategic oversight of all flood-related planning. Delivery was devolved to local municipalities designated as the Lead Local Flood Authority (LLFA). LLFAs are one 'department' of a local municipality and therefore local policies must balance the need for flood protection and a range of other activities including: education; public health; crime; highways etc. Overall these arrangements are broadly successful in enabling a more strategic approach to flood risk management[9] when adequately resourced. There is potential for problems however, including: a lack of resources; differing partner objectives, priorities and regulatory environments; a mismatch between public expectations and delivery; a lack of the necessary partner skills, capacity and knowledge etc.

Belgium, multi-functional and adaptive dike reinforcement: In Middelkerke an existing dike wall is being augmented with a dune system to provide a natural habitat and enhanced recreational opportunities. The dune also provides a natural adaptive capacity and can be widened or heightened to cope with sea level rise.

Belgium coast redevelopment – Courtesy Vlaanderen is maritime

[8] The Environment Agency was the first organisation to achieve ISO 55000 accreditation for flood risk asset management.
[9] Defra (2017) Evaluation of the arrangements for managing local flood risk in England - Final report FD2680 Published January.

Recommendation 2. Mind the gap

The challenge: Strategic planning and operational processes are often misaligned

Good asset management requires strategic plans and perspectives to link seamlessly with operational activities and perspectives. This is easier said than done.

There is often a 'gap' in responsibility, with organisations tending to be divided between strategic and operational activities. This encourages processes to be considered in isolation.

Without a clear line-of-sight from operation to strategy and vice versa, strategic objectives are likely to be undermined by operational realities. Operations may fail to reflect the longer-term direction set by the strategy. This mismatch can lead to poor targeting of investment and inappropriate design and maintenance choices.

The policy recommendation: Link strategic planning and operational processes through a tactical handshake

FAIR promotes the development of a 'tactical handshake' between strategy and operation. Establishing a culture of collaboration (inside and outside of any single organisation) is central to the success of this continuous process. But although necessary, collaborative culture is not enough to ensure success.

A shared understanding of the assets to be managed is vital, including basic information on what and where the assets are, to how they are likely to perform now and in future. Take the adoption of structured assessment processes (methods, monitoring and databases) for example. By progressively refining performance information and detailed level assessments, these processes provide insights for reuse in higher levels plans. Similarly, insights generated from strategic assessments inform more local analysis and activities.

FAIR highlights several strategies that are emerging to aid this process. Progressive approaches to performance help bridge the gap between strategy and operation by providing a common assessment framework at each level. Consider, for example, fragility assessments that enable uncertainty to be reduced without influencing the form of the performance data[10], or 'total expenditure' (TotEx) which enables whole life capital, maintenance, modification, and eventual removal costs to be assessed[11]. Developing a structured understanding of the indicators of asset performance is also central to achieving ISO 55000.

10 Sayers et al., (2002). Risk, performance and uncertainty in flood and coastal management - A review. A report for the Environment Agency by HR Wallingford
11 Klerk, W. & Den Heijer, F. A framework for life-cycle management of public infrastructure. Proc. International Symposium on Life-Cycle Civil Engineering (IALCCE 2016). CRC Press, 101.

Illustrative Examples

Netherlands, reducing life-cycle costs through a more strategic approach to deliver statutory protection standards: Dikes along the river Hollandsche IJssel are operated by the regional water authority (HHSK), but no longer met the statutory standard. This river can be isolated from the main river, Nieuwe Maas, by a storm surge barrier (operated by Rijkswaterstaat) controlling hydraulic loads on the dikes. Improving the reliability of the storm surge barrier decreases the expected hydraulic loading conditions on the dikes; but additional investment in the barrier would be needed to achieve this. By working together, HHSK and Rijkswaterstaat have managed to trade-off costs and benefits between dike and barrier improvements to reduce whole life-cycle costs without compromising standards.
A programme focused solely on dike strengthening would have missed these additional opportunities.

Hamburg, Germany, developing a strategic approach to management of 'on demand' assets: Hamburg is protected from flooding by a complex array of automated flood protection gates that operate (on average) about 10hours/year, to a very high standard of reliability. Understanding the trade-off between the benefits of a highly automated approach and the potential increased chance of error (due to process complexity) is a central challenge. Data and information is central in responding to this problem and LSBG Hamburg is developing a new georeferenced asset information system. In addition to geometry and functions, the system records operational permits, as-built details, and the consequences of failure. Analysis of this data helps to understand system behaviour and to target maintenance resources effectively.

Hamburg, Germany.

Recommendation 3. Prepare for change

The challenge: The future is uncertain, but decisions taken today have long-term implications

Change is inevitable but predicting the future is impossible. Developing flood protection infrastructure in this context presents several challenges: How much should be invested today in strengthening and raising assets? Should we delay investment?

These complex decisions become even more difficult when the long-term choices (that take account of future uncertainties in climate and socio-economic context) clash with short-term political realities and varying perceptions of risk. In response, large-scale infrastructure investments, renewals or upgrades are often preferred over maintenance and monitoring. This 'bias-to-build' leads to solutions that may be unnecessarily costly or mal-adapted to the reality of the future as it emerges[12].

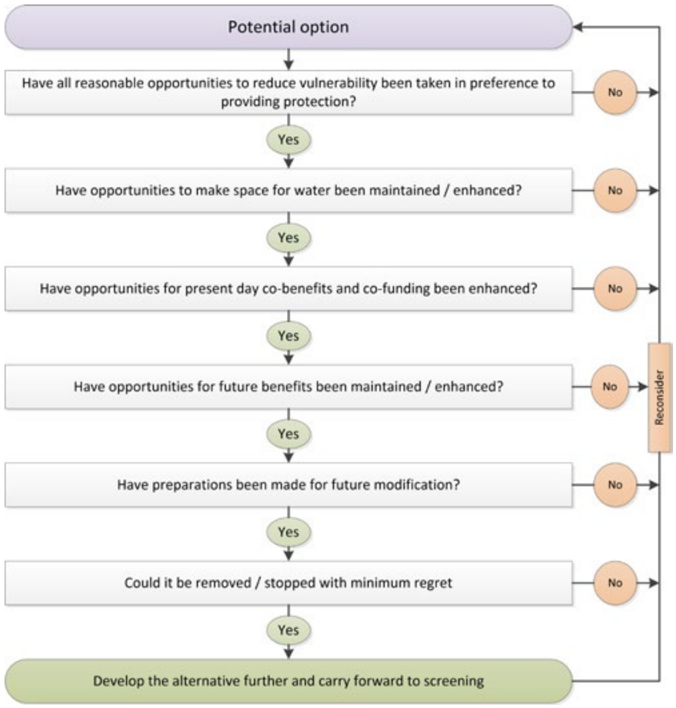
Coastal cliffs, Denmark - Courtesy Sayers and Partners

[12] Sayers PB (2019). Water infrastructure: A strategic approach to combining built and natural infrastructure. (In press, WWF and UNESCO)

The policy recommendation: Develop strategies that are flexible and assets that can be modified

Policies and associated appraisal processes should support development strategies that proactively plan for an uncertain future. And as new evidence and insights emerge, these strategies must be modified accordingly. Investments in monitoring and evaluation (assets, loading conditions, socio-economic setting etc) underpin the continuous process of updating both strategy and operation delivery. Doing so ensures flood risks are well-managed, and plans are adapted in a timely manner.

Developing the capacity for future flexibility is not simply 'wait and see', but a process of purposeful preparation. There is often an immediate cost associated with these preparations, such as securing land for future set back of a dike line, or to strengthen foundations in preparation for future raising. Various tools and techniques are available to help make the case for future-ready investment, from visualising adaptive pathways to formally valuing adaptive capacity (see below). Using these tools and approaches helps asset managers balance performance, risk and cost over short and longer term by maximising societal value and avoiding solutions that may be unsuitable for future conditions.



See footnote 13.

Illustrative Examples

England, developing an adaptive plan for the Thames Estuary. The Thames Estuary 2100 project (TE2100) was established in 2002 with the aim of developing a long-term tidal flood risk management plan for London and the Thames estuary. The resulting TE2100 Plan[14] sets out a management strategy that can be adapted in response to future climate and socio-economic changes.

The Netherlands and England, visualising and valuing adaptive pathways: New guidance and tools are being used to both visualise and value the flexibility offered by adaptive approaches. The guide includes advice on considering adaptive approaches at different stages in appraisal and formally valuing the adaptive capacity[15]. Software tools are used to visualise and explore alternative pathways together with stakeholders, providing insights into the adaptation options available, the sequencing of options over time, potential lock-ins and path dependencies[16].

Denmark, embedding flood and erosion in local planning: In 2013 Danish municipalities were required to prepare climate adaptation plans that integrate erosion and flood protection into long-term strategic planning process (including urban development, wastewater management and environment). Revising these plans is not a statutory requirement but the importance of doing so is widely recognised. Many municipalities continue to work with national organisations to include improved evidence on present and future risks and potential adaptation options within local planning decisions.

[13] Sayers, P., Walsh, C., & Dawson, R. (2015). Climate impacts on flood and coastal erosion infrastructure. Journal of Infrastructure Asset Management.
[14] Environment Agency (2012). Thames Estuary 2100 Flood Risk Management Plan.
[15] Environment Agency (2018). Accounting for adaptive capacity in FCERM options appraisal. Authors: Brisley, R., Sayers, P.et al..
[16] https://www.deltares.nl/en/adaptive-pathways/

Recommendation 4. Make space for innovation

The challenge: Innovation is not consistently embedded in standard practice

The UK's Chief Scientist's Annual Report 2014[17] stated that to be successful, a society must learn to manage risk and not simply seek to avoid it. Innovative solutions, and how to generate the political momentum to deliver them, remains a central barrier to progress. For example, the policy in recent years within England and Wales has been guided by the principle of '*Making Space for Water*'[18], and in the Netherlands providing '*Room for the River*'[19]. Across the NSR the role of nature-based approaches as legitimate flood assets is increasingly recognised. The sentiment of these policy goals is clear, but frequently at odds with local political and public response that prefers conventional, tried and tested, solutions. Consequently, asset managers struggle to promote and deliver more innovative solutions that challenge accepted norms.

The policy recommendation: Accept that new approaches attract risk but managing, rather than avoiding, risks can lead to innovative solutions

Policies should provide a platform for the inclusion of innovation – from ideas to implementation, regulation to analysis, and in the role of institutions and stakeholders. Central to the successful delivery of innovative solutions challenging conventional approaches and to positively promote new ways of working. This means rewarding innovation (using ring fenced innovation and pilot funds etc) and giving space to innovators from industry and academia to transition novel approaches into practice by accepting the potential for greater uncertainty.

Sensors within a dike – Courtesy the Rijkswaterstaat

[17] Walport et al., (2014) Innovation: Managing Risk, Not Avoiding It. Annual Report of the Government Chief Scientific Adviser 2014.
[18] Defra (2004). Making space for water Developing a new Government strategy for flood and coastal erosion risk management in England.
[19] Ruimte voor de Rivier (2018) https://www.ruimtevoorderivier.nl/english/

Illustrative Examples

North Sea Region, learning from others: New practice can emerge from interacting with others addressing similar challenges. FAIR uses Peer2Peer meetings to create an active open space to discuss approaches to reliability, responsibilities, information management and future developments in flood protection. These meetings also challenge established practices and promote opportunities for innovation.

England, natural flood management: The UK is currently promoting several processes, considered to offer multiple benefits. Using natural features to slow the flow of flood waters through catchments and urban spaces, or realignment of the coast to maintain littoral processes for instance. There is currently limited quantified evidence[20] about the ability of these features to manage flood risk, so central Government is funding pilot studies and demonstration projects to encourage take-up and develop the evidence base[21].

Helsingborg, 'innovation of the year': The Municipality awards an annual prize to the most innovative project initiated during the year. There is even a prize for the 'failure of the year' that goes to an innovative project that did not necessarily turn out as expected. By rewarding projects that challenge conventional approaches, stakeholders are encouraged to embrace innovative solutions across all aspects of their work, from conception to implementation, and from public engagement to funding.

Netherlands, proactively encouraging innovative dike reinforcement techniques: The opportunities provided by dike strengthening innovations and emerging monitoring technology are widely encouraged. The national Dutch Flood Protection Program provides support funding for the development and testing of innovative dike reinforcement techniques. Asset owners are also encouraged to use new sensor technologies to gain insight into dike strength and performance (often in real-time an at a relatively low cost[22]) to maximise safety and optimise maintenance activities.

[20] Dadson, et al., 2017. A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 473(2199), p.20160706.
[21] Defra (2018). Monitoring and evaluating the DEFRA funded Natural Flood Management projects.
[22] http://deltaproof.stowa.nl/Templates/pdf.aspx?rId=16

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Further reading

The documents relating to the FAIR project can be found on the following websites:

http://www.fairproject.org/

https://northsearegion.eu/fair/

Partners

FAIR brings together Asset Owners (facing real problems and challenges) and leading scientists (with domain expertise) to share and develop innovative solutions to the management of flood protection assets. In doing so, FAIR is the first collaboration of its kind.

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Adaptive asset management for flood protection

FAIR extended summary

June 2020

Introduction to FAIR

Challenges for flood protection in the NSR:

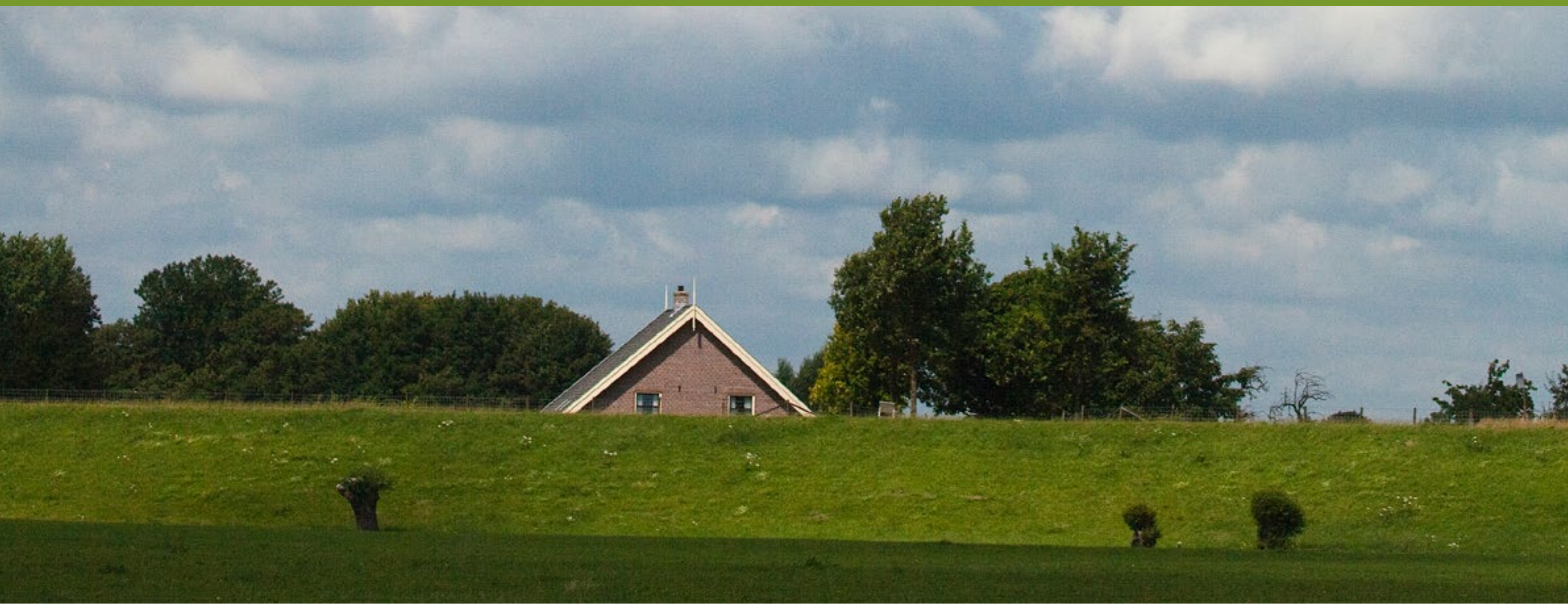
Despite the diverse character of the North Sea Region (NSR), asset managers of flood protection infrastructure face common challenges. This includes threats related to climate and socio-economic changes, along with the ageing of existing flood protection assets. Large investments are needed in order to face these challenges and to keep the NSR as safe as possible from flooding, both in maintaining existing and constructing new assets. Economic constraints mean that adaptation of existing infrastructure needs to be smarter, utilising innovations and latest knowledge, and this can both reduce overall costs and at the same time control the potential impacts. The required large scale of investments provide a unique opportunity to simultaneously improve flood protection and implement climate adaptation measures that are fit for the future; i.e. that are flexible and adaptable.

The FAIR project:

FAIR brings together flood protection asset owners, operating authorities and researchers from across the NSR to share the policy, practice and emerging science of asset[1] management. It aims to reduce flood risk across the NSR by developing and implementing improved approaches for asset management of flood protection infrastructure.

The specific result indicators for the project are:

- Increase the life span of flood protection infrastructure – through smarter maintenance and renovation;
- Reduce the life cycle costs of flood protection infrastructure – through better targeting of investment;
- Encourage the multi-functionality of flood protection infrastructure – through mainstreaming (that is, connecting) investments with other policy objectives.



[1] e.g. Abadie L M., et al., (2019). Risk measures and the distribution of damage curves for 600 European coastal cities. Environ. Res. Lett. 14 (2019) 064021 https://doi.org/10.1088/1748-9326/ab185c and Calafat F M., Marcos M. (2020) Probabilistic reanalysis of storm surge extremes in Europe. PNAS | January 28, 2020, vol. 117, no. 4, 1877–1883. www.pnas.org/cgi/doi/10.1073/pnas.1913049117

[2] Link to end report

Connecting FAIR to practice

The FAIR framework:

FAIR provides guidance to help to address the various challenges facing those with responsibilities for managing the assets for flood protection in the NSR. It utilises a framework comprising three 'contexts' to consider the approach to and processes for asset management.

1. Strategic: corporate and long-term view;
2. Operational: focusing more on day-to-day measures and activities;
3. Tactical: ensuring effective interconnections between strategic and operational

This document provides an extended summary of the main results of FAIR, published in the FAIR end report[2] and is structured around the three contexts.

The experiences of the FAIR beneficiaries demonstrate good practices in asset management in the flooding domain, in five pilot projects. The pilot projects provide a proof of concept, which validate the application of the FAIR framework. This validation has shown that the use of the framework can help to ensure that flood protection assets are designed and used to be as multi-functional as possible, that there can readily be reduced life cycle costs of at least 5%, and a typical prolongation of the lifespan of targeted infrastructure by at least 5%.

The pilots are presented in standalone reports[3] as well as in the end report. A short description of each pilot is given in this table.

Location	Object type	Pilot case
Middelkerke, Belgium	North Sea dike	Combination of measures, including new stilling wave basin and sand dunes with beach nourishment.
Ribe Polder, Esbjerg, Denmark	Storm sluice, three locks and dikes	Reviewing and enhancing the performance of the system, taking an integrated perspective.
Hamburg, Germany	Three public defence gates	Ensuring security and effective functioning of protection of the city of Hamburg from River Elbe.
Flood Protection Hollandsche IJssel, Netherlands	Dike in combination with storm surge barrier	Improving the performance, operation and reliability of the Hollandsche IJssel Kering (barrier) and the river Hollandsche IJssel dike system.
Helsingborg, Sweden	Sea wall in densely populated urban area	Improving the flood protection of the inner part of the city of Helsingborg.

[3] Link to the pilot reports

The FAIR framework

Although the countries in the NSR face similar challenges, there are many differences between regions and even within countries in the planning and delivery of flood protection. There are differences in terms of strategy, delivery, operation and responsibilities. Each beneficiary has to operate within unique funding processes, unique institutional arrangements, delivery and operational approaches. The FAIR project has been able to utilise the concept of three overarching 'planning and decision contexts' to consider the approach to and processes for asset management, including a strategic, an operational, and a tactical context.

The three FAIR action contexts that define the framework used in the project.

The strategic context produces the adaptive management plan for the assets, and the operational context delivers and maintains the plans' requirements. Interconnecting these is the tactical handshake that will feed information in both directions to inform both strategy as to the need for adaptations, and operational practices as to what is expected from the strategic plans.

The framework shows that each context is considered equally, rather than in a hierarchy of, e.g. strategic on a level higher than operational. The infinity shape used in FAIR represents the continuous process of individual and group asset management, and also applies to the integrated asset management process used to decide on how best to manage assets.

The FAIR project has found that there is an essential need to manage assets by connecting and aligning actions across the strategic and operational contexts, via the tactical handshake.

Definitions for the three planning and decision contexts of the FAIR framework are:

Strategic loop - the why and what?

Establish strategy and consequential long term planning processes using an overall integrated system perspective from understanding threats, asset operational effectiveness, responsive policy, standards and processes for interactions within FP asset systems and beyond the flood risk domain. Develop investment priorities to balance cost, risk and performance from an understanding of the flood risks, the opportunities associated with alternative strategies, objectives and functional requirements, and from the performance of alternative adaptation measures necessary to achieve these.

Tactical (handshake) actions - the when, where and what order?

Sustain the interconnectivity between the strategic and operational contexts, providing a means for two way information and knowledge transfer, especially about individual asset performance in the context of overall system performance, and how best to create or modify assets so that these provide the expected service by being adaptable and reliable. Ensuring that the developed strategic objectives inform the adaptive prioritisation and planning for individual and asset systems. This perspective ensures the connection between the two other AM contexts is guaranteed and fulfills the required role in the translation of asset performance to system/ network performance.

Opertional loop - the how?

Operate the assets and maintain service in compliance with strategy, by ensuring functioning through the assessment of the performance (reliability) from monitoring, based on the knowledge gained from the information collected. Where and when necessary, modify, design and construct adaptations to existing and new assets in conformity with and as informed from, the overall strategic planning context.

Strategic asset management

Strategic asset management consists of five main components, numbered 1-5 in the FAIR framework of planning and decision contexts.

1. Performance of the network

This component receives information from component D in the operational loop, via the tactical handshake. This gives the observed performance, predictions of longer term functioning/reliability essential to use in the source-pathway-receptor (SPR) analysis to reveal the performance of the assets and system as a whole and their longer term functioning.

2. Identifying threats and opportunities

Defining opportunities and threats is an important part of the continuous on-going process of asset management. It requires consideration of both external (e.g. climatic, socio-economic) and internal (e.g. asset and asset network functioning) factors. Understanding these opportunities and threats for individual assets and also system/strategic contexts, enables asset managers to plan ways to optimise investments for the operational context. It enables the take-up of opportunities (e.g. mainstreaming multi-functionality of services) and minimises the risks from threats cost-effectively (e.g. potential damage, deterioration of the asset, future accelerated sea-level rise).

3. Setting strategic asset management objectives and requirements

The strategic context aims to establish the desired role that flood protection assets play today and in the future, their performance objectives, and the likely investment needs (at a national, regional and system scale) in a way that delivers multi-value outcomes and that can be appropriately adapted as the trajectory of the future becomes better known. Strategic objectives, based on an understanding of the threats and opportunities, must seek to reflect local and national needs, align multi-institutional and stakeholder interests, set out the requirement performance objectives and should take into account funding, roles and responsibilities.

4. Understanding the performance of the system and system measures

Good decision-making relies upon an understanding of the behaviour of the whole system. This includes developing an appropriate understanding of:

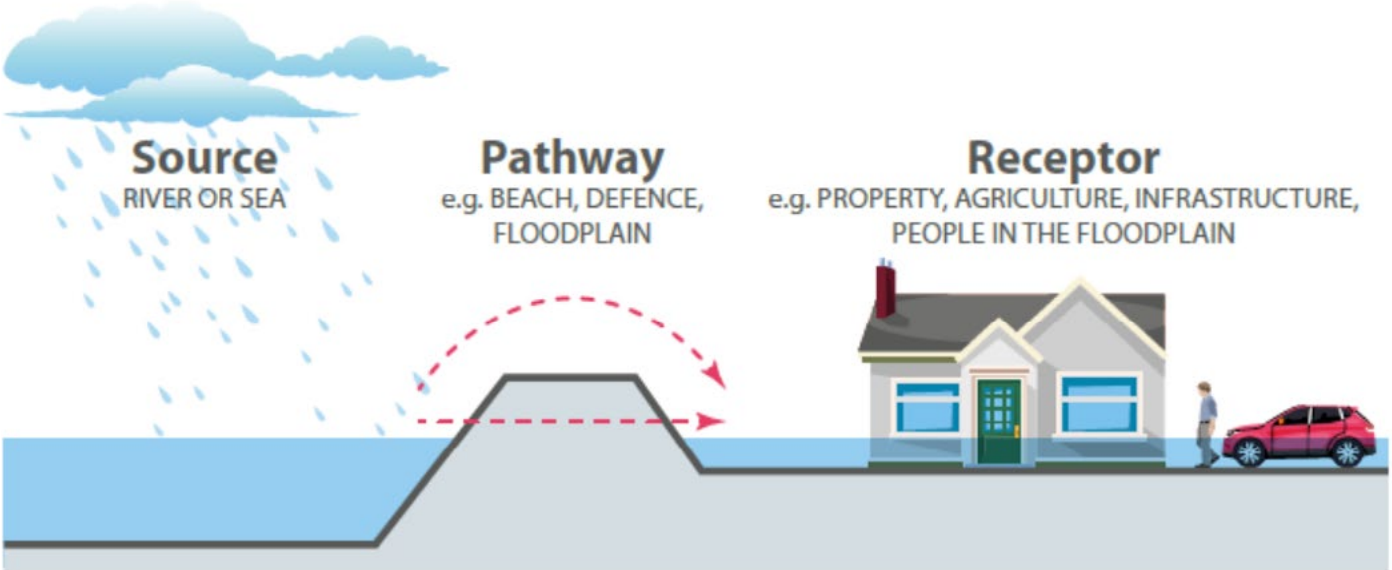
- The geographic boundaries of the system, the vulnerabilities to flooding within that system;
- The external influences that may influence the behaviour of the system over time;
- The hydrological and hydraulic functioning of the system;
- The performance of the flood protection assets in response to the loads and future climate change;
- Routine uncertainties within the data, models and model structures used to represent the performance of the system

5. Developing an adaptive asset management plan

Strategy plans should proactively plan for an uncertain future and can be modified as new evidence and insights emerge. Investments in monitoring and evaluation (assets, the loading conditions and the socio-economic setting) provide the central underpinning of the continuous process of updating both the strategy and operational delivery to ensure flood risks are well-managed and plans adapted in a timely manner.

Tool: the Source-Pathway-Receptor framework

Understanding the performance of the system can be a daunting task. To aid this process, FAIR beneficiaries have promoted the use of the standard Source-Pathway-Receptor framework (SPR).



The Source-Pathway-Receptor (SPR) framework (Redrawn from Sayers et al, 2002) [4]

The SPR framework provides a practical means of disaggregating the basic components of probability and consequence into their constituent components. Consideration is given to both the probability of the initiating event (the **source** of the flood such as rainfall or a marine storm) and the probability that flood waters will reach a particular location in the floodplain, taking account of the performance of the intervening system (the **pathway** of the flood water). The consequences should flooding occur reflects both the vulnerability of the **receptors** and the chance that a given receptor will be exposed to the flood when it occurs.

Illustrative example SPR Ribe: From static/hold-the-line thinking to dynamic planning

Traditionally, Danish asset managers have worked with fixed timeframes following national guidelines and driving operational decisions that typically lead to "hold-the-line" policies. New methods such as dynamic pathway planning are now enabling a more strategic approach to be taken. In the case of Ribe, an SPR analysis has highlighted new possible pathways for how the flood protection systems may respond, based on outside pressures on the system (climate change, urban development), planning cycles (local planning, political cycles) and socioeconomic considerations. The possible responses derive from multiple considerations such as moving the economic focus of some areas from farming to tourism, or to services. All significant assets are incorporated in the analyses and therefore they are appropriately included in the planning and decision-making process.

Integrated hydrodynamic modelling incorporating sea levels, river discharges, groundwater levels and precipitation are becoming key components in the planning toolbox, and a common understanding of the performance of all assets are important prerequisites of any future work.

[4] Redrawn from Sayers P B., et al., (2002). Towards risk-based flood hazard management in the UK. Civil Engineering 2002, 150(5), 36-42.

Operational asset management

Operational asset management encompasses all activities that ensure the individual assets and asset systems continue to perform as required and when required. Operational asset management also provides many of the data building blocks that strategic planning relies upon. Within FAIR this broad remit is considered in the aspects A-D in the FAIR framework of planning and decision contexts.

A. Measures for assets

In this component of the FAIR framework, the overall management of the assets and the measures to be adopted are defined. The measures for assets are defined and refined for each asset, using the requirements from the strategic context and passed through the tactical handshake. At least ensuring protection of assets, data and information management and preparedness for extreme events should be taken into account.

B. Design and construct

The functional requirements for the flood protection assets are implemented in the design procedures for assets. These are given as hydraulic, environmental and economic requirements or may consider a wider range of functionalities such as enabling drainage of the land behind a dike, or securing better traffic flows. In general, the key technical steps of the planning process include a review of local specific problems, the definition of design parameters for flood protection assets, the functional and constructional design of flood protection, a cross check of functionality, constructability and operational requirements and a selection of the final option.

C. Monitoring, maintenance & Operation

Maintenance and monitoring of flood protection infrastructure as well as physical operation of assets during storm events are frequently seen as the basic and most important tasks of operational asset management. Independent of the type of asset there are three main approaches to maintenance strategies: corrective maintenance, predictive maintenance and condition-based maintenance.

D. Performance of assets

The assessment of the performance is a core element in bringing together the asset (operational) and the network (strategic) oriented management of flood protection via the tactical handshake. Understanding and verifying that the performance is as required is a continuous and long-term part of the operational asset management process. A performance analysis is based on the asset condition and the targeted protection level in combination with the protected value. It should also include the performance related to multi-functionality, adaptability, cost effectiveness and possible extended lifetime of the asset. The analysis relies on information and data generated in the other operational asset management components A to C and feeds across the tactical handshake to component 1 of the strategic loop.

Tool: life-cycle costs analysis for an optimal design of flood protection assets

In life-cycle cost (LCC) analyses for optimal design the main cost-based criteria are analysed with the objective to find the solution connected to the minimum cost over the life-cycle, whilst meeting the performance requirements. Life-cycle-costs include:

i) planning and building costs;

ii) operational costs including maintenance, monitoring and inspection costs;

iii) costs of environmental impacts;

iv) repair and replacement costs;

v) decommissioning costs.

These can be divided into four categories: planned; unplanned costs; costs of ownership; and costs of usage. Life-cycle cost assessment is aimed at the selection of the most suitable and economically efficient solution from possible alternatives, fulfilling the desired requirements (functions and required safety standards for the asset at the network level) of a construction. Also consideration of any buildings' environmental impacts should be part of the LCC design process.

Illustrative example: maintenance and LCC in Hamburg

Assets, which are in round-the-clock operation (24/7), require a different maintenance strategy than those which are used only a few hours per year. For this specific case, the LSBG and TUHH developed an adaptive Maintenance Concept. The overall objective was to increase the reliability of the assets as well as reducing the maintenance costs. Furthermore, the quality of the maintenance can be sustained or even enhanced. A constant asset availability is LSBG's top priority. A well-thought-out maintenance concept, which explains the basic strategy as well as the schedules, gives the responsible people more confidence in their actions. Through standardisation, the technical framework for this can be simplified. This adaptation facilitates the easier operation and an improved long-term understanding of the assets by the operational staff.

A holistic view of the entire LCC is an essential aspect of the maintenance strategy. Important feedback from the maintenance organisation is gathered for future asset designs, in order to contribute to sustainable planning and operator concepts. The permanent improvement process is based on the goal of providing optimised and application-oriented systems. The maintenance concept developed from this describes the structure for the maintenance of the facilities in delivering the objectives. This is intended to serve as supporting guidance for all maintenance services.


DOCK 11
Blohm+Voss

Illustrative example: Dike Information System in Hamburg

In Hamburg a central module for the presentation of all relevant data of the flood protection facilities - the Dike Information System (DIS) - was developed within the FAIR project. Its goal was to provide the official supervisory authorities, planners, constructors and maintenance staff with a tool that allows them to work comprehensively. The most important aspects were to determine the data structure, to avoid redundancies, and to convert the data itself into a digital and georeferenced form, since it was often only available in paper form. The application is web- based designed. Information is thus available in the office but also on the dike, out in the field or at any other location. The city of Hamburg is currently developing a system for maintenance management that will include all assets from e.g. school buildings, cycle paths, parks and ... flood protection facilities. The information from DIS is available to this application.

This programme led to significant optimisation of the work. The process enables integrated work at one workstation without asking, searching and collecting information at different locations. This saves a lot of time and helps to reduce errors because all information is available. Importantly, the direct availability of the data enables decisions to be prepared more clearly and better. This makes it easier to avoid costly, less than optimal decisions. The process is being further developed. The data design was chosen in such a way that other applications (as front-end) can also be based on it and use the non-redundant data. With this development and the support of the FAIR project, the digital mode of operation in the flood protection of the city has been significantly improved and cost savings made.

Tactical asset management

The tactical context of the FAIR framework links the strategic and the operational loops with information and communication constantly flowing between these. It provides the link to ensure there is effective communication between strategic planning and decisions and operational activities. There is a flow of information and communication in two directions:

- From strategic to operational: The tactical context helps to link the strategic plans to establish the boundary conditions in space and time for the components in the operational context. In this 'translation' from strategic to operational delivery, prioritisation and programming are key elements.

- From operational to strategic: The tactical context ensures that knowledge about the performance of the assets (operation) as part of the overall system, is presented in an appropriate way to help the asset owner or operator to develop an adaptive asset management plan. This link from operational to strategic processes, includes the translation of performance of single assets to system/network performance.

The five primary components of the guidance used in translating strategic planning into operational processes and vice versa comprise:

- Re-evaluating the tactical handshake. The handshake needs to be made recurrently to ensure that the information such as policy and strategy is translated into delivery in operation, and that feedback is given regarding the operational feasibility of policies, and the progress with their implementation.

- Getting the right temporal and spatial scales. The strategic considerations are typically based on a larger spatial and temporal scale than the individual operational interventions. The translation in the tactical handshake includes aggregation (operational to strategic) or specification (strategic to operational).

- Enabling implementation, incorporating challenges of cross-utility and multi-functional use. Typically flood protection assets are multi-functional, meaning that different performance requirements might hold and different methods of assessment are prescribed. The tactical handshake should align and point to different requirements and desires from different functions.

- Use of appropriate metrics and assessment criteria. A major factor in the success of the tactical handshake is whether the metrics (and associated organisational processes) used for translating strategic to operational decisions are fit-for-purpose and vice-versa.

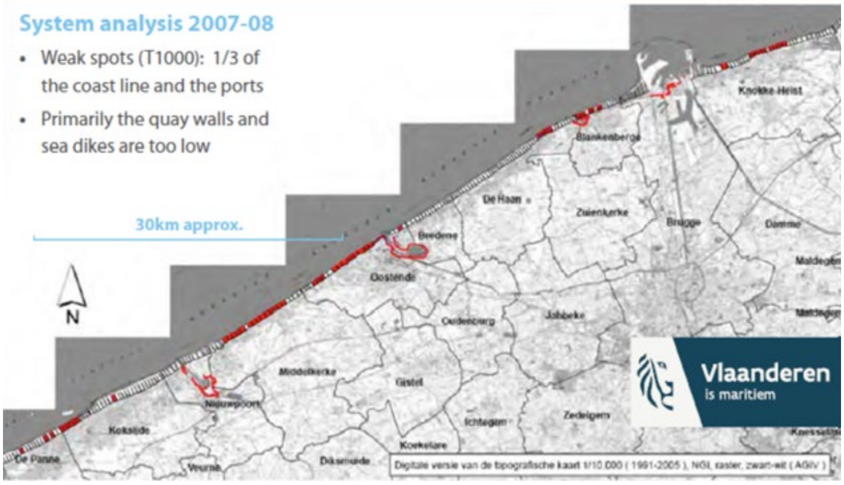
- Looking beyond the immediate management scope. A major challenge in the tactical handshake is that strategic and operational contexts of asset management may be the responsibility of different (branches of) organisations and may receive funding from separate sources. Managing diverse operators or funders is an important part of the tactical handshake.

Tool: intervention planning with ROBAMCI Tools:

ROBAMCI developed tools for Risk and Opportunity Based asset management for Critical Infrastructure (Klerk W J., den Heijer F. (2017)[5]). The tools may be used in conjunction with other assessments to derive planning and cost estimates for alternative intervention strategies. These intervention strategies provide the starting points for assessing specific intervention characteristics, such as (prescribed) maintenance frequency of individual assets. For every strategy, an optimal intervention plan can be determined in order to control the risk. The optimal strategy and corresponding prioritisation and planning process can be selected with the aid of the ROBAMCI tools.

Illustrative example Middelkerke: from strategy to asset requirements

In Belgium, the masterplan coastal safety prescribes a 6 yearly assessment of the entire coastline. The desired safety level is for a storm with a return period of 1000 years. In the 2008 assessment, one third of the coastline was found to be vulnerable (see Figure to the right). Four coastal pilot projects were allocated to address these weakest defences using different rehabilitation projects. For each project, a cost benefit analysis was carried out and different options were assessed. The cost benefit analyses and the variants were reviewed with the various interested parties, as the general funding is provided by the Flemish government, supported by funding from the local municipality for any architectural upgrades. For Middelkerke, the most cost-beneficial option was for a heightening of the beach, where the municipality proposed an expansion of the dike for tourist and economically beneficial reasons. The final selected option is for widening of the sea wall, with most of the funding from the municipality. For the other coastal projects, the preferred solutions were determined in a similar way, although, the specific requirements varied locally. For some projects, the extra cost of heightening the asset was marginal compared with the overall investment costs, and thus a lot of extra safety was achieved with little extra investment. For some of the other existing assets it was found beneficial to invest in an increase in life span; e.g. a storm surge barrier built for 100 years.



Overview of the initial weak spots along the Belgian coastline.

[5] Klerk W J., den Heijer F. (2017). A framework for life-cycle management of public infrastructure. ALCCE.http://www.robamci.nl/wp-content/uploads/2017/12/PaperIALCCE_Framework.pdf

Main outputs, outcomes and effects

The FAIR framework and its components can be used in asset management in the NSR. The FAIR pilots illustrate the beneficial effects that can result from the application of the FAIR framework. These benefits can be assessed by distinguishing different levels of results:

Outputs refer to the improved approaches, methods and guidance provided, such as the Source-Pathway-Receptor (SPR) framework[6]. The FAIR outputs enable usage by the asset owners in the context of the pilots, but also facilitate wider uptake (beyond FAIR). **Outcomes** are the improvements in existing practice, learning or other insights from the usage of the FAIR outputs. This typically means that an asset owner does something differently (behavioural change) or something better (a change in organisational maturity, see below). **Effects** relate to the broader, longer-term benefits from applying the FAIR framework. For FAIR, this will not be evident until a period of time has elapsed after the project completion.

Approach to assess the value from the application of the FAIR framework (examples shown)

The FAIR pilots illustrate how the various aspects of FAIR have come together to help to deliver more effective, efficient and practical asset management for flood protection assets. Although the pilots are from the NSR, the illustrations, showing outputs, outcomes and results, are readily applicable to other cases where flood risks are manifest and likely to be increasing.

Illustration for the operational context: flood protection Hollandsche IJssel

Outputs from FAIR: In tactical asset management, looking beyond the (immediate) management scope is of primary importance. In the FAIR pilot flood protection Hollandsche IJssel, two asset management organisations work together: the dikes along the river are operated by the regional water authority (HHSK) and the storm surge barrier is operated by Rijkswaterstaat (RWS). The dikes no longer meet the safety standard and the storm surge barrier controls the hydraulic loads on the dikes. By using a broader system approach on the entire river of the Hollandsche IJssel, HHSK and RWS together found out that the reduction of failure risk of the storm surge barrier could significantly simplify the dike reinforcement plans.

Outcomes in FAIR: By looking beyond the management scope for asset management in both organisations, HHSK was able to incorporate assets from other asset owners into the analyses. Intensive cooperation was needed and started up because of FAIR, working together on a system analysis, and taking a broad view on possible measures, such as using the flood plains, and improving the storm surge barrier.

Effects: The original costs of the dikes were reduced substantially: life cycle costs of 5%. That is: €30M savings on an amount of €600M. There is also an increase of life span of the dikes, because of using the flood plains. This may in turn result in multifunctional dikes: when heightened, the flood plains may be of use for nature.

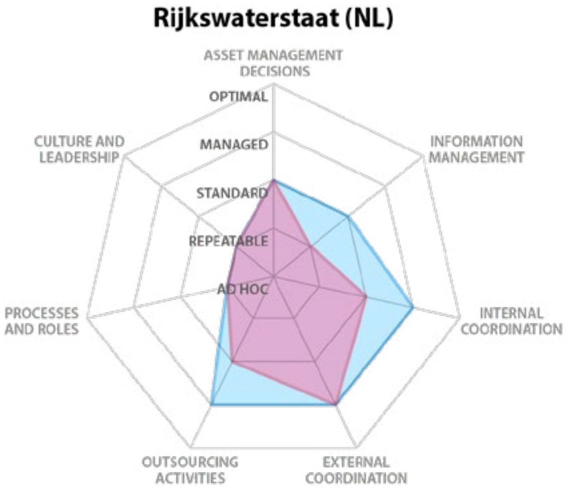
[6] SPR was not developed in FAIR. But FAIR drew the beneficiaries attention to the value of adopting the approach, hence it is classed here as an output.

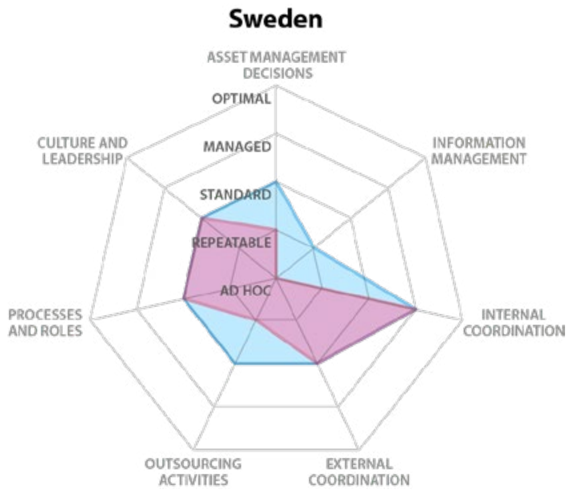
Maturity of the organisations and asset management processes in FAIR

The Framework has been used in FAIR for the beneficiaries to assess their own position regarding their internal processes for management of flood protection assets. Undertaken using a 'maturity analysis' defined for the assessment of how different dimensions or processes within an organisation are able to contribute to a set of pre-determined organisational outcomes[7], the beneficiaries were able to self-evaluate their individual progress in enhancing their asset management processes during the project. A seven-fold Infrastructure Management Maturity Matrix (IM3) was utilised:

Maturity Dimension	Description
1. Asset management decisions	The use of risk management methods and life cycle approaches in decisions at strategic and operational asset management contexts.
2. Information management	The availability and use of (standardised) static and dynamic data-bases for decision making
3. Internal coordination	Coordination and problem solving between the different departments of the organisation
4. External coordination	Coordination and problem solving between the different stakeholders of a project, including communication with users
5. Outsourcing activities	Strategy about and implementation of integrated and performance based contracting and innovative procurement methods
6. Processes and roles	Clarity, definition and implementation of job responsibilities and roles within the organisation
7. Culture and leadership	Level of knowledge, implementation and support of asset management related issues

Two maturity self-assessments were carried out to track whether or not there had been changes in maturity of each of the beneficiaries: the first, a baseline round, in Summer 2017 (red lines below), and the second, an assessment in September 2019, in the last year of the project (blue lines below). Examples for two beneficiaries are shown below, for scales from 0 - Ad hoc (centre of the diagrams) to 4 – optimal (outer limit of diagrams) asset management processes.





The maturity improvements for the Dutch beneficiaries (including Rijkswaterstaat) were the result of innovative FAIR insights, specifically on 'information management' and 'external coordination'. Leading to a shift to a system-wide and strategic perspective, from a single organisational one, over the project duration. Other beneficiary improvements were due to a number of factors including the implementation of ISO standards (e.g. ISO 55000:2014); better coordination due to management change (leadership); Investment management system implementation (government wide); greater clarity of the indicators delivered, and clearer view of the problems; helping to understand the details and costs; greater openness to innovation on the part of organisations to the ideas of specialist consultants. Overall the maturity analysis was deemed to be helpful for organisations in understanding better their existing AM processes and how these could be improved.

[7] Volker, L., et al., (2013). Asset management maturity in public infrastructure: the case of Rijkswaterstaat. International Journal of Strategic Engineering Asset Management 3, 1, 439-453.

Challenges and the way forward

In the context of flood management, an adaptive asset management approach aims to optimise the performance (i.e. value) of flood protection infrastructure at the lowest total cost to the asset owner or operator, whilst providing the best value to society as a whole. However, in reality, a compromised approach is often employed, including accepting sub-optimal performance or using cost-effectiveness as a measure. This is because there are several key challenges for the adoption of an adaptive asset management approach throughout the NSR, which are explained and addressed in the FAIR Policy Brief[8]:

- The institutional context for asset management is often fragmented
- Funding is constrained, especially for maintenance and monitoring
- Strategic planning and operational processes are often misaligned
- Decisions taken today may not account for long-term implications
- Innovation is not consistently embedded in standard practice

Several topics have been identified in the FAIR project by the beneficiaries as considered important to shape the future direction of asset management for flood risk infrastructure and for which knowledge is lacking. These knowledge gaps are addressed in the FAIR knowledge agenda[9].

[8] A perspective on the future of asset management for flood protection - A Policy Brief from the Interreg North Sea Region FAIR project

[9] link to the FAIR knowledge agenda

Gap	Question	Brief description
A. From (big) data to information	How can we better know where assets are, their condition, and measure asset performance and deterioration, and therefore better understand asset dynamics over time?	Relates to knowledge required to determine what data has to be collected and how it has to be interpreted such that it yields the required information both on assets and the socio-economic system these assets serve.
	How can we translate Big Data on all aspects of asset management into good quality and valuable information for decision making?	Multi-disciplinary challenges require data analyses that are fit to combine different data sources.
B. From uncertain information to asset management policy	How do we take robust and adaptive decisions now with uncertain and changing information about the future?	Every flood defence manager struggles with the uncertainties when looking to the future, whilst accepting the need to live with uncertainty and build it into decision making for asset planning, design and operation.
C. From asset management policy to action	How do we manage our organisation(s) to efficiently translate asset management policy into actions?	The realisation that climate and other drivers are changing faster than the lifetime of individual assets means that existing arrangements may need to be reconfigured to adaptive ones.
D. From stakeholder to shareholder	How do we engage relevant key stakeholders in asset management as shareholders, thus creating innovative financing opportunities and (better) sharing of risks?	Asset management should focus on multi- functionality to address the multi-sectoral challenges beyond flood risk that climate change brings. This requires collaboration with a much wider group of stakeholders with a variety of different interests.
E. Engaging Society	How do we engage with society in the way needed to ensure that assets are delivered and managed in the best way?	Effective and mutually beneficial engagement with communities is more important than in the past, especially to help people to understand the need for flood risk management measures and the need to use and maintain these in response to climate change.

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Further reading

The documents relating to the FAIR project can be found on the following websites:

http://www.fairproject.org/

https://northsearegion.eu/fair/

This includes the following FAIR documents:

- End report: Results of FAIR, illustrated by examples from the pilots.
- Pilot reports: Results and lessons learned for the individual pilots in Belgium, the Netherlands, Germany, Denmark and Sweden.
- Knowledge agenda: Identified knowledge gaps in FAIR and suggestions to overcome them.
- Policy brief: Four policy recommendations to improve flood protection asset management in the NSR.

Partners

FAIR brings together Asset Owners (facing real problems and challenges) and leading scientists (with domain expertise) to share and develop innovative solutions to the management of flood protection assets. In doing so, FAIR is the first collaboration of its kind.

Back to Further Reading

Interreg
North Sea Region
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Adaptive asset management for flood protection

A knowledge agenda for 2020 and beyond

June 2020

Summary

Asset management policy, process and practice has evolved significantly in recent decades. However, much of the knowledge relates to products, artefacts and value generation for producers. Although there are numerous useful guidance documents and best practice examples related to water management systems and flood protection infrastructure assets, there is much that is still unclear about how best to plan, deliver and manage flood protection assets in a way that these are sufficiently flexible and adaptable to cope with the significant environmental and societal changes underway. The partners in the FAIR project, situated around the North Sea Region, have both unique and commonplace challenges in managing their assets, for which new and ongoing knowledge developments and understandings are needed. Not least, they need to know when to act or when to wait for new knowledge and understandings to emerge about asset management for flood protection.

What is known is that the process and practice of asset management for flood protection needs to be continually reviewed and when necessary, adapted in response to the changes in insights about the interplay between environmental dynamics and societal needs. Effective asset management requires risk management and flexibility over the lifetime of the asset, aiming for an optimal balance between whole-life total risk, total costs and benefit-costs. To make this possible, assets need to be designed to be adaptive and flexible, using integrated system-level and strategic perspectives. As nature-based assets are invariably more flexible and multi-functional than traditional structural assets, natural and nature-based, or hybrid solutions should always be considered during the design phase using as holistic a cost-benefit analysis as possible. Inevitably this will incur increased analysis and transactional costs (in dealing with the more complex analysis and many more stakeholders involved), but this will often be offset by the increased flexibility, reliability and functionality of the assets that such approaches will bring.

These characteristics and approaches should ensure that asset management can keep pace with the demands of an increasingly complex environment, with an increasing variety and range of available data (and therefore uncertainties), conflicting stakeholders, and a society that is becoming more critical about the necessity of certain types of development.

Therefore, it is crucial to develop technical (like big-data approaches) as well as social innovations (like stakeholder alignment and citizen involvement). Only then, will we be able to provide and sustain the assets needed to address the challenges that climate change and socio-economic growth will bring.

This Knowledge Agenda considers the main challenges and knowledge needs identified in the FAIR project regarding effective asset management for flood protection, framed around a structure derived from ISO 55000:2014. Further background is provided in the project End Report. Here, five main knowledge gaps are identified, with six associated questions. The agenda will interest developers of guidance and practice for asset management for flood protection and flood risk management.

Contents

Preface

This knowledge agenda outlines the knowledge gaps in the field of adaptive asset management (AM) for flood protection (FP) infrastructure, which will help to inform research and development direction in future projects. As an output of the Interreg FAIR project, this document is collectively developed by an international consortium for the North Sea Region (NSR), from Denmark, The Netherlands, Belgium, Sweden, Germany and England and Norway.

The FAIR cascade: from (big) data to informed and inclusive decisions

The agenda presented here is structured using the AM key terms, derived from ISO 55000:2014[1] (Figure 1), which illustrates a cascade from the portfolio of assets, to the AM systems (policies, tools, plans and information systems) that give assurance that the AM activities will be delivered. The organisations should be managed in such a way that the AM systems, and therefore the actions, are implemented as optimally as possible, including facilitating adaptation. In the FAIR project another layer, engaging society at large[2], has been added to address the increasing interaction between organisations and the wider community the assets are serving.

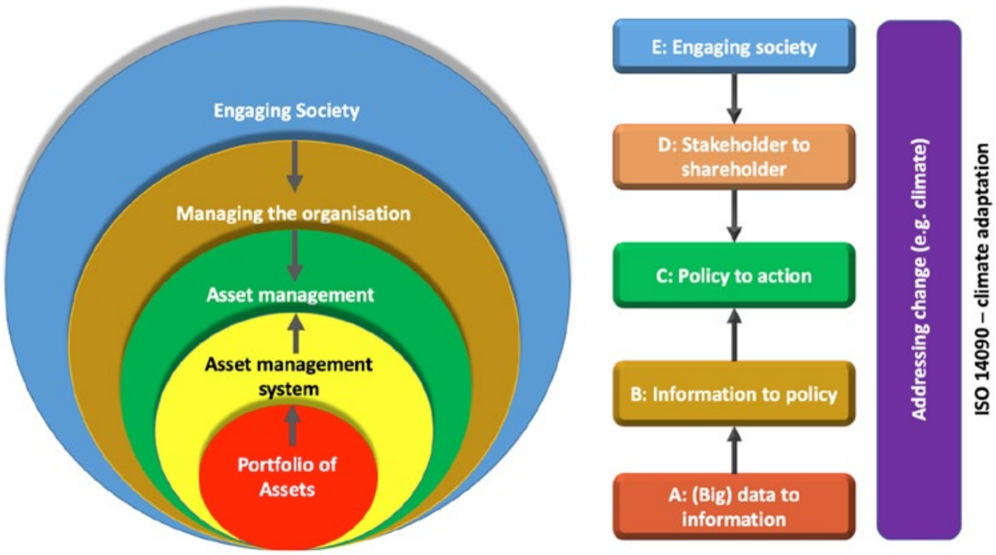


Figure 1 Left: Asset management key terms, derived from ISO 55000:2014. Right: the different categories that have been defined for this knowledge agenda.

[1] ISO, T., & SC, N. (2014). Asset management—Overview, principles and terminology.

[2] Of course, policy and decision makers, experts, shareholders and stakeholders are actually part of and embedded in 'society'. Also representative thereof.

Innovations in asset management concepts

A major innovation from the FAIR project is the bridge between the operational (focusing on day-to-day measures and activities) and strategic (corporate and long-term view) contexts for AM, using a 'tactical handshake' that ensures effective interconnections between the two loops as illustrated in the infinity shape shown in Figure 2.

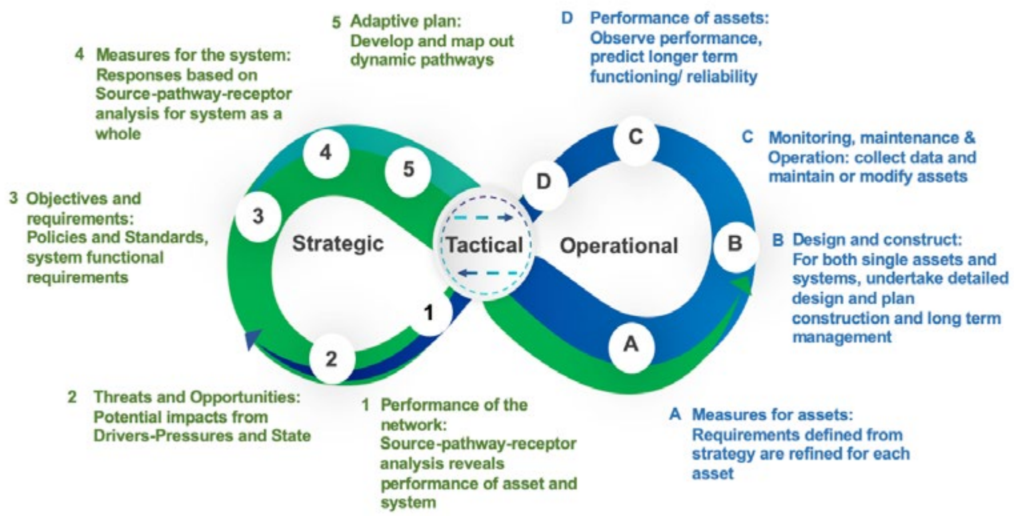


Figure 2 The three FAIR planning and decision contexts that define the framework used in the project.

Central to all aspects shown in the framework are the three main dimensions of analysis: costs, performance, and (related to the latter) risk. Embedded in each of the components shown in the framework in Figure 2 are the organisational, legal and financial aspects of each process and loop. Typically, delivery of effective AM via all of the components in Figure 2 requires strong communication between often disparate and increasingly, a widening range of players. These players include the various different 'cultures' engaged in strategic planning together with those engaged in operational processes. The traditional segregation between 'planning' and 'doing' needs to be broken down if effective AM is to be delivered. Effective AM needs to embed the ability to adapt assets and AM processes, as this will be essential for future response to change.

The FAIR project has clearly demonstrated that a life-cycle approach to AM is crucial, for which the three contexts and the organisational aspects are embedded not only at the design stage, but throughout the asset lifetime.

Assets should be designed for optimal functionality and maintained using a risk-based approach (preferably with a system-perspective), combining the probability of failure of the asset, together with the impact therefrom. Best practice AM will therefore be risk-based and include a whole-life performance[3] perspective, i.e. a lifetime risk trajectory, and a whole-life cost[4] understanding. AM is always a balance between capital expenditure and operation/ maintenance required to maintain the functional condition of the asset; i.e. delivering acceptable risk over the lifetime of the asset portfolio. Numerous frameworks are available that provide guidance towards achieving this such as that shown in Figure 3[5].

3 Literally cradle to grave – from creation of the asset to its' eventual abandonment and removal/recycle; although new ideas are moving to a cradle-to-cradle perspective based on circular economy thinking.

4 Discounted net present value (NPV) over the lifetime of operation, including both capital costs and operational/maintenance/intervention costs

5 Defra et al., (2019). Asset Performance Tools – Project Summary SC140005/S

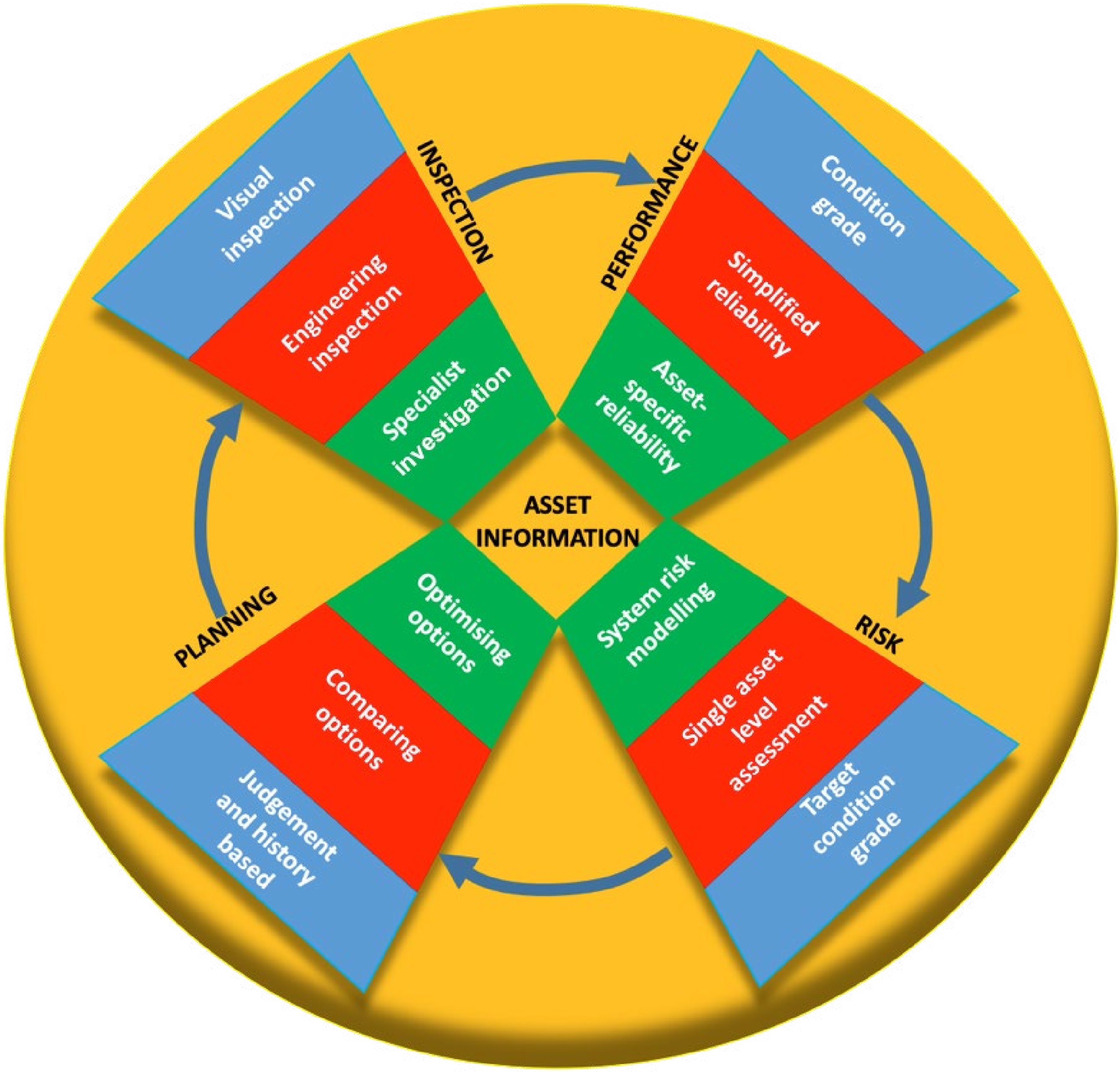


Figure 3 Example of a framework to facilitate proactive asset management (adapted from Defra et al., 20194)

This Knowledge Agenda considers the need for new or enhanced knowledge beyond 2020 that is needed in order to deliver and maintain adaptive assets and to ensure that AM processes are themselves adaptive and flexible enough to face the future challenges. This is set out in terms of five topic 'gaps' (A-E, Figure 1) and six (1-6) associated questions as summarised in Table 1. Examples from the FAIR pilot projects addressing the gaps and questions are also shown. Reference should also be made to the challenges identified in FAIR in the End Report, in Chapter 8.

Some of the topic gaps could be merged, for example, D and E in Table 1, however, these have been differentiated as they relate to the categorisation, based on ISO 55000: 2014, as shown in Figure 1. The Gaps and Questions are considered in more detail in what follows.

Table 1 Knowledge Gaps, associated Questions and FAIR pilots

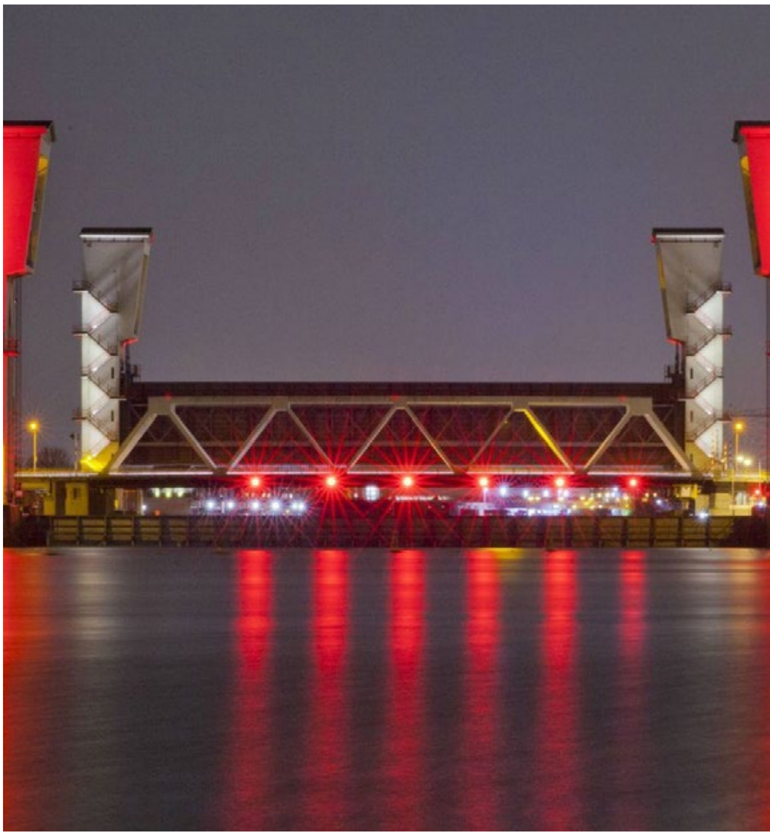
Gap	Question	Example from FAIR beneficiary pilot case studies
A. From (big) data to information	1. How can we better measure asset performance and deterioration, and therefore better understand asset dynamics over time?	FP gates Hamburg: Analysis and documenting asset maintenance processes based on collected data, using long-term experiences of the personnel, questioning of manufacturers' maintenance requirements and failures. Led to revision of data management, maintenance processes and frequency, based on computational analysis to develop risk-based operation.
	2. How can we translate Big Data on AM into good quality and valuable information for decision making?	As well as the immediate actions for FP Hamburg, in (1) above, the long-term collection of data covering all assets and aspects of performance has now been standardised to support ongoing risk based operation. Processes for turning this into useful information are being developed.
B. From uncertain information to AM policy	3. How do we take robust and adaptive decisions now with uncertain and changing information about the future?	Renewing sea dike Middelkerke using natural beach processes provides both robustness (utilising natural processes known to work) and adaptable potential in the future as knowledge increases about future conditions. Ongoing development and monitoring will ensure that as asset performance is observed, defects and shortcomings can be addressed in real time.
C. From AM policy to action	4. How do we manage our organisation(s) to efficiently translate AM policy into actions?	Helsingborg integrated city planning now brings together the range of planning processes for infrastructure, including FP, as well as other systems like transport. AM policy is therefore include across all systems and services in the development of the final city plans. However, many institutional arrangements for FP are complex and bound in such a way that these prevent or inhibit efficient operation and planning. The FAIR maturity assessment process can help organisations to understand where there may be grounds for improvement.

D. From stakeholder to shareholder	5. How do we engage relevant key stakeholders in AM as shareholders, thus creating innovative financing opportunities and (better) sharing risk?	As well as (4) above, FP Hollandsche Ijssel is now bringing together the main players in partnership to deliver an integrated cross-institution FP programme, providing shared funding, shared risks and more efficient assets. But this as yet, is a specific instance that needs to be used to ensure that such partnering becomes normal, even beyond FP, into other asset domains where this can help to share or reduce risks and pool finance.
E. Engaging Society	6. How do we engage with society in the way needed to ensure that assets are delivered and managed in the best way?	Ribe Polder is typical of FP in Denmark, as it closely involves landowners and communities of all sizes, with local dike associations operating sluices. Many citizens are at flood risk in the city due to the adjacency of the sea and also the river, which backs-up. Although analysis of the problems has so far engaged only the main institutions, direct citizen engagement will also be an essential component of developing the FP plans. There are few good examples of effective engagement as yet and more development is needed to provide standardised, or collectively agreed best means of engagement.

Gap A: From (big) data to information

This gap relates to knowledge required to determine what data has to be collected and how it needs to be interpreted such that it yields the required information both about the assets themselves and also for the socio-economic system(s) the assets serve. The Gap relates to both the operational and strategic contexts in the FAIR framework, Figure 2. In the Policy Brief it relates mainly to Recommendation #1: Align multiple planning processes within and beyond flood management.

Question 1: How can we measure asset performance and deterioration, and therefore better understand asset dynamics over time?



FAIR beneficiaries expressed the view that relatively little is known about the deterioration of various types of assets under specific conditions and pressures (for example the UK[6]). The assets should be represented by profiles of performance and costs over time that also shows the effects of interventions. Profiles should be developed for both individual assets and also groups of assets, e.g. the performance of an individual dike and the performance of the dike system, which the dike is part of. This needs to keep in tune with the understanding of societal needs and expectations of performance; i.e. the asset condition and performance profile needs to match the changing needs over the lifetime of the asset.

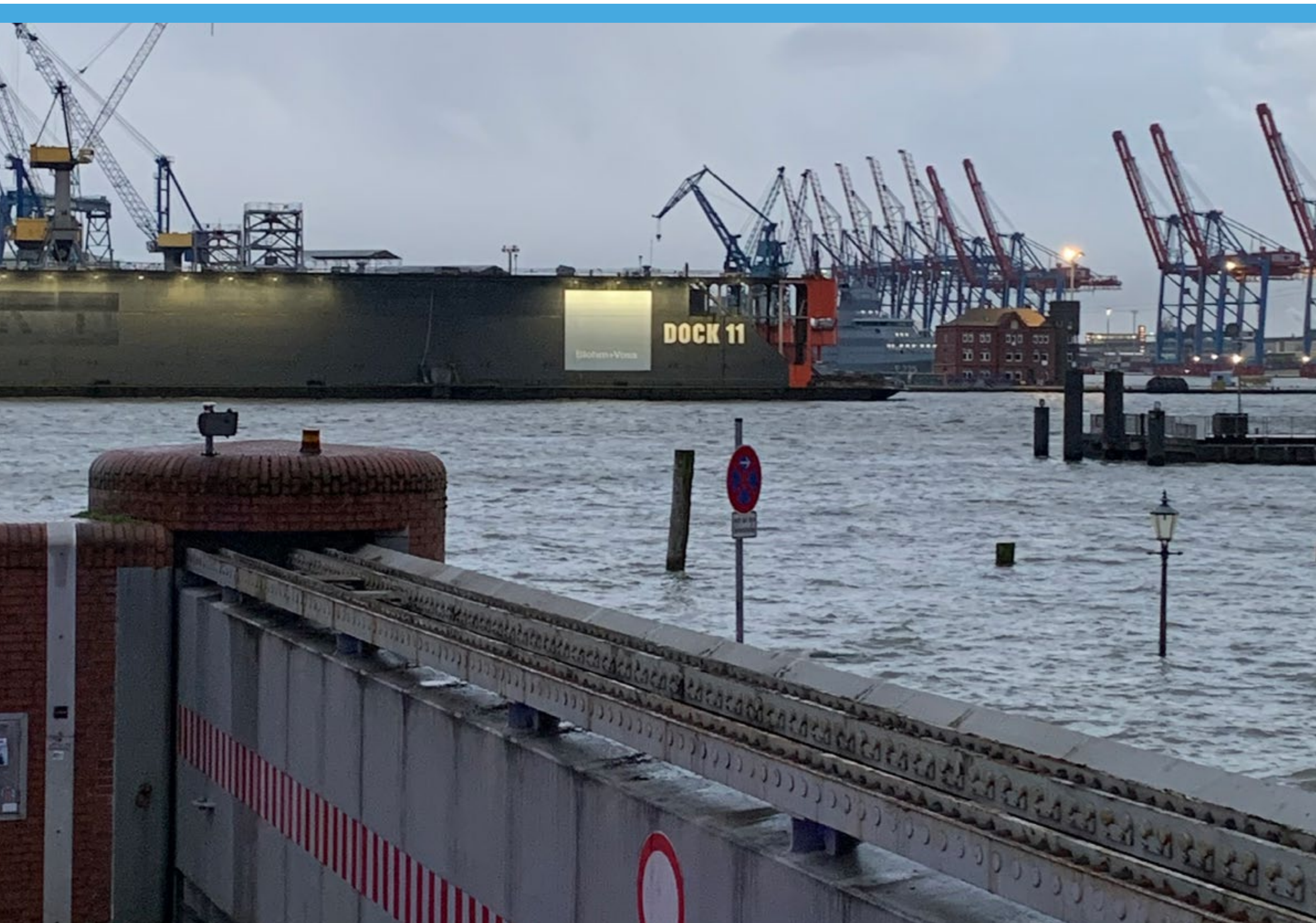
In addition, there are very fundamental questions about existing assets and the need to begin by ensuring that details are known, including: (i) where the assets are; (ii) what is their condition; (iii) what are the asset performance characteristics; (iv) how fragile are the assets? Figure 3 shows various forms of obtaining asset information, from simple visual inspection (that is often misleading) and unless standardised may be counter-productive, to more complex, thorough and costly processes. FAIR beneficiaries collectively have had varying experiences and approaches to data collection about assets they own or operate, in some cases leaving this to contractors (e.g. FP gates Hamburg), and including or not, standardised inspection and data management systems, as in England[7].

[6]Deterioration: "we know less than nothing"- http://evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM/Project.aspx?ProjectID=48961F27-F4B6-4234-865B-EF60FB701020&PageId=a0fe6dfc-506a-452c-9bff-a7ec06b4e6b0

[7]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/779807/Flood_risk__asset_performance_tools_-_report.pdf.

Germany: Greater efficiency in operation and maintenance using past and future data and information in Hamburg

As part of FAIR, the continuing operation of the FP gates for Hamburg has been reviewed and now a more condition-oriented maintenance strategy is being implemented based on data from employee experience, the condition of the facilities, the legal framework for operation, the available resources and operational requirements defined from a risk-based assessment. As part of this, FAIR has helped in defining the best way to document existing historical data in a structured manner and set up a system to maintain direct access to all asset-related data as this continues to be gathered into the future (See information on the Dike Information System (DIS) of the FAIR Hamburg Pilot in Chapter 5 of the project End Report).



There are growing opportunities for utilisation of new sensors, digital hardware, and processing power that are resulting in increasing streams of data becoming available, as illustrated by the utilisation of a range of sensors in the dike information system in Hamburg FAIR pilot, as explained in Chapter 5 of the End Report. An integrated and shared approach for data is being taken in Hamburg between key players. But elsewhere, much of the important data may be collected and held by others, not the FP or flood risk management (FRM) operators and managers, including power suppliers, transport operators including navigation, recreational and fisheries domains. Therefore, it is important to ensure that appropriate linkages and partnerships are in place to both decide on what data are needed and also how best to share data and information across all responsible players and utilities.

Question 2: How to translate (big) data on AM into good quality and valuable information for decision making

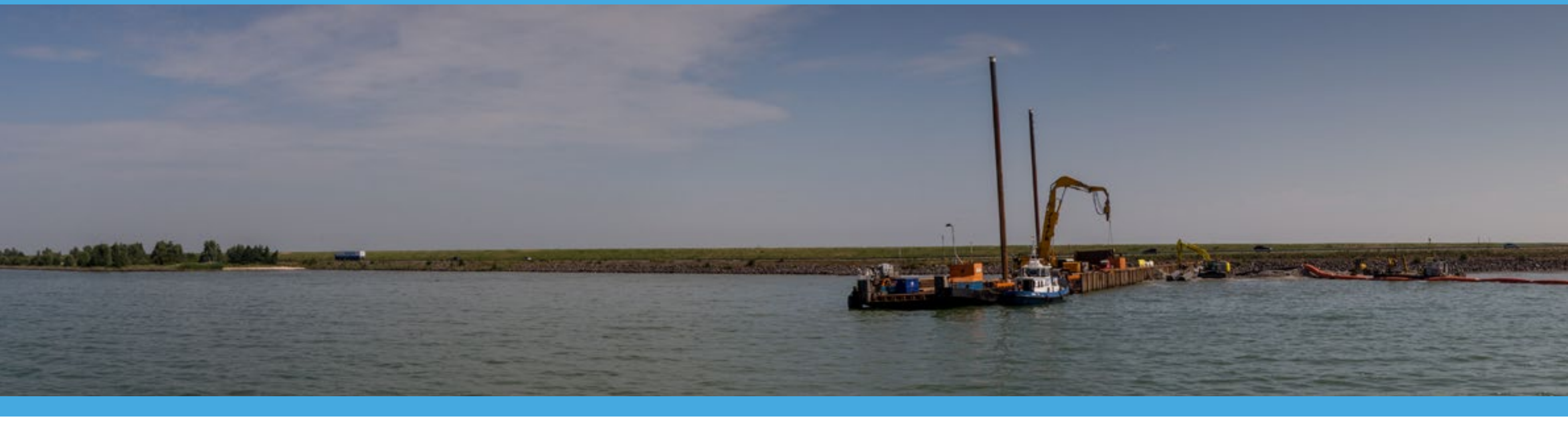
This Question relates primarily to Recommendation #1 in the Policy Brief: Align multiple planning processes within and beyond flood management.

Question 1 considers the need for adequate data and its' acquisition, here it is the scale of data and how best to manage this that is the challenge.

FP depends on knowledge of the environmental conditions experienced by the assets as well as about the condition of the assets. Question 1 was focused on the local aspects of data needs and management for specific assets or asset groups. This information and the supporting data is set within a context of regional, national and even global data and information.

For example, climate change trends are best observed and understood on a global scale, whereas the consequences need to be understood more locally, nationally and regionally. National scale data collection provides important records of local environmental conditions, including natural processes such as weather, sea and wave conditions, as well as public interactions and institutional organisation, operation and management processes. Another major challenge is how to deal with the current assets, that are often end of technical and/or functional life. For example, asset owners need to be able to determine the short-term performance of their assets and systems. This information is also needed to prepare for challenges of the future.

For asset owners and operators in FAIR, the nationally collected data, interpretation and use to inform policy making and decisions relating to FP provides the backdrop to managing local FP and the required assets. Each FAIR beneficiary has considered the project in the context of their nationally defined climate changing predictions and implications for future impacts. For example, the relative rates of sea level rise are predicted to vary around the NSR, by up to half a metre[8] in this century. The FAIR beneficiaries needed to understand and use this information as well as locally observed data and information in planning and operating their FP assets in the project. Climate data is just a part of the overall stream of information that is available both online and from direct measurements and observations of environmental, structural, economic, social and other sources related to FP. For asset managers, understanding where the data are, availability, usability, veracity and how this can be utilised in terms of local AM is a challenge. Also, how best to set up individual data collection programmes and the processing of the data from the various sources, given that there are as yet few examples of applications to FP AM.



[8] Richards J A., Nicholls J. (2009). Impacts of climate change in coastal systems in Europe. PESETA-Coastal Systems study. European communities, JRC 55390. EUR 24130 EN. ISBN 978-92-79-14627-5.

This wealth of available (Big) data is defined as: "the information asset characterised by such a high volume, velocity and variety to require specific technology and analytical methods for its transformation into value[9]". Big Data Approaches (BDA) are becoming increasingly recognised as valuable in AM. Few FAIR beneficiaries are as yet taking advantage of access to this new wealth of data in ways that can best help with AM.

BDAs bring together historical datasets with dynamic incoming data in order to generate information and knowledge about environmental and socio-economic drivers (e.g. weather and climatic conditions), asset condition and asset performance. The increasing availability of (big) data from multiple disciplines and sources needs to be used to improve AM processes for FP. BDA can help understand the sources (of a hazard), its pathways and impacts on vulnerable receptors.

Data is coming from many different sources and disciplines, and current multi-disciplinary challenges require BDA that are fit to combine these different data sources. But BDA techniques are only just starting to get to grips with the challenges in single domains, let alone what is really required spanning utilities including power suppliers, telecommunications to FP. This integration between domains is a future challenge for BDA specialists and domain specialists[10].

The Dutch Datalab (see example below for the FAIR Lead Beneficiary, Rijkswaterstaat) and similar initiatives may be used to support the further optimisation of AM processes and decisions and will become a major component of, and benefit from, the new generation of IT creation of digital twins[11], that can better help understand the performance trajectory of an asset in real time.

The Netherlands: A datalab for managing big data

Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and Water Management) continually handles a substantial amount of incoming data from different sources. Ranging from weather data from 330 weather stations, water heights, road sensors, and many more. Rijkswaterstaat launched a dedicated 'Datalab' to handle and use this data in an efficient way (e.g. with machine learning techniques). This datalab specialises in data from infrastructure assets, like bridges, storm surge barriers (e.g. Oosterscheldekering and The Maeslantkering), tunnels and sluices. It can be used to disseminate the BDA approach to other countries, that have the same challenges, to fully utilise the opportunities big data will bring on a European level.

[9] De Mauro, A., Greco, M., & Grimaldi, M. (2016). A formal definition of Big Data based on its essential features. Library Review, 65(3), 122-135.

[10] Stevens J., et al., (2020). Interlinking Bristol Based Models to Build Resilience to Climate Change. Sustainability 2020, 12, 3233; doi:10.3390 su12083233Review, 65(3), 122-135.

[11] Rotterdam is in process of creating a digital twin of the physical city. [Coumans F. (2019). 'Digital City Rotterdam' Anticipates Human Life 2.0. November/ December 2019 | GEM international. 22-24. https://www.gim-international.com/magazine/november-december-2019

Gap B: From (uncertain) information to AM policy

This gap concerns the link between information and policy in regard to AM. Information will flow mainly from the operational loop in the FAIR framework, Figure 2, via the tactical handshake to the strategic context where policy is formulated and also, when provided from an external source, translated into local AM processes. Given the apparently increasing uncertainty about the future, dealing with this is a major challenge. It relates primarily to Recommendation #3 in the Policy Brief to: Develop strategies that are flexible and assets that can be modified; and Recommendation #4: Accept that new approaches attract risk but managing, rather than avoiding, risks can lead to innovative solutions.

Question 3: How do we take robust and adaptive decisions now with uncertain and changing information about the future?

Effective AM requires risk management over the lifetime of the asset, aiming for an optimal balance between whole-life total risk, total costs and overall benefits. Even with monitoring, data and real-time systems, there are continuing and important uncertainties in planning AM.

Every FAIR beneficiary has had to consider the uncertainties about their existing assets (Question 1) and also when looking to the future. They accept the need to live with uncertainty and build it into decision making for asset planning and operation, using e.g. probabilistic modelling. An ongoing challenge is in understanding how both too much information and a lack of information can influence the policy and decision-making processes. A lack of information is self-evidently an impediment to effective decision making. But, presented with too much information, policy and decision makers can struggle with understanding, especially when faced with the varying degrees of uncertainty associated with different information. A major challenge here is for professionals and asset operators to synthesise information in such a way as to make it understandable by various stakeholders, but without losing any of the important messages. This may require presenting the uncertainties in simplistic ways, for example, using betting odds.

Belgium (Middelkerke): How to make decisions without precise data

In the FAIR project Middelkerke-Westende (Belgium), life-cycle costs (LCC) of the construction and maintenance of a dune system have been estimated. Although the investment costs were known, the maintenance cost estimates for ensuring the dunes provide functionality was uncertain, as performance depended on a variety of factors (e.g. wind, waves, temperature, and precipitation). LCC calculations were highly uncertain due to the lack of knowledge about the changes in natural systems, such as dunes, over time. This knowledge gap had to be addressed by bringing together the expertise of a number of groups of professionals and others, as the best way to understand the likely system performance over time, and improve knowledge and practice.

It is not only the uncertainties in the asset behaviour that are important for effective AM, but also the uncertainties in the socio-economic and environmental factors[12]. Climate and other changes are increasingly being understood to be relatively rapidly changing, with usually greater extremes of the natural phenomena important for FP being predicted from trends in observations[13]. It is therefore important to always take a system-approach, to look at all the assets in a system and the socio-economic conditions in which the assets are providing a service, instead of looking only at one asset or one type of driver. This raises the following important question: how can information give the required support (by reducing uncertainty) to decisions related to whole-life total risk, total costs and benefits, not only for one asset, but also for a system of assets?

The ISO 55000 series says little about uncertainty and it is necessary to look beyond the AM domain for perspectives on and means to manage uncertainty in FRM. Ideas for how BDA (see above) may help to get to grips with aspects of uncertainty are considered in detail elsewhere, for example[14]. Many scientists stress the importance of ensuring flexibility in both the approach to AM and also in the assets themselves as essential to cope with uncertainty. It is worth noting that natural and nature-based systems[15] invariably have greater flexibility than structural infrastructural assets; though flexibility is increasingly being built / designed into structural infrastructure assets. The increasing utilisation of hybrid systems, where both structural and nature-based assets are used together[16], will also bring a new set of uncertainties into AM.

More work is needed on informing and influencing how decisions may best be taken now in the light of such uncertainties and especially the appropriate place of both stake and shareholders (see Question 5 'from stakeholder to shareholder') in the process.

[12] Hino H., Hall J. W. (2017) Real Options Analysis of Adaptation to Changing Flood Risk: Structural and Nonstructural Measures. ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civ. Eng., 2017, 3(3): 04017005.9

[13] Krona W., Löwa P., Kundzewicz Z W. (2019). Changes in risk of extreme weather events in Europe. Environmental Science and Policy 100 (2019) 74–83.

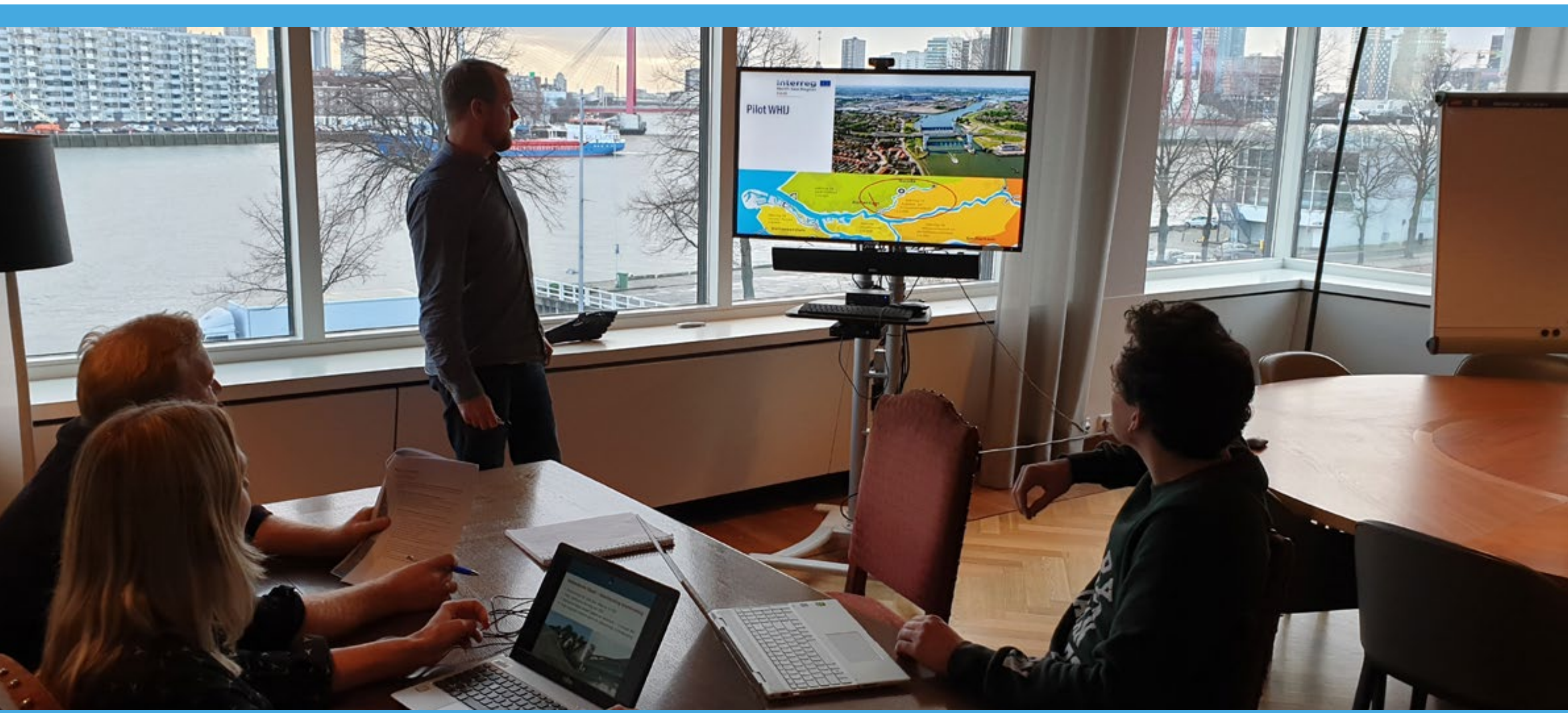
[14] Connelly E B., et al. (2017) Asset Risk Management and Resilience for Flood Control, Hydropower, and Waterways. ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civ. Eng., 2016, 2(4): 04016001.

[15] City of Virginia Beach, Virginia (2019). Nature-Based Coastal Flood Mitigation Strategies. CIP 7-030, PWCN-15-0014, Work Order 6C. Final Report May 16th.

[16] Kapetas L., Fenner R., (2020) Integrating blue-green and grey infrastructure through an adaptation pathways approach to surface water flooding. Phil.Trans. Roy. Soc.A. 378:20190204.

Gap C: From AM policy to action

This Gap considers the need to ensure that AM policy is translated into action and is illustrated in the FAIR framework (Figure 2) by the tactical handshake linking the strategic and operational contexts. The Question/ challenge is about managing organisations in the most effective way to deliver effective AM, and in FAIR, the beneficiaries have reviewed their own organisational processes via the Maturity Analysis as explained in Chapter 3 of the End Report. The Gap relates mainly to Recommendation #1 in the Policy Brief: Align multiple planning processes within and beyond flood management; and Recommendation #2: Link strategic planning and operational processes through a tactical handshake.



Question 4: How do we manage our organisations better to efficiently translate AM policy into actions?

In ensuring that citizens are safe and healthy from flooding and its' affects, the NSR countries have a variety of governance, regulatory, institutional and less formal arrangements in place. Each of the FAIR partner countries has a different and unique arrangement for this (Table 2.1, End Report). For some, there is a main role for central government, whereas for others, the flood risk response functions are primarily at a local level[17]. Every country also has expectations of citizens, that they take some part in ensuring their own safety.

[17] e.g. Jebens M., Sorensen C., Piontkowitz T. (2016). Danish risk management plans of the EU Floods Directive. E3S Web of Conferences e3sconf/201, DOI: 10.1051/ 6. FLOODrisk 2016 - 3rd European Conference on Flood Risk Management.7 23005 (2016) 07230

Organisational and institutional arrangements need to be configured so as to ensure that they are set up in a way that allows them to be efficient and effective and changed, adapted, or even fundamentally reformed if necessary (including termination of institutions where necessary), i.e. they need to be agile; facilitating fit-for-purpose adaptive and multi-functional AM, including for the use of nature-based measures[18]. Organisations also need to be able to respond to 'opportunity windows' when these arise, due to, e.g. a major flooding event, that will provide the means to bring about changes in policy or in the way assets are managed[19].

Cross-sectoral collaboration within and between organisations is essential, as is interdisciplinary working, as described by Rogers et al[20]. Flexibility needs to be supported by the organisations' strategy, including flexible financing mechanisms that allow for budget changes if certain adaptations are needed which were not initially considered in the budgetary processes. Traditionally, FRM organisational processes are arranged in governmental, rather than private sector organisations, although these may provide specialist services and assets[21]. Much can be learnt from how businesses can use an agile approach in informing the best ways to organise the management of flood risk assets and in delivery, which is often impaired by overly burdened internal audit or approval processes.

There are various frameworks that may be used to assess the fitness-for-purpose of the institutions involved[22] and their potential to embed adaptive approaches within their AM processes[23] as well as their organisational effectiveness[24], such as the Maturity Analysis used in FAIR (Chapter 3 in the End Report).

[18] Himmelberger H. & Yang A. (2020) Maximize Asset Management's Triple-Bottom-Line Benefits. Journal AWWA, Engineering and Construction. January 2020, Vol.112, No.1, 71-74.

[19] Hopkins K G., et al (2018). Influence of governance structure on green stormwater infrastructure investment. Environmental science & policy. 2018, Vol.84, p.124-133.

[20] Rogers B., et al. (2020) An interdisciplinary and catchment approach to enhancing urban flood resilience: a Melbourne case. Phil.Trans. Royal Soc. A. https://doi.org/10.1098/rsta.2019.0201.

[21] Radhakrishnan M., Pathirana A., Ashley R M., Gersonius B., Zevenbergen C. (2018). Flexible adaptation planning for water sensitive cities. Cities 78 (2018) 87–95.

[22] Cettner A., Ashley R M., Hedstrom A., Viklander M. (2014) Assessing receptivity for change in urban stormwater management and contexts for action. Journal of Environmental Management 146 (2014) 29-41.

[23] Westling E L., Sharp L., Scott D., Tait S J., Rychlewski M., Ashley R M. (2019). Reflexive adaptation for resilient water services: Lessons for theory and practice. Global Environmental Change 57 (2019) 101937. https://doi.org/10.1016/j.gloenvcha.2019.101937.

[24] OECD (2019), Applying the OECD Principles on Water Governance to Floods: A Checklist for Action, OECD Studies on Water, OECD Publishing, Paris, https://doi.org/10.1787/d5098392-en.

There are therefore various levels of organisational effectiveness, including managing assets, linking between the strategic and operational contexts via the tactical handshakes in the FAIR framework and also the seven dimensions of maturity used in FAIR: 1. AM decisions; 2. Information management; 3. Internal coordination; 4. External coordination; 5. Outsourcing activities; 6. Processes and roles; 7. Culture and leadership. Although FAIR has set these out, derived from beneficiary needs and experiences, they need to be further examined to evaluate their sufficiency for and with other organisations and applications to AM for FP and FRM.

Denmark (Ribe): Working together to manage increasing risks from rivers and the sea

The Danish Coastal Authority (DCA), Esbjerg Municipality , local dike associations and land owners all have a part to play in adapting the existing FP and water level control systems for Ribe, the King River and the Wadden Sea. The Municipality and DCA have primary responsibility for ensuring policy is effective, followed and implemented. The Municipality designates areas at risk of flooding and includes remediation in municipal planning and DCA provides guidance in e.g. implementing the EU Flood Directive. Although every landowner is responsible to protect their own land. Hence the FP of Ribe Polder is having to balance these many complex circumstances and interests. It is beneficial for all to strengthen both the internal and external cooperation within and beyond organisations. For example, in Esbjerg Municipality internally amongst the department responsible for managing the assets, the department responsible for the rivers and the department for climate adaption planning. Externally amongst the local dike associations, citizens, climate adaptation planning and DCA and the municipality in order to transfer knowledge and improve acceptance of possible new solutions.

Gap D: From stakeholder to shareholder

This Gap relates to the need to bring partners together in a meaningful way to ensure effective AM for FP. Although 'stakeholders' have long been considered in all aspects of public AM, there is a need to ensure that organisations with a more direct stake, e.g. as tangible economic beneficiaries; i.e. 'stakeholders' are faced with and included in the planning, funding and operation of assets. This Gap relates mainly to Policy Brief Recommendation #1: Align multiple planning processes within and beyond flood management; and Recommendation #4: Accept that new approaches attract risk but managing, rather than avoiding, risks can lead to innovative solutions.

Question 5: How do we engage relevant key stakeholders in AM as shareholders, creating innovative financing opportunities and sharing the risk?

The FAIR project has demonstrated that a system-approach is important for best practice AM. It is increasingly recognised that AM planning for FRM should focus on multi-functionality for economic efficiency[25], and to address the cross-sectoral challenges beyond flood risk that climate change brings. There is a need to have a broader, integrated appreciation of FP infrastructure (by everyone) and to capture long-term value in as many ways as possible.

This typically requires collaboration between a much wider group of stakeholders than in the past, each of whom will have a variety of different interests and business planning models. It is crucial that all relevant stakeholders are engaged and aligned during all project phases, from initiation to operation and maintenance[26]. New and more effective ways of bringing all stakeholders into the planning and management of AM and the AM processes need to be developed if the necessary projects are to come about. This is especially true for shareholders - a special type of stakeholder – engaged in the co-creation of the plan and in responsibility for delivery and maintenance and bringing innovative or alternative sources of funding.

New ways of assessing the economic benefits of using alternative FP and FRM assets have been developed[27], including for nature-based and hybrid assets, have shown that there is typically a wider range of beneficiaries and potential shareholders than had been realised previously[28]. This raises opportunities for engagement with a wider group of shareholders in planning and managing an asset, where each of them can see direct tangible economic benefits and value from doing so.

Sweden: From one responsible organisation to many shareholders in Helsingborg

The city of Helsingborg is both the asset owner and operating authority of any existing FP. But as the city area adjacent to the ocean is being redeveloped there are numerous opportunities to bring in other interested parties when planning to adapt to future flood risks, i.e. coordinated with overall city development in both space and time. However, timing of the various plans is not coordinated, so an agile FP strategy is necessary, to utilise opportunities as the plans develop. There is also a need to raise awareness amongst both citizens and internally in the Municipality about the risks from flooding. Greater awareness will provide greater commitment and buy-in (more shareholders) so that every opportunity to add FP into development as it proceeds will be taken up.

[25] Ashley R, Gersonius B, Horton B. 2020 Managing flooding: from a problem to an opportunity. Phil. Trans. R. Soc. A 378: 20190214. http://dx.doi.org/10.1098/rsta.2019.0214

[26] Ruangpan, L. et al. (2019). Nature-Based Solutions for hydro-meteorological risk reduction: A state-of-the art review of the research area. Nat. Hazards Earth Syst. Sci. Discuss. doi:10.5194/nhess-2019-128.

[27] Hargreaves A.J., et al., (2019) Engineering for the far future: rethinking the value proposition. Proc. Inst. Civil. Eng.-Eng. Online, 1 April 2019. (doi:10.1680/jensu.19.00020)

[28] Fenner R. (2017). Spatial evaluation of multiple benefits to encourage multi-functional design in blue green cities. Water 9, 953. (doi:10.3390/w9120953)

Gap E: Engaging society

The need to ensure proper and effective ways of bringing society into the way assets are planned, managed and operated for FRM is obvious, especially as in future in the NSR and similar parts of northern Europe, citizens will need to become comfortable with seeing more water in places not normally covered with water. Greater engagement with society as a whole should also ensure that AM for FP is understood to be important and appropriately financed. This Gap relates mainly to Policy Recommendation #3: Develop strategies that are flexible and assets that can be modified.

Question 6: How do we engage with society in the way needed to ensure that assets are delivered and managed in the best way?

With increasing river discharges, rising sea levels, and increasing population densities for many European countries, the impacts of flooding and the importance of FP measures (e.g. dike reinforcements) are increasing. The European population is expected to rise until at least 2044[29], which means that more people are likely to be located[30] in the most at risk (i.e. usually low-lying[31]) areas, many of whom are in the NSR, within the FAIR beneficiary countries. Citizens cannot any longer delegate all responsibility for managing flood risks to national or local organisations and need to be effectively engaged in the process of AM and planning as part of taking more responsibility.

There have always been difficulties in engaging with communities and populations about risks that are only occasionally evident, like flooding. The NSR partners, in common with other authorities, are concerned that there is no clear way to effectively engage communities, despite the guidance and research findings on the topic. Bad, or ineffective, engagement processes are known, but still used by unscrupulous authorities and experts to bias or misinform citizens in order to come to a 'preferred solution' that maximises the value to the authority, rather than to society or individuals. For example, Trowsdale et al[32] shows how 'techno-dominance' has been used in the City of Auckland, New Zealand, to dissuade a large community from taking up water re-use measures despite their already having paid for the assets. In London, the new 'supersewer' is being constructed using 19th Century technology in order to maximise the income to the private company involved, rather than to maximise societal benefits[33] or provide an integrated water system.

There are community-based attitudes and resistance to many of the changes we need to make to bring in the assets needed to cope with the future risks. For example, the increasing use of nature-based assets in urban areas is posing particular challenges, as many of these assets take up valuable land space, impacting more on land owners than for the equivalent buried assets, like pipes, or these can lead to 'gentrification' issues, displacing the poorest in communities[34].

[29] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20190710-1

[30] Live, work, travel into or through

[31] Flooding can occur anywhere, even on tops of hills, as rain falls everywhere.

[32] Trowsdale S, Boyle K, Baker T. (2020) Politics, water management and infrastructure. Phil. Trans. R. Soc. A, 378: 20190208. http://dx.doi.org/10.1098/rsta.2019.0208

[33] Loftus & March (2019) Integrating what and for whom? Financialisation and the Thames Tideway Tunnel. Urban Studies 2019, Vol. 56(11) 2280–2296.

[34] Pearsall H., Keller J.K. (2020) Locating the green space paradox: A study of gentrification and public green space accessibility in Philadelphia, Pennsylvania. Landscape and Urban Planning Volume 195, March 2020, 103708.

In the Netherlands, well-educated and well-connected individuals have tried to stop necessary FP measures (see Box below). In view of the above, effective and mutually beneficial engagement with land owners and a wide range of communities and even individuals, is clearly even more important than in the past, especially to help people to understand the need for FRM measures and the need to use, fund and maintain these in response to climate change. Ideally communities need to be engaged from the very start to engender a sense of ownership[35] and share in the formation of plans and policies and to help with final designs and plans for operation, even assuming responsibilities, as described by Lawrence et al[36]. 'Language' used by experts needs to be tailored to the community being engaged[37], to avoid misunderstandings, and asset owners/operators failing to engage. Poor use of language inhibits public support for the new ways of delivering FP. This includes allowing some temporary 'flooding' of land spaces to protect properties and societal activities[38], and other not perceived traditional 'protect at all costs' approaches[39]. The earlier INTERREG IV NSR project MARE[40] developed Learning and Action Alliances as a means of better engagement between professionals and communities. In urban areas the public co-creation of green infrastructure, addressing stormwater management such as in Philadelphia[41], necessitates public engagement as stakeholders (Question 5) to be successful. One approach to effective engagement is that of 'telling a story'; the need for such approaches is illustrated in the box below.

The Netherlands (Markermeerdijken): Opposition by famous Dutchmen to dike reinforcement program

The FAIR beneficiaries are often challenged in planning and operating FP assets by other (semi-) specialists or people with a lot of public influence. The scientific and technical aspects of AM for FP are often difficult for citizens to understand and hence there is a need to tell 'the story' from an alternative perspective. For example, the necessity for the dike reinforcement programme Markermeerdijken (The Netherlands) was challenged by a group of famous Dutchmen (scientists, actors, retired engineers). They opposed the plans for dike strengthening, especially as this would have damaged large parts of the existing dikes, which have important cultural historical value. With the increasing need for FP measures in a changing climate, and less land available due to a growing population, there is a need to find effective ways to assuage the increasing resistance from society at large.

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Further reading

The documents relating to the FAIR project can be found on the following websites:

http://www.fairproject.org/

https://northsearegion.eu/fair/

Partners

FAIR brings together Asset Owners (facing real problems and challenges) and leading scientists (with domain expertise) to share and develop innovative solutions to the management of flood protection assets. In doing so, FAIR is the first collaboration of its kind.

Back to Further Reading

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Pilot flood protection gates Hamburg

A Practice Brief from the Interreg North Sea Region FAIR project

June 2020

Preface

The FAIR project

Collectively, EU Member States invest an average of €3 billion per year in flood protection infrastructure. Nevertheless, a combination of climate and socio-economic change is increasing the average annual damage caused by flooding. Complex and difficult decisions will need to be taken in response to these threats, especially in coastal regions, as rising sea levels challenge the sustainability of existing policies and plans. An improved approach to the planning, design and management of new and existing flood protection assets will be crucial to address this challenge.

FAIR brings together flood protection asset owners, operating authorities and researchers from across the North Sea Region (NSR) to share policy, practice and emerging science of flood protection asset management.

This Practice Brief

This Practice brief presents;

- **Why** this project is proposed.
- **How** we dealt with the challenges that we are confronted with.
- **What** we achieved within the FAIR project.

It also considers the FAIR Policy recommendations and approaches presented in the FAIR end report.

The FAIR results

The storm surge protection facilities in Hamburg, including some very complex structures, are working effectively due to good maintenance by qualified experts. Nevertheless, it is essential for us to extend the lifespan of the assets and reduce the life cycle costs at the same time.

In the future however, we need a more condition-oriented maintenance strategy that, in addition to valuable employee experience, focuses on the condition of the facilities, the legal framework for operations, the available resources and operational requirements. Furthermore, adaptability, multi-functionality and the whole life cycle of an asset need to be taken into account.

In addition to setting up this future-oriented maintenance concept, it is necessary to find a suitable way to document existing data in a structured manner, to have direct access to all asset-related data. International exchange and collaboration with scientists and asset managers in FAIR is a valuable support to achieve this goal.

There are many complex and interacting planning processes and factors that influence effective asset management (often with centralised processes delivered by dispersed, local operators).

Well-aligned asset management is dependent on having a coherent strategy in place to link flood asset planning, construction and operation, with broader planning objectives. In many cases, strategic oversight by, for example, a responsible authority, is required to provide the bridge between these multiple planning processes and flood protection asset management.

Significant new ideas and methods are being developed to ensure best value asset management options are identified for both existing and new infrastructure. However, their alignment with socio- economic policies and supporting governance systems is often neglected. FAIR recognises these challenges and identifies the following four priority policy recommendations to advance flood protection asset management:

1. Break-free of the silo.

2. Mind the gap.

3. Prepare for change.

4. Make space for innovation.

Summary

Assets, which are in round-the-clock operation (24/7), require a different maintenance strategy than those, which are used only for a few hours per year. For this specific second case we selected three flood protection gates in the city centre of Hamburg as our pilots in the FAIR project. The overall objective, to which all further insights relate, is to increase the reliability of these assets despite reducing their maintenance costs.

Furthermore, the quality of the maintenance should stay high or even increase. **A constant asset availability is our top priority.** A well-thought-out maintenance concept, which explains the basic strategy as well as the schedules, gives the people responsible more confidence in their actions.

Manufacturers of components installed in equipment typically recommend maintenance instructions and intervals designed for 24/7 operation. This is precisely where an adapted maintenance strategy needs to be developed, addressing the needs of individual parts but also taking into account the entirety of the system. Changes compared to the maintenance instructions or recommendations of manufacturers are only to be carried out if they are not detrimental to the components. Usually, the manufacturer's warranty of the component will be invalid in these cases.

The experience from the last 5 years shows the tendency that (as of a certain point) with increasing complexity (automation, redundancies, external power supplies, etc.) the reliability of the entire system decreases, because failure of a single, small component can compromise the overall functionality. So one of the important goals in the future is to define which degree of complexity relates to the maximum point of reliability (see Fig. 1).

Due to the higher complexity and thus, an increased number of components, a gate is considered a vulnerable system.

On the one hand, we considered the failure of individual components in a gate (the entire system) and on the other hand the incorrect operation by personnel. The most probable reasons in case of incorrect function would be a lack of experience of the operation team. Another difficulty is posed by the fact that some gates are too complicated to easily perform troubleshooting if problems occur during operating. Nowadays, there are no in-house operation staff available and tasks have to be outsourced to external contractors. Incorrect operation can easily occur because of the high level of stress for the task force while operating the gates - especially if failures occur.

In addition, complex assets, even more so than simpler ones, require a clear process regarding action and strategy for maintenance. This needs a complete and action-friendly documentation and legal certainty. From the insights gained in the FAIR project, the development of such a system has been initiated. At

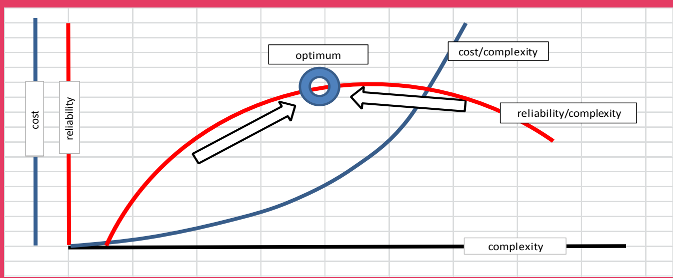


Fig. 1: Relations between reliability, complexity and cost (LSBG, 2015)

least for assets that are more complex and therefore much more expensive in investment and maintenance.

In summary, less complex flood protection gates with the same reliability are cheaper in terms of investment, maintenance and operation.

The Context

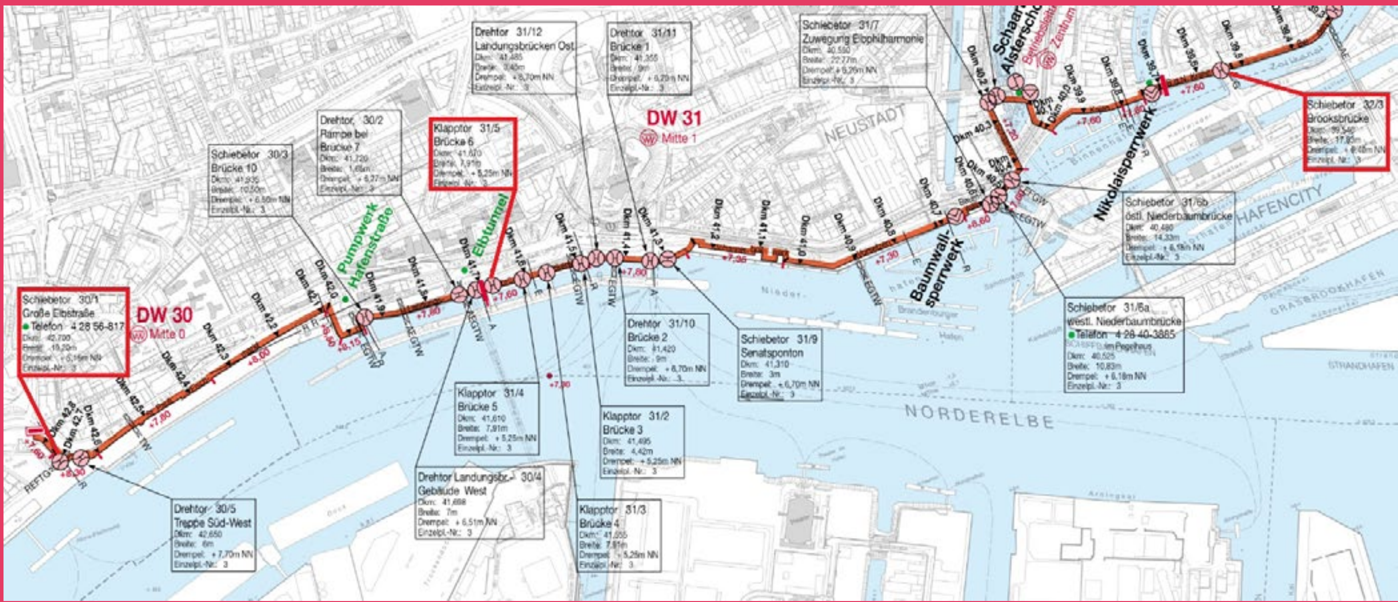


Fig. 2: Location of the FAIR Pilot Gates in the city centre of Hamburg (LSBG, 2015)

Among other tasks, the "Agency of Roads, Bridges and Waters" (LSBG) is responsible for the maintenance of most of the public flood defence gates in Hamburg. In the Interreg FAIR project three of these gates have been identified and selected as pilots. These gates were chosen because they feature the functional criteria present in the challenges we are facing (more information in chapter "Summary" first section and "The Purpose"). The base case is as follows.

The gates are fully automated and almost every component in the system is redundant. By design a stop lock system represents a second dike security line. In case of power failure the power supply is partly supported by an emergency power generator. All pilots are remotely monitored but not remotely operable. The operating time is approximately 10h per year, which is very seldom, but the gates must be highly reliable at these precise moments.

A previous strategic decision meant a large number of operational and maintenance tasks were outsourced and contracts were set up with external companies. These external companies are not as familiar with the assets as in-house LSBG staff would be and they do not have a similar in-depth knowledge of the gates.

Many documents including inventory documents, maintenance instructions and permits cannot be retrieved centrally and in some cases they are not complete or do not exist at all. Data, which is relevant for the flood protection assets are stored in different places so it is sometimes difficult to find out which data is available for a specific asset.

In the FAIR project we have realised that these problems are widespread and affect other partners as well.

Why: The purpose

The key challenges

The key challenges of the Hamburg pilot are to optimise asset management.

The optimisation essentially includes the improvement of the maintenance concept for the flood protection assets as well as the integration of all relevant data in one information system that is web based and can be operated intuitively. We need to start focussing more on a LCC oriented approach instead of an investment costs oriented one. Furthermore, we strive for a standardisation of solutions (e.g. monitoring of all assets, remote control and unified structure concepts).

We are looking for the optimum degree of automation of the flood protection assets and want to define this point. Another huge challenge will be the design and construction aspect of selecting a single contractor offering a warranty and complying with the EU machinery directive.

The intended effects

Within the FAIR project, we want to question the optimum degree of automation to either confirm our asset design strategy or adapt it in the upcoming building program. With a new structured process-oriented maintenance concept for Hamburg's flood protection assets we want to increase asset reliability whilst reducing maintenance costs. Furthermore, through the standardisation of solutions like monitoring, remote control or basic structure concepts, we can simplify the technical framework. This adaptation facilitates an easier operation and the long-term understanding of our assets by the operational staff.

By developing a web based "Dike Information System" (DIS) we aim to increase the efficiency of our staff and all shareholders through better accessibility of all relevant data related to the flood protection assets.

In the upcoming building program we strive for only one general contractor, for example a manufacturer of a flood protection gate. This will give the people responsible the necessary certainty to release/transfer/hand over a completed, legal to operate, compliant, asset to the operational team and avoid litigation regarding warranty.

To be able to provided focussed maintenance work in the future we assess the whole floodgate operation system. The System is divided into units such as flood forecasting, flood warning, mobilisation and closure. The risk-based approach enables us to zoom into the processes that a successful closure of a flood protection gate requires, hence critical processes can be highlighted and focal points regarding maintenance reorganised accordingly.

How: The approach

To get a detailed overview of our pilots we started to analyse and document our maintenance processes. For this, we were using the long-term experience of the responsible maintenance personnel as the basis of our analysis. After the first evaluation, we decided to question the manufacturers' maintenance requirements for specific components because we use these components in a unique way. The idea behind this action is that many components presumably do not need the requested maintenance intervals defined by the manufacturers. Additionally, we document all failure occurrences and sort them by technical or human failure to get an idea which kind of problem we have to handle or are confronted with.

Together with the Hamburg University of Technology (TUHH) we performed a risk analysis of emergency operation processes of flood protection gates. This action should give us more detailed information regarding possible failure sources including technical and human errors. We documented all possible sources of interference and gave them a probability of occurrence and an appropriate time value. Therefore, we can identify realistic delays for the operation process. With this data, we can define the time schedule for operating the gate and respectively the build-up of the second defence line.

What: The outcomes

The results of the FAIR project for LSBG are essentially an adapted, well-structured process-oriented Maintenance Concept, which takes into account the several particularities as well as the development of a web-based "Dike Information System" (DIS), which can be operated intuitively. For now, the DIS is already available for a specific group of people in Hamburg and provides all relevant data of the flood protection assets.

Furthermore, a performance analysis and the comparison with other non-complex flood protection structures to optimise the reliability and LCC of the flood protection gates have been carried out as a basis for construction decisions in the future.

As an extra benefit, we also accomplished several non-priority results, which are;

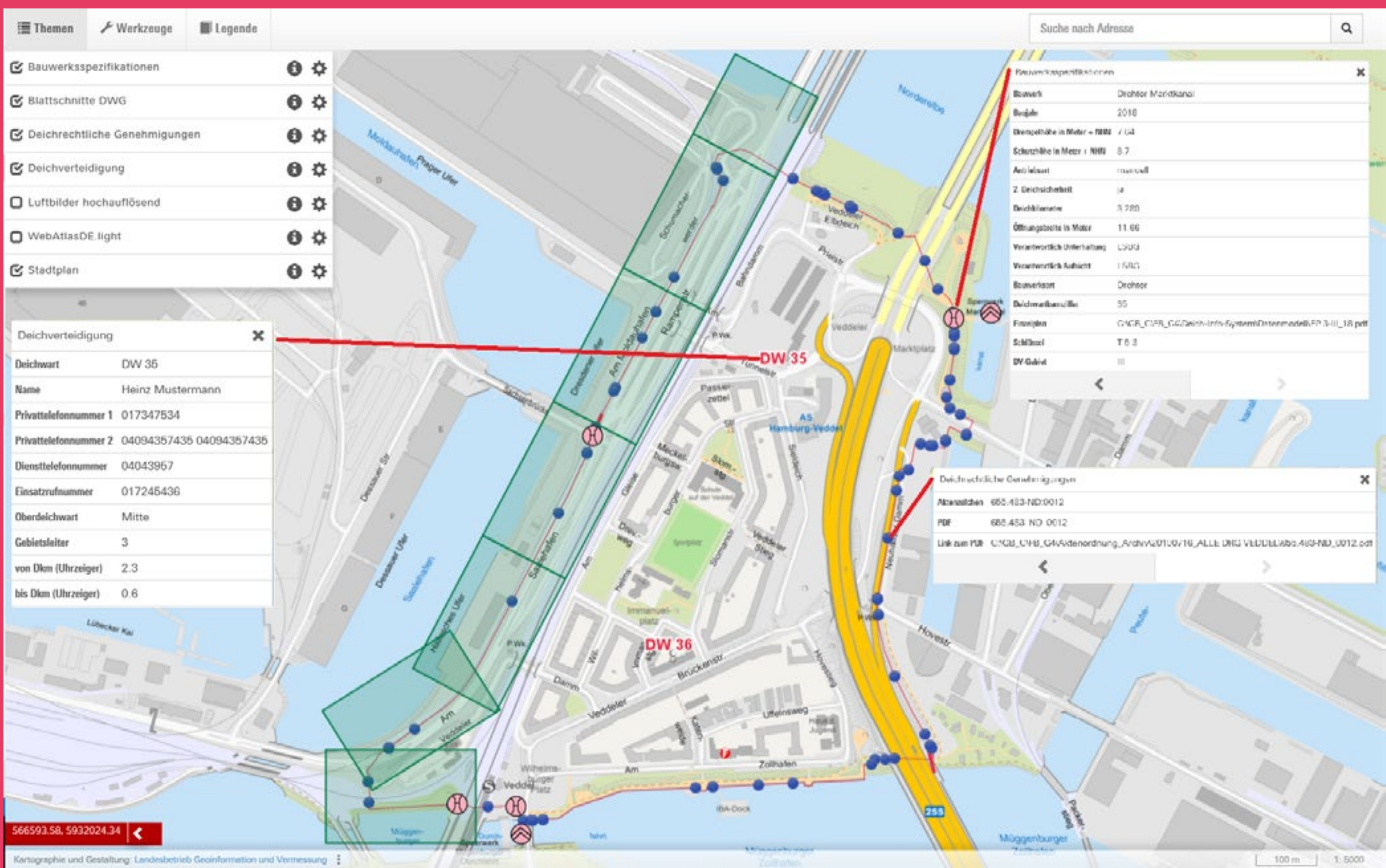
- LCC – start discussions internally.
- Improvement of the internal awareness.
- Policy Brief.
- Policy debate.
- Peer 2 Peer meetings/exchange experiences with partners.
- Improvement of internal collaboration.

Reflection on innovation

An essential part of the FAIR project was the innovative approach to look at the existing gates critically and from different points of view in order to get a better understanding of their function and operation. With these new insights we can optimise these assets in the future. Furthermore, it provides us with important information for the future improvement and design of new gates as well as for a legally compliant operation.

A special, innovative step is the development of a geo-referenced, web-based information system. Data, which is stored at various locations in the city of Hamburg, can be presented in an integrated way and used by authorised people in a fast and unambiguous way. This will result in a considerable work advantage in terms of quality and acceleration of work. In this context, it is also important that the data represents the current status of all information available on the flood protection asset (e.g. dike or gate) without exceptions.

In the course of the project work, a maintenance concept was developed that enables us to manage the maintenance of the facilities in a structured and sustainable manner. A permanent improvement process is the key to identifying and improving the strengths and weaknesses of the assets themselves as well as the maintenance work.



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Pilot Helsingborg

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Preface

The FAIR project

FAIR brings together flood protection asset owners, operating authorities and researchers from across the North Sea Region (NSR) to share the policy, practice and emerging science of asset management. Despite the diverse character of the NSR, asset managers face common challenges across the region.

The FAIR project aims to develop and implement improved approaches for asset management of flood protection infrastructure. It will optimise investment planning by exploring mainstreaming of these investments with other policy domains, and by mapping planned investments across a wide portfolio of flood protection assets. FAIR will also identify cost-optimal adaptive infrastructure upgrades by exploring a variety of technical designs, with adaptability and life cycle costing for various performance levels.

This Practice Brief

FAIR supports the delivery of local upgrade or maintenance projects and schemes for flood protection assets or systems. This Practice Brief presents **why** the project or scheme has been proposed. It provides an overview of the key challenges and intended outcomes. It elaborates on **how** these challenges have been addressed, and presents **what** has been the outcome from implementing this approach. Finally, the Practice Brief reflects on the innovation of the pilot with respect to the best practices in the FAIR end report and the FAIR recommendations.

The FAIR results

The demonstration and subsequent widespread implementation of the improved approaches and techniques will reduce the probability of flooding and minimise the impact of floods across the North Sea Region. This will improve the climate resilience at target sites covering most of the NSR. 'Target sites' are those areas being protected by entire flood protection systems (e.g. Danish coast, Swedish Coast, Flemish Coast, Dutch Delta) and individual assets (e.g. Hollandse IJssel storm barrier, Hamburg flood gates, etc).

The result indicators for the FAIR project are:

1. Reduce the life cycle costs of flood protection infrastructure through better targeting of investment;
2. Encourage the multi functionality of flood protection infrastructure through mainstreaming (that is, connecting) investments with other policy objectives;
3. Increase the life span of flood protection infrastructure through smarter maintenance and renovation.

Summary

Helsingborg Municipality's participation on the FAIR project has been the starting point for our work to protect the central parts of Helsingborg from rising sea levels and storm surges. Previously studies have been focussed on the effects of elevated sea levels, but through FAIR we have been able to focus on how we can protect the city and at what cost.

Since Helsingborg has not been affected by major flooding, we can now conclude that it is crucial to have a long-term strategy. The need to inform and raise awareness is also crucial to be able to move forward. The FAIR project has funded a report that identifies critical points and objects in the city centre. With the help of this documentation and previously made impact reports, a risk and impact analysis has since been carried out and finally, for the first time, we have been able to produce a socio-economic cost analysis for an inner protection, and outer protection on a longer time scale, and for mobile protections feasible in the near future.

The outer protection is dependent on other major infrastructure investments and needs to be handled accordingly. A detailed feasibility study for the inner protection will be needed to map all aspects of surface water, sewage system, urban mobility, urban environment and impact on existing bridges and quays.

With the help of a long-term strategy, we can continuously implement flood protection in our urban environment, starting from now, to be well equipped for future climate change.

The Context

Helsingborg is located along the Öresund in southern Sweden. The city of Helsingborg has 146 000 inhabitants and is a regional centre in the region of greater Copenhagen. The busy ferry route to Elsinore connects passengers to intercity and commuter trains and buses at the central station which is situated close to the old city and the inner docks. At high sea levels and during storm surges, the northern portal to the railway tunnel, the busy alongshore main road, and the central station are at risk of inundation. This threat will increase with rising sea levels. As of today the city does not have a full scale flood protection or flood policy, but awareness amongst politicians, inhabitants and the municipality is increasing – which has led to the generation of this pilot report.

Figure 1. The inner docks of Helsingborg with the city centre on a low level. The old tower "Kärnan" in the background is in the upper part of the city. Courtesy Helsingborg Municipality.

The city of Helsingborg is both the asset owner and operating authority of any existing storm protection. There is a small wall protecting the northern portal to the railway tunnel but it is only designed for a storm event with a 100-year return time. We are currently preparing for mobile temporary protections around stairs and lifts to the underground central station. New urban development in the harbor area is raised to +3.5 metres, which corresponds to the still water level of an extreme storm event. There is a plan for future changes to the infrastructure in the area. In about ten to fifteen years the main railway line will be expanded and the existing tunnel will probably be extended, which will decrease the risk of inundation. A road and railway tunnel to Denmark between Helsingborg and Elsinore is also a longer term possibility. This would affect the existing ferry route to Elsinore, and provide new possibilities for storm surge protection in the future. In the municipality of Helsingborg, located on the ad hoc wing of the asset management maturity scale, flood protection planning needs to be coordinated with overall city development in both space and time.

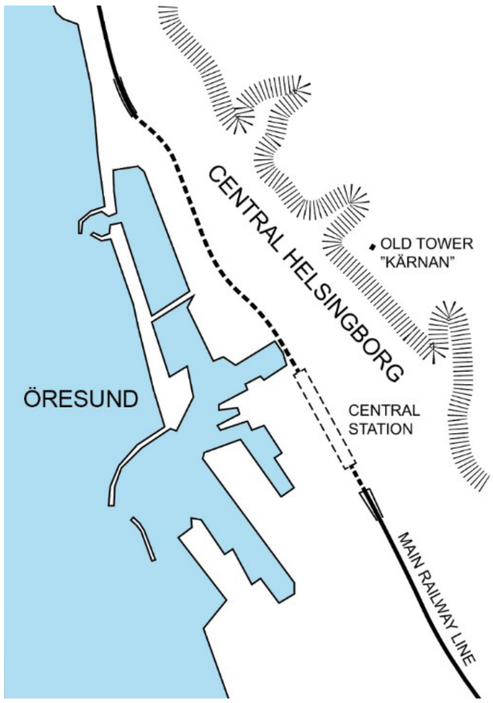

Figure 2. Map of the pilot area.
Courtesy Helsingborg Municipality.

Why: The purpose

The key challenges

Helsingborg is one of many Swedish municipalities all facing the same challenges associated with rising sea levels but has not experienced a major flood in modern times. The city does not have a governing body or dedicated resources for flood protection and there is low awareness of the issue and no early warning system in place to protect citizens.

Challenge 1: Define a long-term strategy

Flood management must be integrated into overall city planning. As planning standards need to consider larger areas and public interests, an agile flood protection strategy is necessary. A clear strategy is needed in order to plan and build a storm surge protection over a longer timescale. Cost-effective solutions are needed for both the current situation and a future with higher sea levels. By doing a risk and impact assessment, we can get a much better picture of the investment that may be required in the short and long term. These will have to be compared with the cost of mitigation measures, in order to assess the socio-economic profitability. The outcome will provide a foundation for decision-making.

Challenge 2: Increase awareness

The second challenge is to increase awareness of flooding among citizens and politicians. This is important for funding and to create an understanding of the measures which will need to be taken to protect the urban environment. The awareness of our stakeholders also needs to be increased so that our work with flood protection becomes a natural part of all of the administration's work and assignments.

Challenge 3: Make space for innovation

To be able to solve future flood threats it will be necessary to support innovations along with traditional development. Since 2013, the municipality of Helsingborg has had a vision for the city in 2035. One milestone is the city's expo H22 which aims to make Helsingborg one of Europe's most innovative cities. This vision provides the city with the courage and energy to make positive change.

Figure 3. Visionary image of the inner harbor.. Courtesy Krook & Tjäder 2017.

The intended effects

Our intended effects of the pilot were:

- Short term future action plan on how to deal with rising sea levels in the inner city and the comparison with the current situation including a cost-benefit analysis.

- Long term future strategy for city planning and bigger measures.

- A communication plan to raise awareness with of the pilot results.

Through the FAIR project and the pilot report we can understand the nature and scale of the work that is ahead of us. The report will provide us with the initial information on how we should proceed with our work and an action plan for the initial stages. We can also see the socio-economic effects with a zero alternative demonstrating the consequences of not protecting Central Helsingborg. This can then put this against the cost of the various protection alternatives recommended in the report.

The report should also form the basis for how we should organise ourselves in order to meet future flood threats.

The outcome of this pilot will be the ability to cost effectively protect the most important objects of public interest in the city. Communicating our strategy and the results achieved over the coming years can positively influence urban infrastructure planning and make climate adaptation a central part of all future developments.

Figure 4. Visionary image of the inner harbor with example of inner protection. Courtesy Krook & Tjäder 2017.

How: The approach

The end product of the pilot project was in the form of a consultancy report proposing and evaluating possible flood protection measures on a shorter and longer timescale. The report is based on the SPR framework methodology. As the city currently is not in possession of any larger coastal protection infrastructure, the Source-Pathway-Receptor model was adjusted. In the analysis, Source was defined as high water levels and waves, Pathway as the flooding event and Receptor as buildings, infrastructure, people and the environment.

Step 1 was based on simulations of a 100-year flooding event in 2035, 2065 and an extreme flooding event in 2100. All scenarios followed the climate scenario RCP8.5. During step no 2 and 3, stakeholders responsible for the national railway system, sewage and water distribution, electricity network distribution and the harbor were involved in workshops regarding vulnerability, costs and maintenance.

The case report was conducted in six steps:

1. Analysis of existing high water model and flooding scenarios.
2. Identification of values to protect in the central parts of the city, such as the population, traffic system and infrastructure, buildings and key societal functions.
3. Impact assessment for flooding scenarios in the near and long term future.
4. Risk assessment.
5. Proposal of actions in order to protect the central city in the long and short term.
6. Cost-benefit analysis.

During the pilot other stakeholders were engaged in the process of collecting data and knowledge of existing facilities. The most important stakeholders are Swedish transport administration, NSVA (Water Services Company), Öresundskraft (Energy Services Company) and the rescue administration.

The sharing of experience is an important factor, and we visited Esbjerg in Denmark and Gothenburg and Halmstad in Sweden. In Esbjerg, we learned a great deal about how outer protection could be constructed and the economic cost of various options. We also discussed similarities and differences in our local government, and how politics play a very important role. For example Gothenburg has the same problems regarding rising sea level and infrastructure as Helsingborg, but on a larger scale. In addition to technical lessons, officials from the city of Gothenburg emphasised the need for networks to disseminate knowledge and contribute to increased awareness of the flood issues of both politicians and officials. In Gothenburg, they have set a time limit for various measures, which we in Helsingborg should also start to consider. In Halmstad, we looked at the large elevation project in the industrial harbor from +2.2 metres to +3.0 metres, and the creation of an outer sea wall further reinforcing the protection level. Overall we built up a detailed understanding of how large scale storm protection can be organised and financed.

What: The outcomes

The predicted flood risks facing the city in 2035 are severe. A 100-year storm would cause the water level to rise to at least +2.22 metres causing flooding of the inner harbor and the southern tunnel entrance. The risk of flooding at the main entrance to Helsingborg Central station and the northern tunnel entrance increases. The busy ferry link would be rendered inoperable. A 100-year flooding event in 2065 would result in a more tangible risk to life and health. The sewage system would be severely affected and rail and road systems would shut down. An extreme event in 2100 will have roughly the same surface coverage as the 2065 event, but with greater water depth and greater damage to life and property. In 2065, the damage costs to buildings and technical supplies would also be significant. Cost estimations of a 100-year event in 2065 equate to roughly EUR 7 million and the figure rises to EUR 11.5 million in the 2100 scenario. Significant disruption of rail and ferry operations represent the highest socio-economic costs in these scenarios.

Protection actions proposed in the report:

- Small dedicated protection – mobile protection around stairs and elevators in the central station and other openings to the railway tunnel. Measures will also be needed in underground parking and the sewage system.

- Inner protection – walls and dikes can be constructed along the quays from north to south to protect the city centre and the railway tunnel. To handle surface water the barrier needs to have several smaller openings so as to not create flooding on the inside of the wall, which will require a mobile protection. The inner protection should have a protection level of +3.0 metres, which would be sufficient in order to handle an extreme storm event in 2100.

- Outer protection – existing groynes can be reinforced by landfill with sluice gates to the central harbor and northern harbor that closes at high sea level. The outer protection is mostly evident in connection with a new road and rail tunnel to Denmark. At that point, smaller boats will replace the ferry traffic. The outer protection can give long term protection at extreme events in 2100.

Small dedicated protections reduce the risk of impact on the main railway line at high water levels and during storm surge, which is a good cost-benefit. The establishment of an inner protection can achieve a positive cost-benefit if it is coordinated with urban development and the asset management of quays and public spaces over a longer period of time. To establish the inner protection in a short time would be much more expensive due to major unplanned costs for restorations of quays, boardwalks and the sewage system.

No action plan for either the coexisting outer or inner protection exists today. Whether either an outer protection or an inner protection is enough in itself is not investigated enough to provide a definitive answer. The outer protection has a low cost-benefit today, but could be the only way to protect the city in the long term. This will have to be further investigated.

The result of the study is that flood protection needs to be integrated into strategic planning and be incorporated into on-going operation and maintenance of quays, promenades and technical infrastructure.

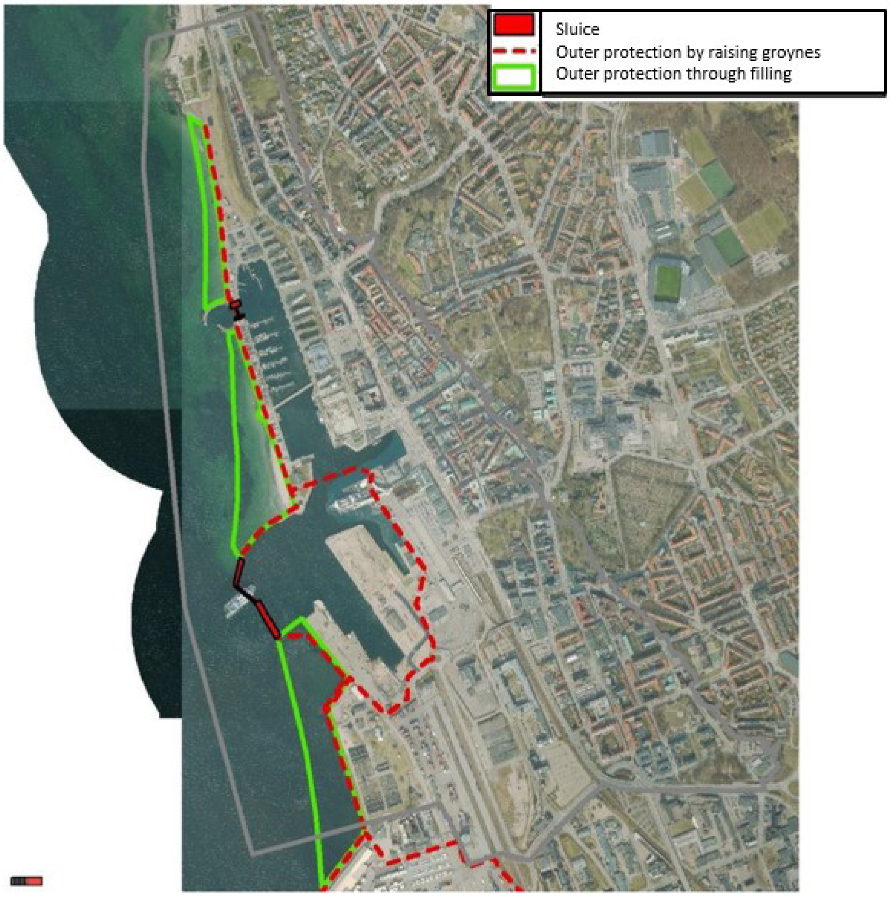

Figure 5. Proposal of outer protection including sluices, outer protection and reinforcement of existing groynes. Courtesy WSP 2019.

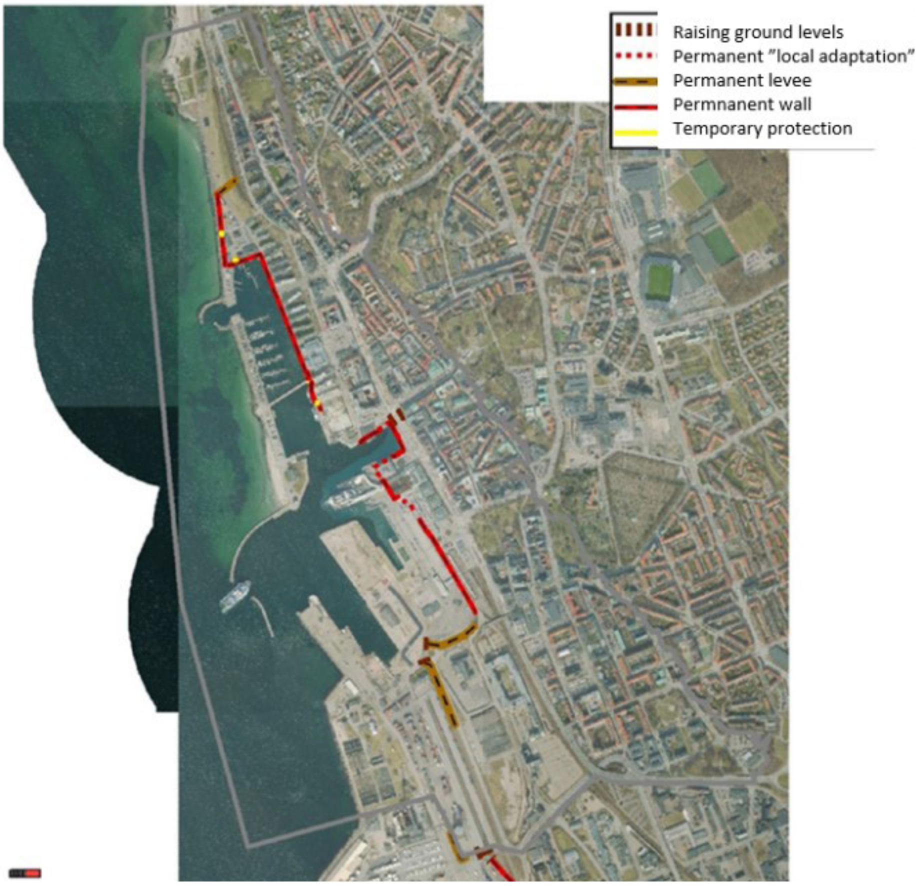

Figure 6. Proposal of inner protection including raising ground levels, permanent local adaptation, permanent levee, permanent wall and temporary protection. Courtesy WSP 2019.

The following conclusions can be drawn from the pilot project:

- Start with small, dedicated protection of functions with high public interest. As a direct result of the FAIR project, we have begun work on the proposed measures around Helsingborg Central Station and the entire tunnel to obtain the right measures and during 2020 are raising funding for completion.

- A detailed feasibility study for the inner protection is needed to determine the solutions from north to south including all aspects of surface water, sewage system, urban mobility, urban environment and impact on existing bridges and quays.

- The inner protection can, after that be built step by step, coordinated with urban development and asset management from 2030.

- An outer protection is needed to protect the city in the long term, but this could be constructed in stages, coordinated with a new tunnel between Helsingborg and Elsinore. A decision on this should be made before 2030.

Figure 7. Example of a protection along a quay to the left (inner protection) and a barrier with a sluice gate in Esbjerg to the right (outer protection). Courtesy Torgny Johansson, 2019.

- A detailed feasibility study for the outer protection needs to be carried out before or at same time as the planning of the tunnelling project. Important issues are the size of ships able to enter the inner docks, the environmental impact on landfill and how landfill could be multifunctional both ecologically and as a place for city life.

- The development of both inner and outer protection needs to be included in urban planning documents.

- We need to constantly monitor new research about rising sea levels, which will affect the strategy.

- Awareness is key to establish a sustainable organisation for storm protection today and in the future.

Reflection on innovation

As Helsingborg is initiator, funder, owner and maintainer of its own coastal protection, we have a unique opportunity to form a cost effective, integrated coastal protection program. Embarking on this journey will mean answering questions regarding investment returns, cost allocation, design, adaptation agility and parallel processes.

Reflection on best practices

The stakeholder analysis defined the network of stakeholders needed for the upcoming work. It is clear that when we approach the first flood defence actions, all stakeholders need to be involved at an early stage and in close collaboration. We aim to seek solutions that are suitable for all stakeholders in space and time.

Reflection on knowledge gaps

In the beginning of the project, we identified a few knowledge gaps. They were mostly related to how the railway tunnel is constructed. Few details are recorded and are not in the possession of the municipality of Helsingborg as the Swedish National Transport Administration governs the railway system. Now, we have identified and filled the knowledge gaps and we have a more collaborative approach than before, with railway and traffic stakeholders working together as part of a team.

Reflection on policy recommendations

The outcome of the project for Helsingborg is a strategy for the future, including feasible actions as well as the required planning processes for larger investments. The aim is to prepare for change by encouraging the multi-functionality of flood protection infrastructure through the correlation of investments with other policy objectives. The results of the study will be integrated into comprehensive planning as well as maintenance planning. In Helsingborg there is already a process for including many objectives in one single investment, but not on this scale and not so long in advance. The scope of this project includes securing land for future investments and communicating the strategy to co-workers within the organisation.

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Further reading

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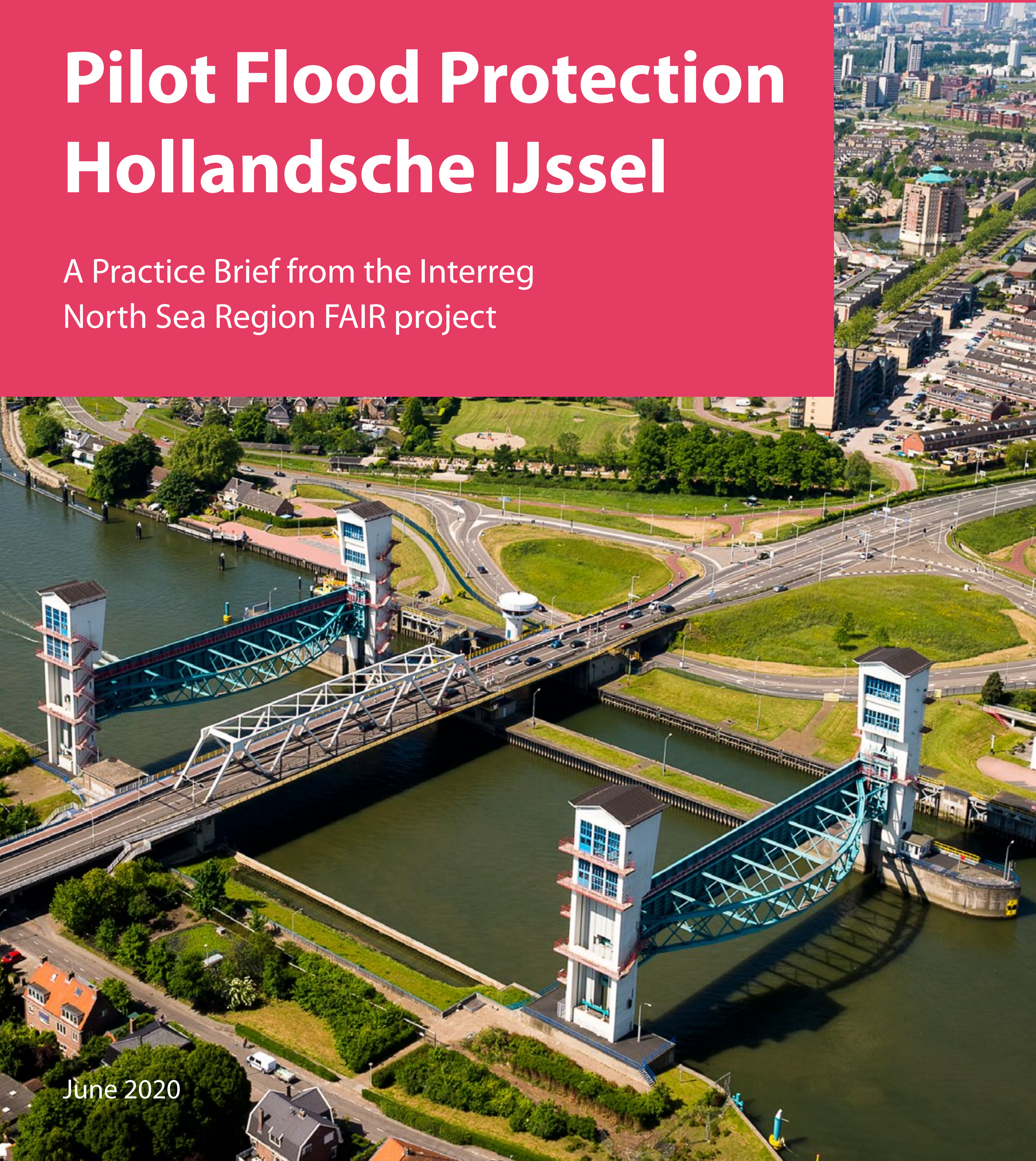
Pilot Flood Protection Hollandsche IJssel

A Practice Brief from the Interreg North Sea Region FAIR project



June 2020

Preface

The FAIR project

FAIR brings together flood protection asset owners, operating authorities and researchers from across the North Sea Region (NSR) to share the policy, practice and emerging science of asset management. Despite the diverse character of the NSR, asset managers face common challenges across the region.

The FAIR project aims to develop and implement improved approaches for asset management of flood protection infrastructure. It will optimise investment planning by exploring mainstreaming of these investments with other policy domains, and by mapping planned investments across a wide portfolio of flood protection assets. FAIR will also identify cost-optimal adaptive infrastructure upgrades by exploring a variety of technical designs, with adaptability and life cycle costing for various performance levels.

This Practice Brief

FAIR supports the delivery of local upgrade or maintenance projects and schemes for flood protection assets or systems. This Practice Brief presents **why** the project or scheme has been proposed. It provides an overview of the key challenges and intended outcomes. It elaborates on **how** these challenges have been addressed, and presents **what** has been the outcome from implementing this approach. Finally, the Practice Brief reflects on the innovation of the pilot with respect to the best practices in the FAIR end report and the FAIR recommendations.

The FAIR results

The demonstration and subsequent widespread implementation of the improved approaches and techniques will reduce the probability of flooding and minimise the impact of floods across the North Sea Region. This will improve the climate resilience at target sites covering most of the NSR. 'Target sites' are those areas being protected by entire flood protection systems (e.g. Danish coast, Swedish Coast, Flemish Coast, Dutch Delta) and individual assets (e.g. Hollandse IJssel storm barrier, Hamburg flood gates, etc).

The result indicators for the FAIR project are:

1. Reduce the life cycle costs of flood protection infrastructure through better targeting of investment;

2. Encourage the multi functionality of flood protection infrastructure through mainstreaming (that is, connecting) investments with other policy objectives;

3. Increase the life span of flood protection infrastructure through smarter maintenance and renovation.

Summary

This report is about pilot Flood Protection Hollandsche IJssel (FPHIJ), which is a pilot for project FAIR.

Dikes along the river Hollandsche IJssel are operated by the regional water authority (HHSK), but they no longer meet the statutory standard. The Hollandsche IJssel river can be isolated from the main river, Nieuwe Maas, by a storm surge barrier (operated by Rijkswaterstaat, RWS) which controls hydraulic loads on the dikes. Part of the Dutch Delta Program was to make an integrated flood risk management plan for the entire river of the Hollandsche IJssel. HHSK and RWS worked together on this plan. The main outcome was to improve the reliability of the storm surge barrier while decreasing the expected hydraulic loading conditions on the dikes. Additional investment in the barrier would be needed to achieve this.

Figure 1: The Hollandsche IJssel storm surge barrier

By working together, HHSK and RWS have managed to trade-off costs and benefits between dike and barrier improvements to reduce entire lifecycle costs without compromising standards. The cost reduction is expected to amount to approximately 5% of the total of dike and barrier improvement cost (30 M€ on 600 M€). This also includes smaller dikes with less impact on the existing landscape. A program focused solely on dike strengthening would have missed these additional opportunities.

At the end of 2019, the Dutch Flood Protection Program (HWBP) has indicated that they are positive on the exchange of financial means (e.g. savings in the costs of dike reinforcements are used for investments in the barrier). HHSK and RWS are now working out the details to get the final approval for the exchange of means in the middle of 2020.

Figure 2: The Hollandsche IJssel dike

The Context

In this report about pilot Flood Protection Hollandsche Ijssel (FPHIJ), actually two pilots are being described; the dike reinforcement project KIJK (abbreviation for strong Ijssel dike Krimpenerwaard) and the project WHIJ (abbreviation for integrated flood risk management Hollandsche IJssel):

- KIJK is focusing on the dike reinforcement of 10 km dikes along the Hollandsche IJssel. The project is run by the regional water authority Hoogheemraadschap van Schieland en de Krimpenerwaard (HHSK). Dikes are assets for HHSK, but the Dutch Flood Protection Program (HWBP) finances 90% of the reinforcements.

- WHIJ is working on an integrated flood risk management plan for the entire Hollandsche IJssel, in which the water system is broadly analysed and all possible measures are looked into. The project is part of the Dutch Delta Program, and run by Rijkswaterstaat (RWS, the national agency for roads and main waterways including storm surge barriers) and HHSK.

The main reason for one pilot report for both pilots is that we (RWS and HHSK) are working together on a cost-effective solution for flood resilience of the Hollandsche IJssel river system, including the dikes of KIJK.

Struggle to get the collaboration started

In 2014, it was agreed to start a joint study under the Delta Program on the flood protection of the Hollandsche IJssel. In the first years, it was a struggle to get both authorities enthusiastic to start working together on this. It was seen as a risk that a broad analysis of the system would result in a delay of the necessary dike reinforcement. Also, in the beginning the benefits were not so clear due to the type of reinforcements being proposed. It was expected that the stability of the dikes needed to be improved and not the height (the stability of dikes is not influenced by a better storm surge barrier).

Triggers

In 2017, the urgency to start the dike reinforcement increased with the introduction of new legislation and different standards (based on national flood-risk assessments) and the incorporation of the failure rate of the storm surge barrier in the models. The new standards meant that on top of stability, the height of these dikes didn't meet the standard.

In June 2017, in a meeting between HHSK and RWS, all parties finally saw the benefits. HHSK really wanted to collaborate with RWS as the dike reinforcement turned out to be very complicated and RWS suggested a possible solution could be found, although no thorough study was immediately available. At this meeting, both parties talked openly about problems and options, and this was the final trigger to get the joint study started. Since then, both parties have been jointly researching integrated flood risk management plans.

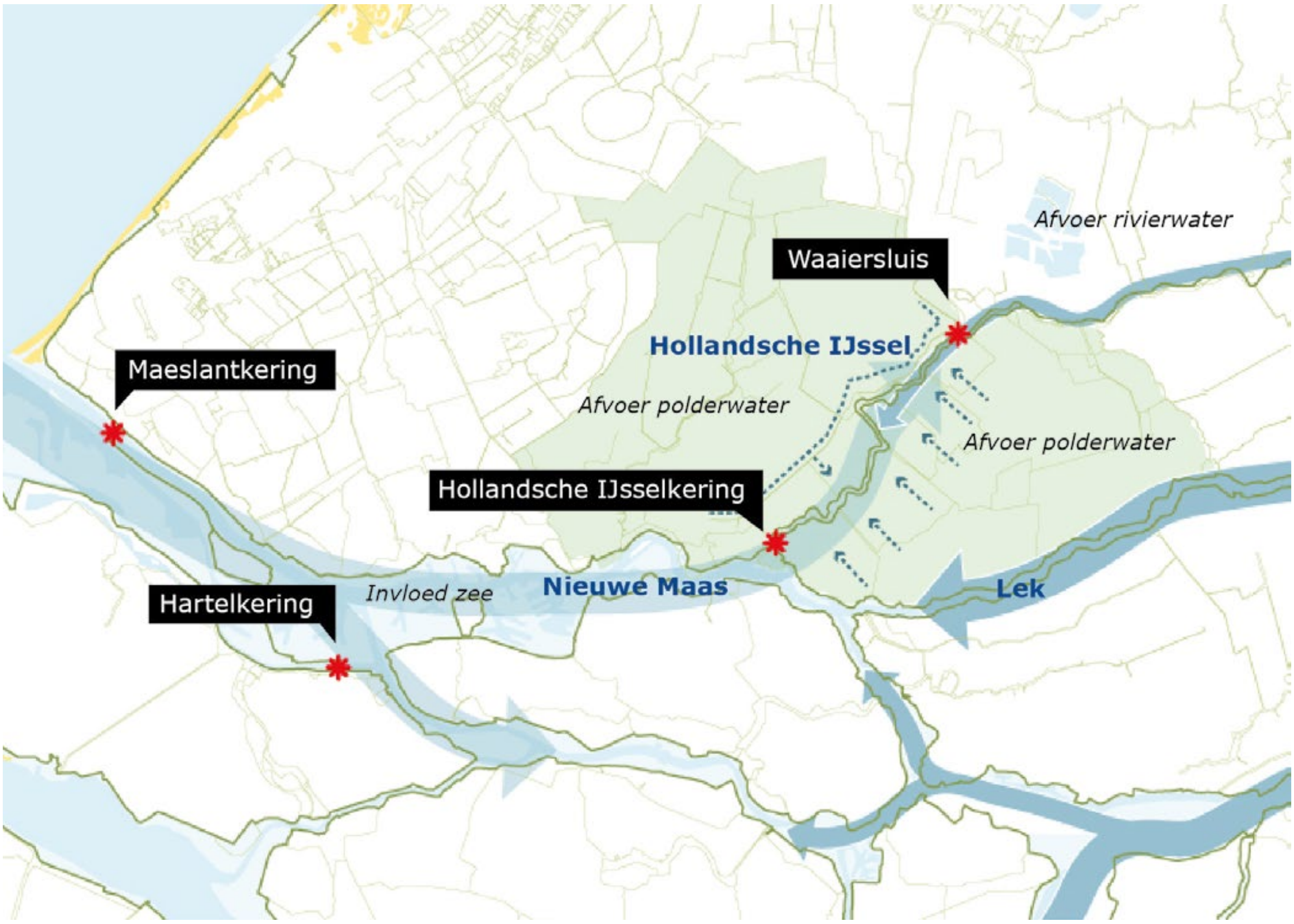


Figure 3: Factors of influence on the water system Hollandsche IJssel. Maeslantkering and Hartelkering are also storm surge barriers. Waaiersluis is a lock at the beginning of the Hollandsche IJssel.

Why: The purpose

The key challenges

In this pilot FPHIJ, our aim is to get a cost-effective solution for flood resilience of the Hollandsche IJssel river system, including the dikes of KIJK. While working on this aim, we experienced a number of challenges.

Challenge 1: Break free of the silo while working at the Hollandsche IJssel

The challenge was (and to date still is) to break free of the silo. Not to think of the self-interest of individual organisations but to focus on the bigger goal.

There is no external incentive to optimise the water system, apart from the Delta Program. As further described in challenge 3 every organisation deals with its own unique assets and risks which means resources are limited.

Challenge 2: Deal with the Hollandsche IJssel as a unique and complex water system

The Hollandsche IJssel is a unique and complex water system, with numerous factors playing a role for flood protection:

- High water from the sea (with the influence of the Maeslantkering Storm Surge Barrier and with potential sea level rise in future).
- High water from the river Lek (with potential higher discharges in the future).
- Regional water discharge at the Hollandsche Ijssel.
- Wind, causing waves at the Hollandsche Ijssel.
- Land subsidence (also under the dikes).

It was complex to really understand this system and to model it in order to work with it in our study. We used the Source-Pathway-Receptor Framework to get a mutual understanding of the system.

Next to this, there are various measures that can be taken for flood protection (dikes, HIJ storm surge barrier, flood plains, and limiting regional water discharge). These measures also interact, for example a better storm surge barrier ensures that more flood plains can be taken into account. These measures were included in our model to get an understanding of their impact on flood resilience.

Our approach was to include all necessary expertise, including the wider expertise within FAIR, in our project and have joint sessions to discuss and improve the results.

Challenge 3: Make space for innovation, together dealing with risks

The third challenge in this project is to make space for innovation: embracing and managing the risks of new approaches to develop innovative solutions. Both organisations (HHSK and RWS) are taking risks in this project. Our approach is to be open about these risks and discuss the best way of dealing with them.

- For RWS, the challenge is as follows. On the one hand, RWS has undertaken technical studies, indicating that the failure rate of the Hollandsche IJssel Storm Surge Barrier can become substantially lower. On the other hand, if RWS promises a lower failure rate, then RWS also wants and needs to fulfil this promise.

  How can you promise a failure rate that is not too conservative and not too promising?

- A further challenge is that RWS will get a lump sum amount for the investments in the storm surge barrier. Also, additional maintenance costs need to be paid for by RWS.

  How can you ensure that the financial risks are controllable?

- For HHSK, the challenge is that the current dike reinforcement is in preparation. On the one hand, HHSK wants to meet the deadlines; on the other hand, HHSK also wants to be flexible for new insights.

  How can you still be open for new challenges without losing sight of the end goal of the project?

- By working together, we are developing an approach that can deal with lower or higher failure rates than now expected. At the time of reporting work on this challenge is still on-going.

The intended effects

The intended effect is that the area around the Hollandsche IJssel is well protected against flooding with a cost effective package of flood resilience measures, taking into account climate change and other developments (e.g. soil subsidence).

It is an important boundary condition that the package of measures is accepted by all relevant parties (RWS, HHSK and the HWBP) as well as by society, and that it is financed appropriately with the risks being taken into consideration.

For KIJK, this means specifically: on going dike reinforcement anticipates the effects of the water system measures for the medium to long-term future. By doing so the project is more cost effective and fits better in the surroundings.

Another very positive effect of the pilot is that it has improved collaboration between the organisations involved.

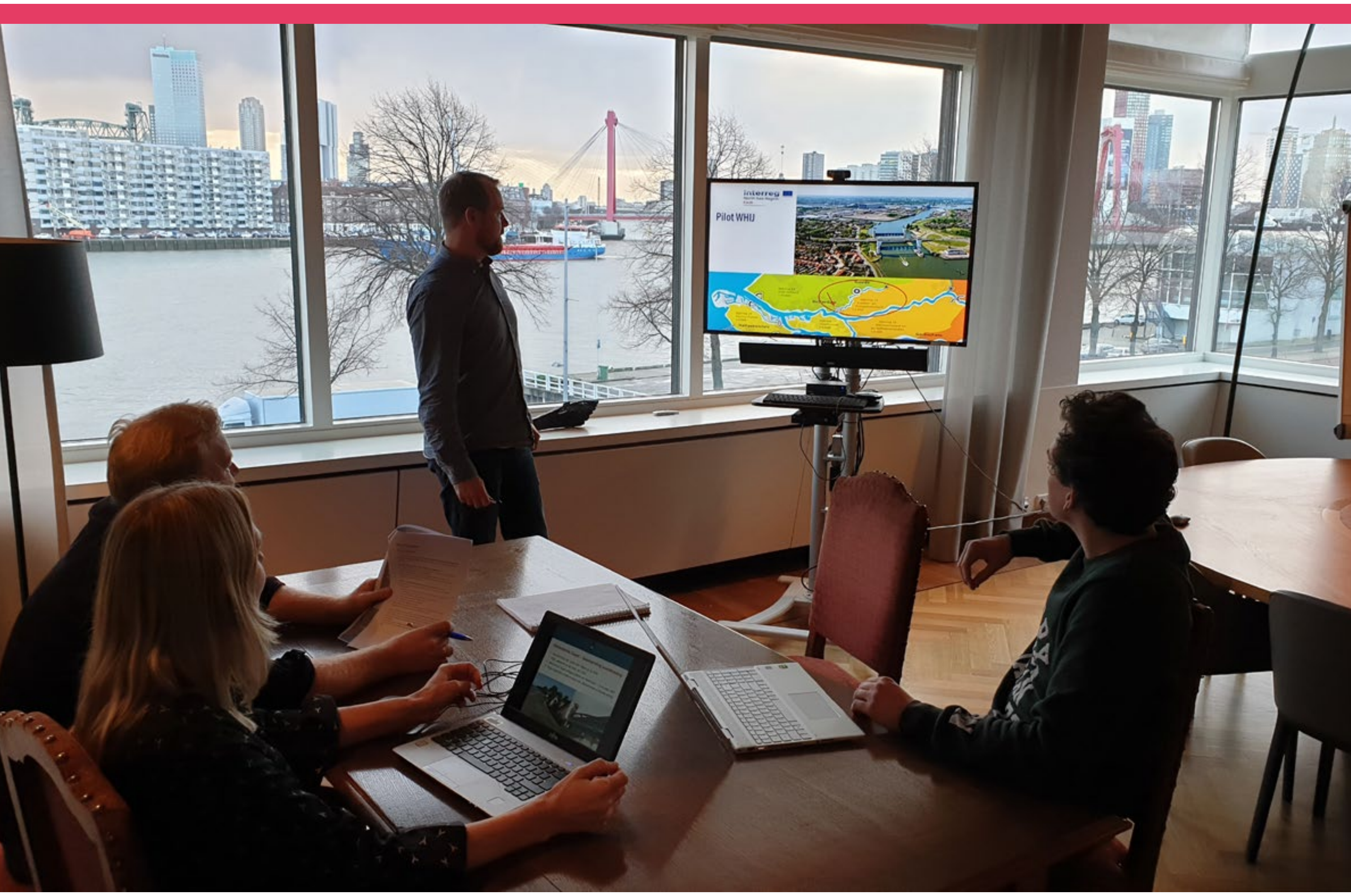


Figure 4: Collaboration between RWS and HHSK at the office of HHSK.

How: The approach

We have used a number of different approaches in order to deal with the challenges of the project.

Solution 1: Cooperation

The challenge was to break free of the silo. Not to think of the self-interest of individual organisations but focus on the bigger goal.

The pilot project team was formed by members from RWS and HHSK with an approach from the outset to look for common understanding and to utilise and respect members' specific knowledge, connections and expertise.

It was important to recognise that internal stakeholders including decision makers and their advisers were vital to the success of the project and needed to be involved and regularly updated from start to finish. This was achieved using stakeholder analyses and engagement techniques.

Solution 2: (Contra) expertise

Some of the studies touch on one of a kind knowledge (for example to determine the chance of failure for a storm surge barrier) for which there are few experts in the Netherlands. Because of this, the project team determined that for sensitive studies done by RWS or HHSK experts, independent experts would conduct second opinions.

For example, to determine the failure rate of a storm surge barrier is a very complex analysis (how big is the chance of failure of every part, how vital is that part for the whole barrier, what are the interdependencies between parts?). The outcome of these analyses is key information on which to determine the adaptation pathway for the whole water system HIJ.

This leads to the second challenge, the analysis of the water system. This can be achieved by collecting all of the knowledge from the surrounding water authorities and RWS, assembling all the collected information and analysis and combining this into different choices for adaptation pathways for implementation of water system measures.

The SPR framework was used in the pilot project to generate a common understanding of the system. After this, three separate analyses were conducted:

- Quantitative system analysis to analyse the impact of measures on the flood risk management.
- Failure rate analysis for the storm surge barrier.
- Cost-analysis of different measures, including investment costs, operation and maintenance costs.

Solution 3: No-regret dike design

For project KIJK it is important to design no-regret dike reinforcement. From the beginning of the project, changes of hydraulic loads in the future are foreseen. It was clear that around the expected end of lifetime of the storm surge barrier (probably between 2050-2100), the adaptation pathway for the HIJ would need to be updated. Also different progress scenarios of climate change play a role.

The way for KIJK to anticipate these future events is by adjusting design parameters along the way to a definitive design and to build a dike with the possibility of expansion.

Crucial design parameters are the potential failure rate of the storm surge barrier and the design period.

To ensure all decisions are based on the most up to date information available, KIJK and WHIJ have monthly meetings on the progress of studies and the conclusions.

Solution 4: Decision making process

The key parties were involved early in the process which enabled us to jointly formulate decisions and to discuss risks and potential conflicts and develop options to counter these.

To summarise our approach:

- Working in a project team consisting of team members from both organisations.
- Paying attention to stakeholder analysis and engagement.
- A communication process with the stakeholders.
- Managers and decision makers are involved from the start to the finish.
- Second opinions by authorities/experts on the subject being considered.
- The SPR framework was used to create a commonly accepted system image and identify the key parameters that influence the flood risk.
- Making use of each other's expertise and connections.

What: The outcomes

The main outcomes of the pilot are:

1. A better and joint understanding of the water system.
2. Adaptable dike design that is better suited for the environment.
3. Options for improvement of the storm surge barrier.
4. Working towards a 5% cost reduction on flood resilience measures and future flood risk reduction.
5. Improved cooperation between the water authorities.

The outcomes are expanded on below.

1. Understanding the water system

The System analysis (SPR framework) and Performance analysis provided an overview and common understanding of the water system. This formed the basis of the further analyses.

Next to this, the project WHIJ delivered a better quantitative model that helps to understand the system, the impact of measures and already optimises the design of the dikes. The model is already implemented in the statutory standard for the dike design. For KIJK, according to calculations done by this model, the hydraulic loading is significantly lower, which was expected. The reduction of required height is around 30 cm.

The other analyses done by WHIJ give insight into the possible measures by providing:

- A better understanding of how to improve the failure rate of the Hollandsche IJssel Storm Surge Barrier and the feasibility.

- Conclusion on how to deal with closing the Hollandsche IJssel Storm Surge Barrier – closing at low tide is a very effective measure.

- A better understanding of the impact of water from the regional water system on the Hollandsche IJssel – the regional water system has relatively little impact on the HIJ and at the moment does not have to be taken into account for possible measures.

2. Adaptable dike design

Before the pilots, when looking at the life cycle of project KIJK, it was clear that around the expected end of lifetime of the storm surge barrier (2058), the adaptation pathway for the HIJ will need to be updated.

At the end of 2019 the need to improve the storm surge barrier by 2030 to a failure rate of 1:1000 was apparent. The final decision on this will be taken by RWS, HHSK and HWBP in 2020. It is very likely that in the long-term future a much better storm surge barrier or even a permanent closure of the HIJ will be implemented.

One of the conclusions of a broad perspective study conducted by KIJK in 2017 was that the implementation of water system measures on the HIJ would mean that lower hydraulic loads on the dike are feasible. Based on this study HHSK decided to also lower the design period for height of the dike from 100 years to 50 years. This is for a design solution for construction updates to the dike. For a dike reinforcement solution in soil, the design period was already set to 20 years because of soil subsidence. There is a fair chance that system measures in the future will help in further reduction of hydraulic loads on the dike. If so, then the shorter-than-usual design period will be prolonged up to its usual lifespan of 100 years.

But if for any reason there is a setback in the performance of the flood defences, the design should have in-built ability to be easily expanded to the new statutory standard. Causes could be faster than expected climate change in the future, or the failure rate of the storm surge barrier is not able to meet expected improvement. These risks or chances are incorporated in this design.

Also the other way around, HHSK is now looking for dike reinforcement where it is easy to collapse the top of the construction, because of even higher than anticipated performance of the storm surge barrier or faster policy changes around the storm surge barrier.

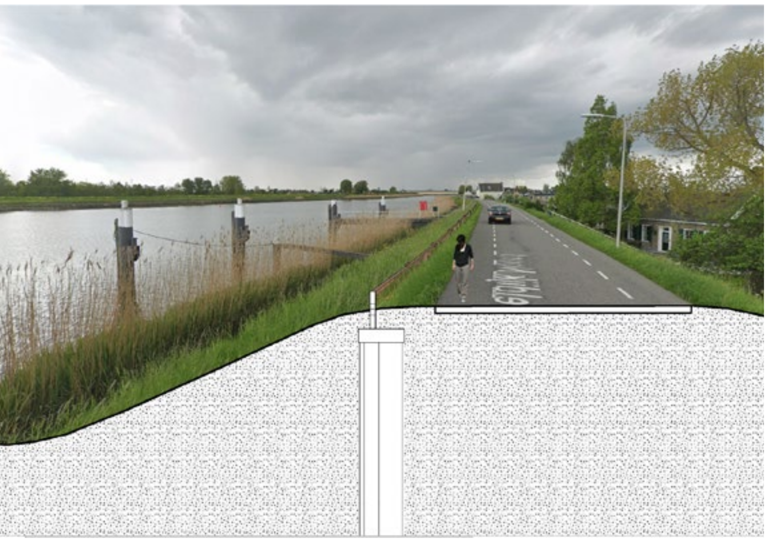


Figure 5: Adaptable design of the dike for the top of the construction

3. Storm surge barrier improvement

The water system analysis in 1 combined with a study on the improvement of the storm surge barrier concluded that it is feasible and cost effective to reduce the chance of failure from 1:200 (the current safety standard) to 1:1000. Dike reinforcement cost reduction will be 40 M€ and the expected cost for the barrier improvement is approximately 10 M€.

The next step is to look for finance for all measures, regardless of who the asset owner is. Dike reinforcements are 90 % financed by the national flood defence program. This program is for dikes that don't meet the safety standard. By the end of 2019, the HWBP had approved in principal on the exchange of financial means (e.g. savings in the costs of dike reinforcements are used for investments in the barrier). HHSK and RWS are now working out the details to get the final approval for the exchange of means in the middle of 2020.

Figure 6: One of the doors of the Hollandsche IJssel Storm Surge Barrier is closing due to a storm surge at sea

4. Adaptation pathway update

Project WHIJ has worked on an optimal solution for flood resilience of the Hollandsche IJssel. In the analyses, we were not only looking at the investment costs but also at the operation and maintenance costs of the assets. The cost benefit analysis concluded that an investment in the storm surge barrier would result in substantial savings of the total costs for flood protection measures along the Hollandsche IJssel (approximately 5% savings in total costs, 30 M€ on 600 M€).

If the final approval on the exchange of means is made in 2020, the adaptation path will be updated and the investments in the storm surge barrier will be included. These changes will be for the middle to long-term period (10-30 years). This joint update of the adaptation path resulted in a better understanding between RWS and HHSK and a willingness to look further than the borders of each individual organisation.

5. Cooperation

Finally, the pilot FPHIJ contributed to a better understanding and cooperation between RWS and HHSK. In the future, we intend to keep collaborating as we did in the pilot, because new knowledge of sea level rises and of the water system will give us the ability to work on the next optimal solution.

The overall benefit of increased cooperation will be to align multiple planning processes.

Reflection on innovation

In our pilot, we experienced some new challenges. To face these challenges, we used different working methods and approaches, but also experienced knowledge gaps. Finally, we realised that some of the policy recommendations, given earlier in the Policy Brief, were also applicable to our pilot.

Reflection on best practices

During the pilots, the following practices worked very effectively:

- Firstly, the basis was an initial thorough analysis ensuring both parties had the same deep understanding of the system, which allowed us to improve the hydraulic loads for the development of the dikes.

- Secondly, we learned to consider the lifespan of our assets. HHSK lowered the lifespan of the dikes to be developed making it adaptable for future improvements within the system.

- Thirdly, a thorough analysis of failure rate improvement was done. This analysis was done with a number of representatives of the asset owner, which created support within the organisation for the possibilities for lowering the failure rate.

Reflection on knowledge gaps

During our work, we also experienced a number of knowledge gaps.

- Firstly, how do we engage key relevant stakeholders in asset management as shareholders and come to an innovative financing arrangement? For our pilot, we need to connect financial budgets across sectors (financial means for dikes need to be transferred to financial means for storm surge barriers). These budgets are both held by the HWBP and they are strictly separated. The transfer from one to another has not been done before in the Netherlands. To find the best way to do this we have held several meetings between HHSK and RWS and also with HWBP to discuss the best options. By the end of 2019, the HWBP had indicated that they are positive on the exchange of financial means (e.g. savings in the costs of dike reinforcements are used for investments in the barrier). HHSK and RWS are now working out the details to get the final approval for the exchange of means in the middle of 2020. Also we use the guidelines for Room for the River projects (in which this transfer might be done in the future). A challenge will also be to retain shareholders involvement in the future to keep the focus on the entire system (instead of on individual organisation's priorities).

- Secondly, there is a knowledge gap in how to communicate effectively with the public, specifically taking into account the uncertainties in our models and the translation from technical findings to create an understandable and engaging story.

- Thirdly, by permitting innovations on the design of the dike reinforcement, introduce the chance (or risk) of adjustment of the design of the dike but there remains a question of how to do this in the most efficient way.

Reflection on policy recommendations

- A key challenge at the outset of this project was to break free of the silo, which was achieved by collectively analysing the total water system to ensure the team started from the same place with the same information. This allowed us to plan the investments in flood defence, together with the water authority and RWS, and to make arrangements to cover finance and risk.

- The second policy recommendation is to make space for innovation. In our pilot we demonstrate how to embrace and manage the risks of new approaches. Our practice here was to be open about the benefits and risks for ourselves and discuss these collaboratively.

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Pilot renewing sea dike Middelkerke

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Summary

Flood risk calculations of the Coastal Safety Master Plan show that there are major risks for victims and damage caused by flooding from the sea in Middelkerke. Tackling these risks is therefore a priority. This weak zone extends from Westende, part of Middelkerke, to Middelkerke.

The option that was chosen to reinforce this weak zone consists of widening the current sea dike with a stilling wave basin (SWB) and providing dunes and beach nourishments in front of the existing sea dike. It concerns two sub-zones of Middelkerke: Westende-Bad and Middelkerke-Bad. The project area is approximately 4 km long. At the Middelkerke-Bad casino, the necessary safety is obtained by providing a water barrier seaward from the casino. This must connect to the development of the sea wall on both sides of the casino. The usage of dunes and beach nourishments is very adaptive (the beach or the dunes can be heightened) to accommodate the expected sea level rise and the resulting uncertainties. The project is innovative; a stilling wave basin is very efficient in reducing the wave energy and this project will act as the first use of it on a large scale. The dune before dike principle hasn't been tested before and will be a pilot project. The chosen measures are adaptive. In case of a sea level rise, the beach in front of the new sea dike can be strengthened or the dune itself can be heightened. The new dike and dune can facilitate different functions: recreation, nature, economic and so forth.

Figure 1: new sea dike Middelkerke, courtesy: Afdeling Kust

The Context

The renewal of the sea dike is a unique opportunity for the municipality of Middelkerke to put Westende back on the map as a tourist resort. The attraction of the two areas is closely related to the way the forces of nature, wind, sun and sea have, over time, dramatically evolved the landscape, especially the dunes..

The experience of these forces of nature has changed dramatically over time. Every new phase in the development of the coastal towns brought new elements into the coastal landscape. This project offers the opportunity to recreate the individuality of the coast with a structured design for the sea dike.

The original design of the first sea dike from the Interbellum was built on top of the existing dunes and focused strongly on the effects of seawater on the landscape. The adjacent buildings were only three to four storeys high so that the promenade on the sea front was not overshadowed by the buildings. Because the dike was much higher than the beach, a panoramic view on the horizon was created. During storm tides, the sea crashed against the sea dike, an attraction in itself. Sporadic dune formation for the sea dike was left undisturbed. The benches were placed parallel to the sea dike and there were no railings present.

From the 1970s, the sea dike was renewed and the unit gradually disappeared in materialisation and detailing, through the addition of windshields, covered terrace extensions and railings. At the same time, the adjacent buildings were raised to 9 storeys and became sand replenishments for coastal safety reasons; as a result of this the tide line was further away from the sea dike. Because of these changes, the attractiveness of the natural features of the landscape has declined. The current sea dike is outdated and the local government are strongly in favour of a new, more attractive sea dike.

This project is part of the Coastal Safety Master Plan to protect the Flemish coast against flood from the sea (return period of 1000 years). The project aims to incorporate as much varied residential, economic, tourism and recreational benefits as possible. The Flemish government also provides funding for the project, but only the basic solution, the extra costs for the architectural upgrade have to be funded by the local government whom, along with key stakeholders, have been involved from the beginning.

Why: The purpose

The key challenges

The Flemish government only finances basic flood protection but realises that a mono functional design will not meet the wishes of the stakeholders. The challenge is how to make stakeholders (local governments) into shareholders. Stakeholders are not the problem, but part of the solution. The design of the project together with the financing was and remains a big challenge. Each party has different views and interests and they do not necessarily align, also much of the design was also unprecedented due the usage of dunes and stilling wave basins.

The original assignment was to develop a wave-damping extension on the sea front at Middelkerke and Westende to fulfill the need for a new protection against flood from the sea, due to predicted climate change until 2050. The challenge was to turn this important investment into an opportunity and to give both Middelkerke and Westende a unique meaning.

Also the natural environment was important to attract tourism and all groups including residents who use the area to meet and relax on a daily basis.

The biggest challenge was to offer a solution which was deliverable within the available budget. A hard structure installation was too expensive and therefore the innovative and more cost effective dune solution was proposed.

A second challenge was how this investment can look beyond 2050, taking into account future trends and changes, where climate change will certainly require additional measures. Both the dune and the stilling wave basin are very efficient and adaptable towards a future sea level rise.

The intended effects

The main ambition behind this project is to re-introduce nature as a dynamic coastal defence system and to bring back the contact between nature and the sea. Hard structures require large investments and seem, because of unpredictable climate change and sea level rise, to have an expiration date. Creating more environmentaly friendly, instead of hard, infrastructure is an innovative way to develop new coastal defences. With this project we demonstrate that natural structures, which are cheaper and easier to construct, are a more sustainable solution and moreover have a greater experience value than hard infrastructures. A more flexible and cheaper structure requires more management, however, this management provides some employment. The further follow-up of the project through regular monitoring and data collection/analysis can also be the perfect opportunity for scientific learning. So this represents an opportunity to develop an innovative and a cross-border model that supports the belief in the concept of a green sea dike.

How: The approach

The Coastal Safety Master Plan includes various innovative and adaptable solutions to protect Middelkerke and Westende against flooding from the sea.

The Flemish government tries to include local cities and communities as much as possible but can only offer a basic solution. Local governments can participate in the different projects with extra funding to include architectural upgrades or even different solutions, which can be beneficial for their specific locations but have to finance these extra costs.

This incorporates certain risks. The local government does not always have the necessary funding and due to a change in the management of the cities and communities, visions and decisions can change. By including them they will become a shareholder and can actively try to build support for the project. During the design phase there is intensive cooperation and consultation with local inhabitants and local businesses as well as relevant governments agencies, through meetings and the sharing of information and opinions.

Figure 2: new dune in front of the sea dike, courtesy: Afdeling Kust

What: The outcomes

The standard solution was to secure the municipality of Middelkerke by means of a large beach nourishment which would be financed entirely by the Flemish government. Another possibility was to expand the existing sea dike and to provide a larger beach in front of this sea dike. This (much more expensive) solution was preferred by the municipality who were also willing to co-finance the project. As a result, the municipality was immediately involved and there was sufficient support for this project.

The result is an innovative and adaptive design that lends its own character to both Middelkerke and Westende, is very flexible and can easily be adapted to cope with the sea level rise. The design also takes into account the different environmental, economic, tourism and recreational needs of the locations. Due to the use of the dune-for-dike principle, whereby instead of a hard dike a natural solution is used, less investment is required, which increases maintenance costs but is more cost-efficient in the long term. The increase in maintenance costs is caused by the dunes tendency to grow requiring periodical maintenance to prevent build up which will obstruct the view from the sea dike towards the sea.

The implementation of the project was delayed due to a change in the management of the municipality and a shift in the proposed projects, a risk that was difficult to estimate in advance.

In the project great importance was attached to consultation with all relevant partners. The construction of the sea dike is an important investment from which all parties need to benefit. Focus interviews, workshops and information updates were used to understand what local communities, businesses and other interest groups saw as important factors in relation to the project. Clients and key stakeholders are involved in an umbrella working group that closely monitors the project. The steering committee records and evaluates interest group opinions before a thoughtful transition can be made through the various steps in the design process.

Reflection on innovation

The dune-for-dike principle is innovative. It is the first time that a hard structure will be replaced by a dune over such a large distance. This solution is not only cost effective, but also uses natural principles. This solution is adaptive, when the sea level rises, the dune and the beach in front can easily be raised to meet safety standards. The dune area itself can become a natural attraction and support tourism as well as the local environment.

The use of a stilling wave basin on such a scale is also innovative. This structure provides a very efficient damping of the attacking waves during a storm. Because of this, a less high beach needs to be installed for the sea dike.

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Further reading

The documents relating to the FAIR project can be found on the following websites:

http://www.fairproject.org/

https://northsearegion.eu/fair/

Partners

FAIR brings together Asset Owners (facing real problems and challenges) and leading scientists (with domain expertise) to share and develop innovative solutions to the management of flood protection assets. In doing so, FAIR is the first collaboration of its kind.

Back to Further Reading

Interreg
North Sea Region
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Pilot Ribe Polder

A Practice Brief from the Interreg
North Sea Region FAIR project

June 2020

Preface

The FAIR project

FAIR brings together flood protection asset owners, operating authorities and researchers from across the North Sea Region (NSR) to share the policy, practice and emerging science of asset management. Despite the diverse character of the NSR, asset managers face common challenges across the region.

The FAIR project aims to develop and implement improved approaches for asset management of flood protection infrastructure. It will optimise investment planning by exploring mainstreaming of these investments with other policy domains, and by mapping planned investments across a wide portfolio of flood protection assets. FAIR will also identify cost-optimal adaptive infrastructure upgrades by exploring a variety of technical designs, with adaptability and life cycle costing for various performance levels.

This Practice Brief

FAIR supports the delivery of local upgrade or maintenance projects and schemes for flood protection assets or systems. This Practice Brief presents **why** the project or scheme has been proposed. It provides an overview of the key challenges and intended outcomes. It elaborates on **how** these challenges have been addressed, and presents **what** has been the outcome from implementing this approach. Finally, the Practice Brief reflects on the innovation of the pilot with respect to the best practices in the FAIR end report and the FAIR recommendations.

The FAIR results

The demonstration and subsequent widespread implementation of the improved approaches and techniques will reduce the probability of flooding and minimise the impact of floods across the North Sea Region. This will improve the climate resilience at target sites covering most of the NSR. 'Target sites' are those areas being protected by entire flood protection systems (e.g. Danish coast, Swedish Coast, Flemish Coast, Dutch Delta) and individual assets (e.g. Hollandse IJssel storm barrier, Hamburg flood gates, etc).

The result indicators for the FAIR project are:

1. Reduce the life cycle costs of flood protection infrastructure through better targeting of investment;

2. Encourage the multi functionality of flood protection infrastructure through mainstreaming (that is, connecting) investments with other policy objectives;

3. Increase the life span of flood protection infrastructure through smarter maintenance and renovation.

Summary

The town of Ribe is located in an area with multiple sources of flooding. To the west, a dike protects the town and its surroundings from flooding from the Wadden Sea. For now, this dike still has the capacity to fulfil its function, but climate change will put pressure on the dike through sea level rise and increased storminess. Flowing through the pilot area, two streams, the Rivers Ribe and King cross the dike through sluices. In the winter season, large amounts of water are present in the polder. The winter season also brings the highest discharge in the streams, which cannot flow into the sea, as the sluices are frequently closed for long periods of time due to high water levels in the sea. Pressures on the system will increase in the future, making the current state of affairs unsustainable.

Through FAIR, The Danish Coastal Authority and Esbjerg Municipality have gained understanding of the system surrounding Ribe. The experience from this pilot site is used in order to demonstrate the solutions of the FAIR project, and this experience is transferable internationally.

The Context

The city of Ribe as well as the area around Ribe faces special challenges according to future climate change. Historically the city of Ribe and the Ribe polder has suffered from many and severe storm surges. In 1912 a dike to protect the polder in which Ribe is located was established. Where the Rivers Ribe and King run to the North Sea, sluices were built. These assets have prevented the city of Ribe from being flooded but they will need renovation/improvements because of expectation of raised sea levels and more frequent and heavier storms in the Wadden Sea Region.

Due to climate change the sluice is expected to be closed both more frequently and for longer periods when compared to the present situation. This will increase the problems created by backwater from the Rivers Ribe and King, because the water will be stowed behind the sluices. The problems are already present in the towns of Gredstedbro and Vilslev, situated along the River King, where primarily agricultural land, but also a small number of residential houses have been suffering from flooding during the winter period.

Accordingly, it is expected that it will be necessary to invest in more adaptive solutions against flooding in the future. These solutions need to be cost effective under the uncertain impact of climate change and likely high levels of investment. It will probably be cost effective to implement some solutions continuously during urban development and during civil engineering works, while other solutions are expected to have their own planning and implementation cycles.

It is also characteristic to the pilot that in Ribe the water level upstream of the city is intentionally varied through the year, by the operation of three locks. The total catchment area is 925 km² and up to 55.000 litres/sec is distributed between the three locks and one stream (the Stampemølle stream). The locks are of tourist interest but their function as water level regulators is also important for the moistening of the subsurface layers of partly organic material/culture sponge of Ribe. If the cultural sponge is drying out, the old buildings are in risk of setting and will affect the cultural heritage of Ribe in a negative manner.

The 3 locks in the city of Ribe are owned and managed by Esbjerg Municipality as is the Kammer Sluice.

The dikes along the Wadden Sea and the sluice at the River King are owned and managed by local dike associations, but with significant economic help from the municipality and some limited technical guidance from Danish Coast Authority. Danish regulation demands municipalities to designate areas at risk of flooding and to include remediation in municipal planning. Also landowners are responsible for protecting their own land. Therefore the flood protection of Ribe Polder will have to balance rather complex circumstances and interests.

Why: The purpose

The key challenges

From ad-hoc management to strategic approach via tactical handshake. When renovating dikes and sluices or implementing other interventions in the polder it is of vital importance to integrate climate change predictions in the protection standards. Lack of standards regarding design levels, which include climate change, has been one of the challenges for Ribe polder.

To set these standards, a system analysis of the whole Ribe Polder is needed.

Another key challenge is the opportunity to analyse performance of existing assets with the right preconditions. An up to date flooding map is needed, considering the joint probability aspect of storm surges and long-lasting rainfall on a wet polder in wintertime, under different scenarios.

It is a yearly wintertime experience, that the polder will be wet with visible standing water on both sides of the ring road around Ribe. The water source can be ground water as well as runoff from the rivers.
This means, that it is necessary to set a basic water level before calculating the effect of rain events.

This has already been done in Esbjerg Municipality´s own previous flood mapping, but this simply adds rain events to a terrain model and does not include detailed modelling of river systems.


Ill: Ribe polder viewed from the Wadden Sea in a winter-situation, 2014.

Analysing performance of existing assets also includes asset strength calculations; in the case of Ribe polder it means calculation of dike strength as well as assessing the performance of the sluices.

As explained, the responsibility and expertise of flood protection is divided among different organisations. It is therefore beneficial for Esbjerg Municipality to strengthen both internal and external cooperation. Internal cooperation amongst the department responsible for managing the assets, the department responsible for the rivers and the department for climate adaption planning. External cooperation amongst the local dike associations, citizens, landowners, climate adaptation planning and Danish Coast Authority as well as the municipality in order to transfer knowledge and improve acceptance of possible new solutions as alternatives to existing pathways. Articulating this discussion between stakeholders with legitimate different interests is a key challenge.

Assets for flood protection usually require large investments, often made without certainty therefore, it is beneficial to use a decision-making tool/model to strengthen the basis for decision making. In FAIR it has been assumed relevant to use the so-called DAPP (Dynamic Adaptation Policy Pathways) for this purpose.

Explained in short, the model operates with certain adaptation pathways combined with different climate scenarios. See further explanation below.

The intended effects

The ultimate objective for Esbjerg Municipality and the Danish Coastal Authority in this project is to provide the citizens of Ribe with a safe, liveable and sustainable town. To support this objective, increased understanding of the system must be achieved, and knowledge gaps identified.

Considering limited availability of funds and the complexity of the task, asset management must become more effective. In practice, this means mainstreaming flood risk planning with other planning activities on a strategic level, setting requirements based on data on the asset-level, and linking these processes among other things.

On a practical level, FAIR aims to provide a good understanding of the following issues in order to reduce the future risk of flooding:

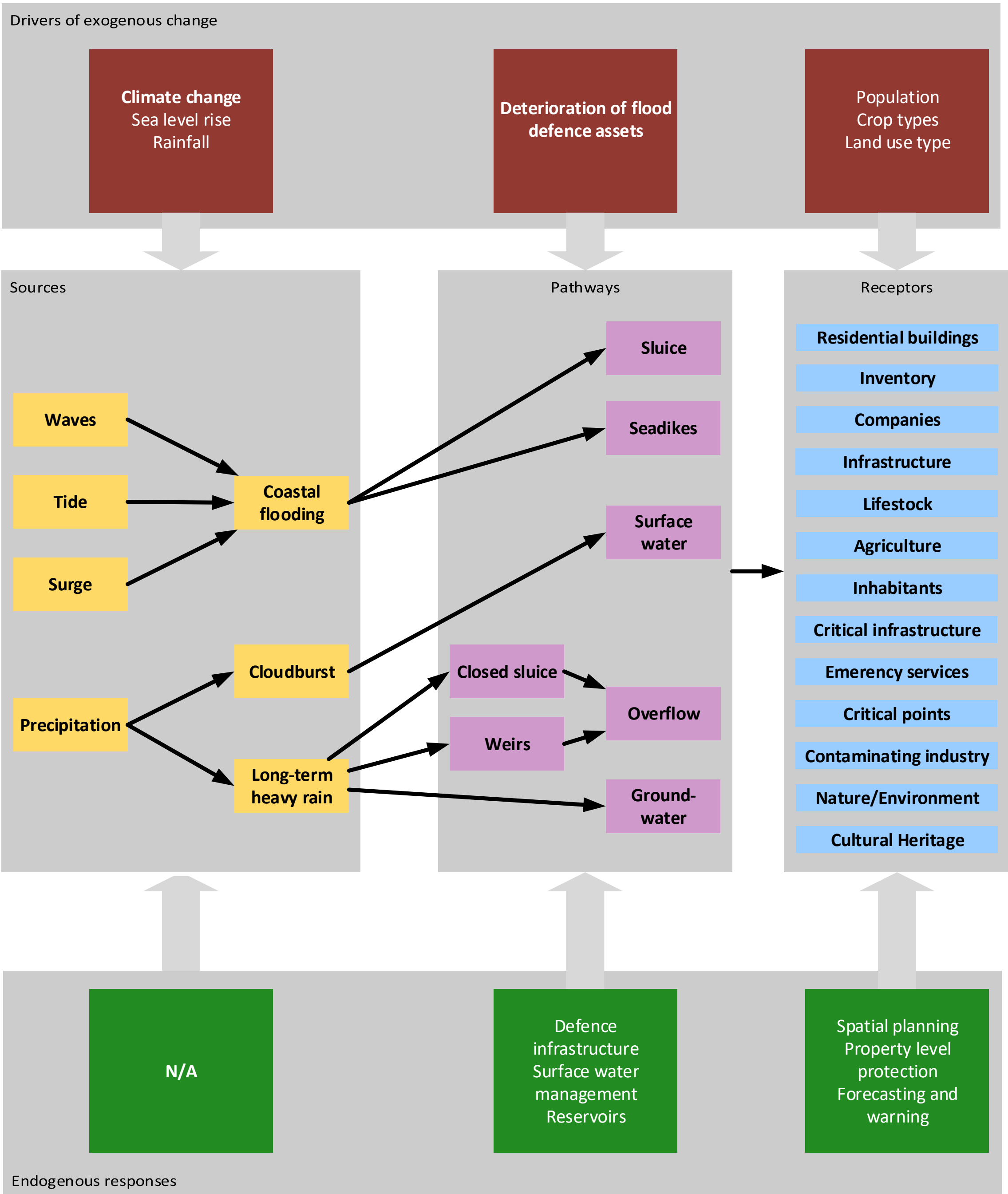
- Existing assets and their co-dependencies in a system context.
- The sources of flooding.
- Flooding mechanisms.
- How requirements can be set (Denmark does not have a national standard).
- Risk and acceptable risk.

Working with these issues will help the local authority, landowners and stakeholders to improve the strategic approach in climate adaptation planning and asset management.

How: The approach

The SPR analysis

The first step of the approach is making a low-level systems analysis, also called a “system description” using the SPR framework. The city of Ribe, where most of the flood receptors are located, lies in a flood plain of approximately 95 km^2. A flat sea dike and a sluice at the Wadden Sea are the main assets in the area. The dike is grass covered, with a sand core, a crown height of 6.88 m and 1:10 seaward slope. The main sources of flooding considered in the analysis are the sea and the watercourses. The largest watercourse in the area is the River Ribe , which flows through Ribe city and the polder. A sluice is located at the intersection between the sea dike and Ribe. The River King is the second largest watercourse in the area. It crosses the northern part of the polder and flows into the Wadden Sea through an outlet on the sea dike.



A preliminary analysis of flood sources has highlighted the need for better understanding of the causes of floods and the impact of climate change. Consequently, the main sources of flooding are analysed in detail in a series of technical reports that look at the joint probability of high sea levels and high discharge in the streams. This is especially important because of the mechanism of flooding of the Ribe polder.

The floodgates on the River Ribe close automatically when the seawards water level exceeds the inland water level (this situation can sometimes last for several days). If the discharge is high enough, the stream overflows causing flooding. The amount of long-term rain is critical as it can saturate the polder and increase the discharge into the stream, leading to an increased likelihood of flooding, especially when the floodgates close because of high water levels in the sea.

Sea Water Level

The statistical return values for Ribe (Højvandsstatistikkerne 2017, Kystdirektoratet), at present and the future climate affected return values are presented below in Table 1.

The calculations of the future water level return values are based on:

a) DMI's expected water level rise for the IPCC scenario RCP 8.5 (Notat om havvandstand – Middelvandstand I Danmark, Juni 2015) and

b) The isostatic lift rate of Ribe area. The isostatic lift is subtracted from the expected water level rise resulting in a 32 cm water level rise for scenarios in the year 2065 and 80 cm for the year 2115.

Table 1

Univariate Statistical Data - Projected data

Water Source	MT50 2017	MT100 2017	MT50 2065	MT100 2065	MT50 2115	MT100 2115
Ribe Sea (m)	4.70	4.88	5.02	5.20	5.50	5.68
Ribe river (l/s)	42691	44825	47600	49735	52104	54239
King river (l/s)	24958	26333	27828	29203	30488	31862

Precipitation and discharge

Changes in the weather will influence the current amount of yearly precipitation. DMI have estimated a local increase in precipitation (up until year 2100) based on IPCC's global future precipitation models (scenario RCP2.6 and RCP8.5) (Fremtidige klimaforandringer I Danmark, Danmarks Klimacenter rapport nr. 6, 2014) and KDI have extended the curve for scenario RCP8.5 to reach year 2115 (see figure 1 below). KDI calculates and increase of 11.5% in year 2065 and 21% in year 2115 for winter scenarios.

For the modelled climate scenarios the increase in precipitation (+11.5% in 2065 and +21% in 2115) is used as a direct response in discharge. This means that an increase of 11.5% in precipitation equals an increase of 11.5% in discharge (for a winter scenario). This method produces a best estimate, and not a highly accurate description of the local situation. Table 1 shows the return values of the two streams in year 2065 and 2115. In both cases, an increase of 11.5% and 21%, for the respective return periods, is used.

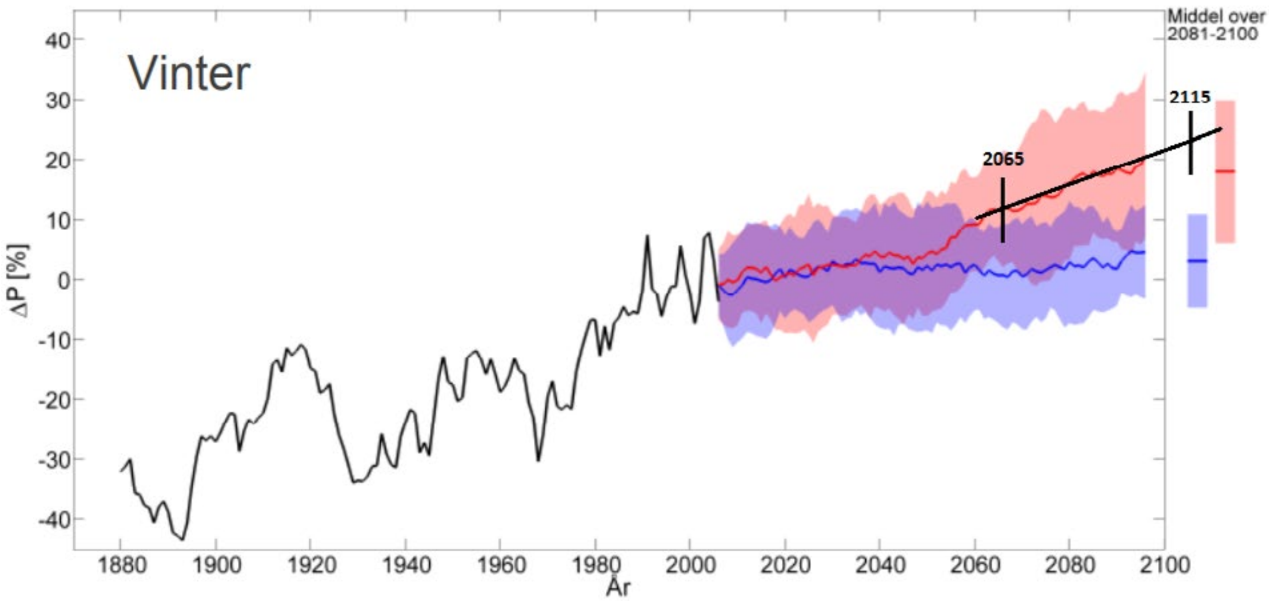


Figure 1

The statistical return values for the discharge can be seen in table 1. The original statistics are then projected to fit the model boundary. Data is projected upstream for both Ribe river and King river. The future scenarios are produced by adding 11.5% and 21% to the MT50 and MT100 scenarios (for the year 2065 and year 2115) see above.

The event length (in days) of the Rivers Ribe and King is 5 days for MT50 and 7 days for MT100. The lengths are estimates based on a comparison analysis between several catchments (around Denmark) and the lasting time of the respective events.

A quick analysis of the uncertainties related to flood sources highlight that any technical solution for the system has to be adaptable. The main sources for uncertainty are data quality, sea level change, and river discharge scenarios and data series length.

Pathways

A preliminary analysis is made based on earlier work and using a static flooding model. Given present conditions, the main dike is predicted to withstand a 400-year event from the Wadden Sea. It is also expected to be able to withstand a 100-year sea level in 2065 but not in 2115. Flooding from the stream occurs in the event of a discharge greater than a 20-year level in 2019. The main failure modes for the dike are, overflow, overtopping and breaching.

For the sluice, two failure modes are considered. Open and shut. In addition to this it is important to note that the height of the gates is 1 metre lower than the djacent dike.

In Denmark, the construction and maintenance of flood defence infrastructure is decentralised. The dike is maintained by a local board, which collects a dike tax from the protected properties in the polder. Following the biannual inspections performed by the dike board and the Danish Coastal Authority, condition grade reports and recommendations are compiled.

Historically, the state, the regional administration and the local authority have jointly financed large reinforcement works, with the local authority being responsible for regular maintenance. Future work on the dike and sluice is not expected to follow the same financing model, as no party is legally required to do so. All major reinforcement and maintenance works are currently performed impromptu, typically in the aftermath of flood events or significant degradation. The main weakness of the model is the diffusion of responsibility and lack of provisions for long-term planning of reinforcement and maintenance. Future projects should include a life-cycle study that includes building, inspections, maintenance, reinforcements and, if relevant, removal/demolition.

To further the understanding of the system, the Danish Coastal Authority is performing a performance analysis for the most important assets.

Flood modelling

The extent of the flood given different scenarios is calculated using a dynamic numerical model using an unstructured mesh. The model takes into consideration the terrain surface and type, but does not account for infiltration, precipitation or evaporation.

A precise model has been created for the two watercourses: the Rivers Ribe and King. The model includes structures such as bridges, culverts, weirs and sluices and accounts for longitudinal difference in rugosity along the streams.

Two flood scenarios have so far been modelled in detail:

1. 50-year seawater level for the Wadden Sea, 50-year level discharge for the two streams.

2. 50-year seawater level for the Wadden Sea, 50-year level discharge for the two streams in the year 2065, considering expected changes in sea level and river discharge.

The municipality manages the rugosity of the river by biannual interventions. The positive effects of this are also apparent in the model. Seasonal differences in rugosity or difference along the same watercourse have a great influence on flood extent. Careful management of the rugosity of the riverbed can lead to better control of flood extent. This can be studied further by using the river part of the model.

The models produced by the Danish Coastal Authority appear to underestimate the extent of flooding for the given scenarios. The main reason for this is the lack of a groundwater model and the relatively short modelling period. Suggestions for improvement of the model are provided.

The model can accommodate changes in order to explore different technical solutions for the system. For example, different operating rules for the Frislusen weir can be simulated using the river model. Further refinement of the model is possible, as will be described later.

Vulnerability analysis

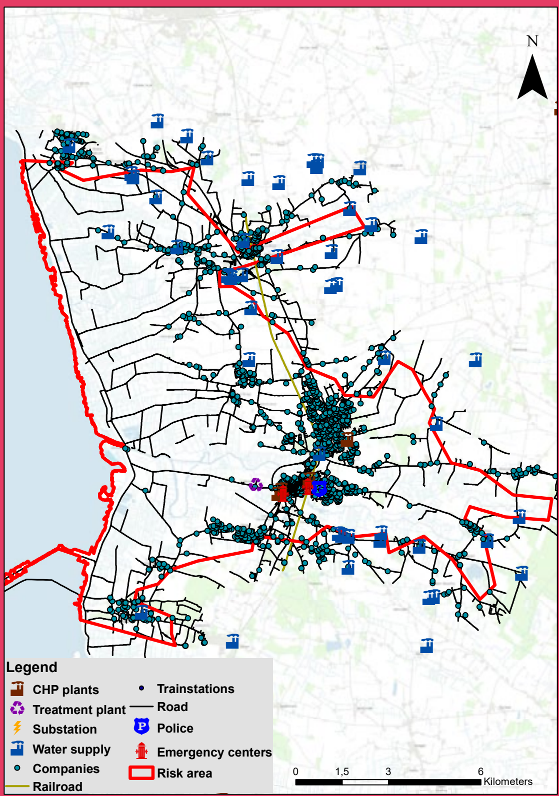
For the mapping of the receptors, the following indicators are considered:

- Residential buildings
- Inventory
- Companies
- Infrastructure
- Livestock
- Agriculture
- Inhabitants
- Critical infrastructure
- Emergency services
- Critical points
- Contaminating industry
- Nature/the environment
- Cultural heritage

Each type is then assessed using five vulnerability categories: 1/Very Low, 2/Low, 3/Medium, 4/High, 5/Very High.

Vulnerability mapping

The figure below shows where the receptors are located within the risk area. The area around the town of Ribe is shown in the second image.



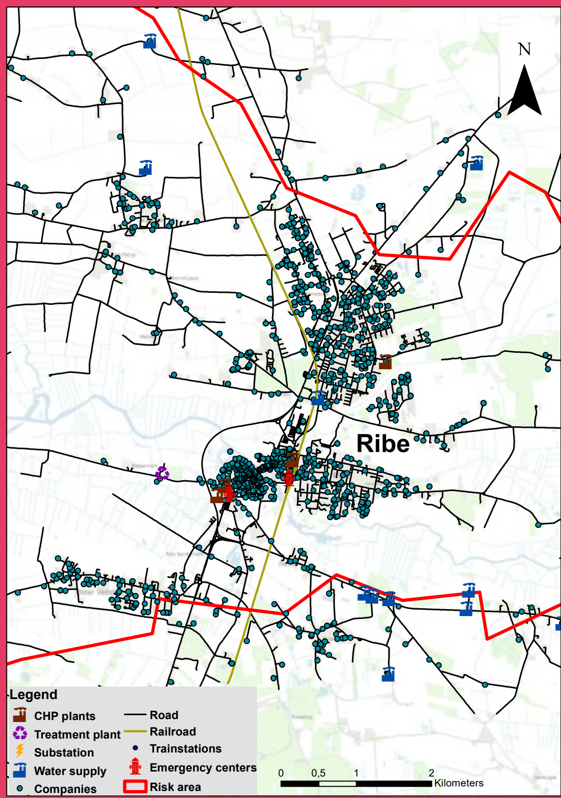


Figure 2

In the event of flooding it is important to know which areas are likely to be affected and the extent of damage the flooding may cause. Therefore, several vulnerability analysis models are produced to map the areas which could be affected by the different flooding scenarios. The vulnerability models are divided into tangible and intangible models. The vulnerability and risk models are listed in table 1. For more information on the models, see Kystdirektoratet, 2013.

Table 2

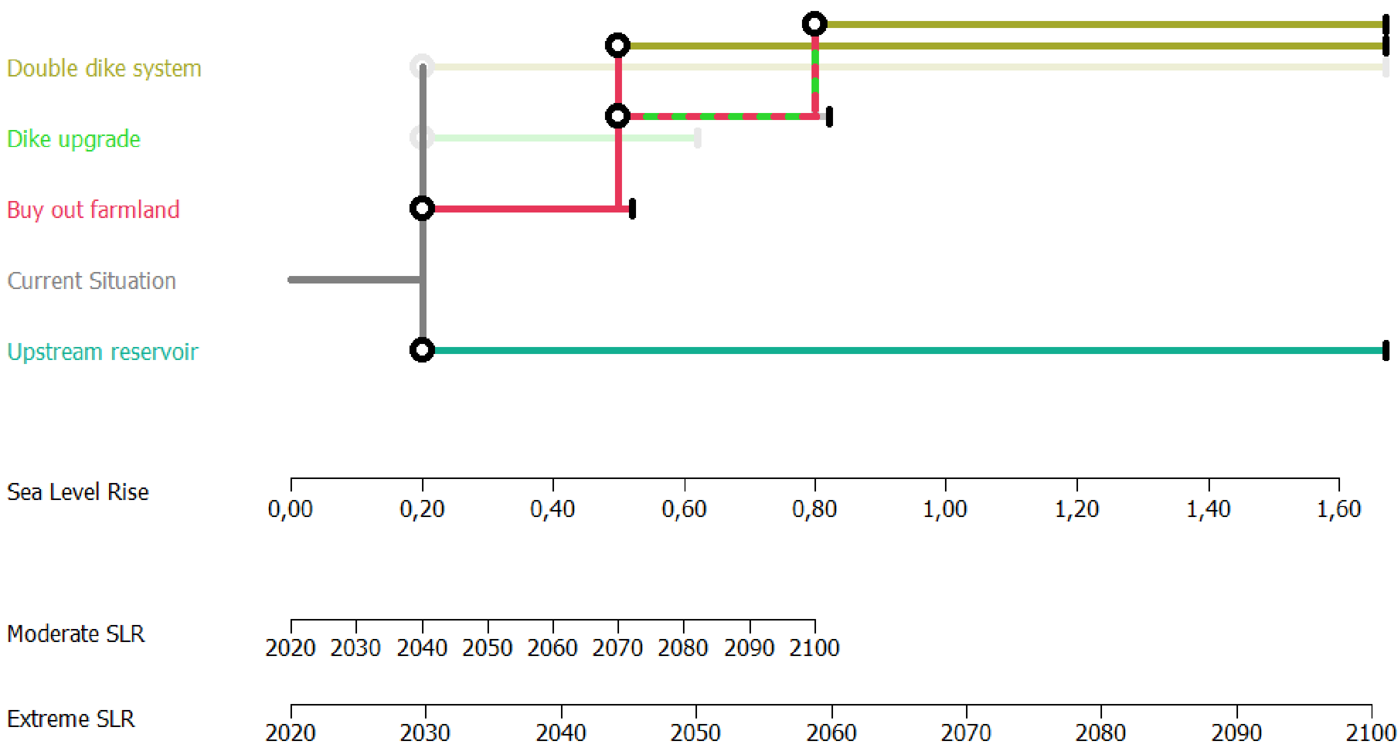
Vulnerabilty/risk models			
Tangible Damage maps	**Intangible Vulnerability maps**	**Flooding Danger maps**	**Risk Risk maps**
Damage to buildings	Inhabitants	Flooding extent	Total economic damage
Damage to inventory	Critical infrastructure	Flooding depths	Risk
Company damages	Emergency centres (first responders)		Risk area
Damage to infrastructure	Polluting companies		
Crop damage	Cultural heritage		
Damage to livestock	Nature & environmental interests		
	Vulnerable infrastructure (daycares, schools etc.)		

A large number of businesses operate in Ribe (figure 2) and a flooding of a number of these will potentially have severe economic impacts as stock/inventory can be damaged and those businesses affected may have to close during the clean-up period. Therefore, it is important to assess which are most susceptible to flooding. It is also important to know which roads may be affected by flooding, as well as the flooding depth, in order to secure safe and direct passage for emergency vehicles and residents. During extreme discharge events in combination with closed floodgates, the main road around Ribe may get flooded and hinder direct passage for emergency vehicles.

In addition to the features shown in the vulnerability maps, agriculture and livestock, schools, day-care centres, houses and others are susceptible to flooding. In Ribe, vast agricultural areas in vicinity to the major streams are prone to flooding which may have economic impact.

Policy Pathways

Issues regarding planning are being addressed by the use of a decision making tool called Dynamic Adaptive Policy Pathways. In a workshop organised by Esbjerg Municipality, experts highlighted several possible solutions for the system at Ribe. These solutions are mapped below based on their expected effects. In the diagram, circles represent tipping points, where a choice can be made. Lines represent stops, where a certain measure no longer can fulfil its function.



Map generated with Pathways Generator, ©2015, Deltares, Carthago Consultancy

What: The outcomes

Accompanying the DAPP map, the scorecard below illustrates the expected costs and effects of different actions based on a first estimate.

Color	Action or pathway	Target effects	Costs	Side Effects
	Current Situation	0	0	0
	Double dike system	+++	---	0
	Dike upgrade	++	--	0
	Upstream reservoir	+	-	0
	Buy out farmland + Dike upgrade	0	0	0
	Buy out farmland	++	--	0
	Buy out farmland + Double dike system	0	0	0
	Buy out farmland + Dike upgrade + Double dike system	0	0	0

As more information becomes available, the tool can be updated. The FAIR project has created closer and increasingly beneficial cooperation between internal teams in the Esbjerg Municipality for asset management, river management and climate adaptation planning management.

Discussions on objectives and alternative pathways for the Ribe Polder will have to take place in steps. Many different interests are present and a close dialogue between these stakeholders as well as the municipality and the national level is needed.

A policy debate around adaptive pathways has been set up in order to highlight the key challenges of the Ribe Pilot. A workshop was held in the organisation Esbjerg Municipality, with external participation of the Danish Coast Authority (DCA) and members from FAIR Scientific Team to assist facilitate the discussions on alternatives.

The system analysis used in FAIR was presented and DCA presented preliminary flood maps for the polder. Limitations and improvements in the model were discussed. Two groups worked on different flooding scenarios and suggested objectives and which alternative pathways to explore.

The policy debate will be followed soon by a phase 2 debate and a similar workshop with the politicians from two City Council boards at Esbjerg Municipality; Planning & Environmental Board and Technique & Building Board.

These initiatives are expected to improve the agenda of the strategic approach to flood protection for Esbjerg Municipality.

Results and discussions can be incorporated in the further climate adaptation planning for Esbjerg Municipality.

Reflection on innovation

Given the complexity of the task and the limited time and knowledge available, it has not been possible to perform a precise calculation of the contribution of each factor to the overall result uncertainty. However, an analysis based on current expertise shows that prediction of the flood sources is by far the main source of uncertainty, followed by the limitations of the hydraulic model. Some recommendations for managing these uncertainties are given.

Based on the work so far, technical recommendations are formulated and ranked. The ranking is based on the ratio between how much effort is required to implement a recommendation and the expected improvement. Recommendations are thus listed in order of expected efficiency:

- Keep updated on the newest IPPC and DMI assessments and update the models accordingly.
- Include infiltration and evaporation maps in the flood model.
- Include rainfall as a flood source in the joint probability analysis (including long-term rain scenario and torrential downpour).
- Ensure the quality of input data for the statistical calculations by having the data supplier verify the raw data source and performing quality checks .
- Extend the model to include three extra branches of the River Ribe.
- Extend the model to include groundwater.
- Extend the length of data series for the flood sources by analysing correlation with other physical factors.
- Find a more accurate way of calculating the expected increase in discharge. Including, for example, evaporation.
- Compare univariate and bivariate statistics and the corresponding models to evaluate the effect of shorter e.g. data series.
- Find out when a water level in the streams becomes critical (closed sluice scenario) and explore the sensitivity of the water level.

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Further reading

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https://northsearegion.eu/fair/

Partners

FAIR brings together Asset Owners (facing real problems and challenges) and leading scientists (with domain expertise) to share and develop innovative solutions to the management of flood protection assets. In doing so, FAIR is the first collaboration of its kind.