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Jordan, Philipp; Manojlovic, Natasa; Fröhle, Peter

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Maintenance of Flood Protection Infrastructure in the North Sea Region – An Analysis of Existing Maintenance Strategies

P. Jordan, N. Manojlovic & P. Fröhle
Institute of River and Coastal Engineering, Hamburg University of Technology, Hamburg, Germany

Abstract: Many flood protection assets in the North Sea Region (NSR) are in the end of their life cycle. In the years to come many assets will have to be rebuilt or replaced. With the aim to improve the life expectancy and functions of flood protection assets and minimize costs and investments lessons can be learned from the management of the existing assets. The EU Interreg project FAIR is dealing with these challenges. Although proper maintenance of flood protection assets is crucial in order to maintain a constant level of safety, its importance is still often underestimated. Documentation of maintenance processes and strategies is often insufficient. This hinders mutual exchange of experiences and a common improvement process in the NSR. In the framework of the FAIR project maintenance processes of the FAIR partners in the Netherlands, Belgium, Germany, the United Kingdom, Denmark, Sweden and Norway are being analyzed through expert interviews. The analysis of maintenance of flood protection assets shows varying approaches to the structural organization and the conduction of maintenance in the NSR countries. First results of this inventory analysis will be presented in this paper.

Keywords: flood protection, maintenance strategy, maintenance processes, North Sea Region, funding, responsibilities, best practice, FAIR

1 Introduction

Particularly, coastal regions are affected by catastrophes like floods and storm surges caused by extreme hydro-meteorological events (Balica et al. 2012). The increase in extreme weather events due to climate change with a corresponding increase in flood risks in coastal areas, combined with rapid urbanization, is leading to a significant increase in flood risk in Europe and worldwide. Hence, ensuring the long-term performance of core flood protection infrastructure is essential for the sustainable development of the affected coastal communities (Masood et al. 2016).

There are high demands on operational safety since the flood protection system has to withstand the stresses of an extreme flood at any time. At the same time, this demand considerably increases the costs of design, construction, maintenance and operation of such facilities, which have to be covered permanently. Thus, the conception of these assets is changing more and more from 'simple' design to life cycle analysis. The optimization of planning processes of flood protection assets on the basis of knowledge derived from maintenance and operation is increasingly regarded as highly relevant (Fröhle et al. 2018).

Difficult decisions will need to be taken in the next years as a reaction to the posed threats and to meet the demands. Existing strategies and flood protection systems are challenged by rising sea levels. To address these challenges improved planning, design and management of new as well as existing flood protection assets is required. The EU Interreg FAIR project recognizes and tackles these challenges bringing together asset owners, operating authorities and researchers from the North Sea Region (NSR) to share and discuss their strategies and processes in flood protection asset management (Sayers et al. 2019). FAIR promotes the principle of the 'tactical handshake' (see Fig. 1) to link strategy and operation.

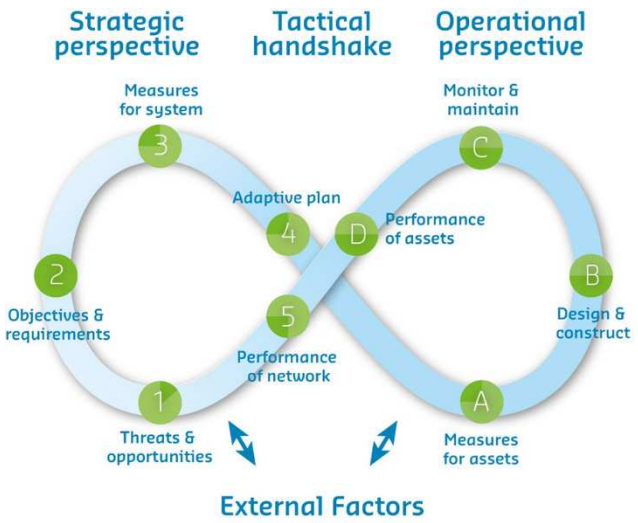

Fig. 1. The FAIR tactical handshake between strategy and operation (Sayers et al. 2019).

Maintenance plays a key role in the tactical handshake. Hence, in asset management successful and sustainable maintenance of flood protection assets requires a lot of effort as well as thorough and structured planning. Yet, the necessary effort is still often being underestimated and maintenance is only conducted sporadically. The analysis of existing maintenance processes and strategies in the NSR is being conducted in the framework of the FAIR project and a share in assessing the scope of maintenance for flood protection assets. Aspects of maintenance and organization in which the NSR countries can profit and learn from each other are being highlighted. Furthermore, the drivers for maintenance and its perception in institutions and the public are determined, which is an essential prerequisite for sustainable maintenance on a constantly high level. An analysis of maintenance strategies and processes broken down to the level of the German federal states is running in parallel to this within the research project EcoDike (Jordan et al. 2019).

2 Setting the scope of the study

2.1 Maintenance in current standards

Taking a look at the legal frameworks in the NSR countries with regard to maintenance different aspects have been addressed by a wide range of documents, from laws and regulations, over standards and specifications, to guidelines and recommendations. The existing guidelines provide support to the institutions and decision-makers who are in charge of the maintenance of flood protection assets while avoiding prescription-like suggestions or precise recommended procedures.

The first basic point that needs explanation is the term ‘maintenance’ itself and which actions or procedures it encompasses. In Germany for example the general norm “DIN 31051: 2012-09 Fundamentals of Maintenance” defines maintenance as a ‘combination of all technical, administrative and management actions during the life cycle of a unit, which serves to maintain or restore its functioning condition so that it can perform the required function’. Since there is no exact definition for the concept of maintenance regarding flood protection systems this general norm can be applied to those. According to DIN 31051 (DIN 2012) maintenance consist of four basic measures which are servicing (measures that extend or maintain the designed lifespan), inspection (measures to assess the actual status of a unit to derive necessary consequences), repairs (measures to restore the function of a failed unit) and upgrade (measures to increase the reliability/maintainability/safety of a unit without altering the original function).

Every partner country in the NSR is working according to their own standards, federal laws and country-specific guidelines and regulations. European or international regulations or recommendations concerning the maintenance of flood protection structures are sporadically published and available. The relevant source of reference with significant European participation is the International Levee Handbook (CIRIA 2013) which resulted from a cooperation between the United States, France, and the United Kingdom with support from the Netherlands, Germany, and Ireland. As stated in the title

the International Levee Handbook is only relevant for dykes and describes best practices in maintenance and design of dykes based on the experience gained in Europe and the United States.

However, based on this analysis, it is to conclude that each country has individual standards and regulations and therefore different approaches to maintenance. There is no inter-European guideline in place regulating the maintenance of flood protection assets. Furthermore, it appears that in many cases the maintenance measures of flood protection facilities are carried out subjectively based on personal experience of the maintenance personnel on the ground even though laws and regulations are at least partially in place in most of the NSR partner countries (with the exception of Sweden).

2.2 Maintenance strategies in coastal engineering

Independent on the type of asset there are three different approaches to a maintenance strategy in coastal engineering (Glimm et al. 2009).

With the *Failure Approach* an asset or a unit is being replaced when a failure or damage is existent. When following the *Prevention Approach*, depending on the expected wear and tear, maintenance measures are planned and timely initiated before a failure occurs. The *Inspection Approach* schedules regular inspection to gather information about the degree of wear of single units of an asset. Tab. 1 gives an overview of the three strategies' advantages and disadvantages.

Tab. 1. Maintenance strategies in coastal engineering, advantages and disadvantages (Glimm et al. 2009).

STRATEGY	ADVANTAGES	DISADVANTAGES
Failure	- Optimum use of life span - 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 damages
Prevention	- Avoidance of high follow-up costs from damages	- Severe planning effort (extensive data collection) - Technical life span rarely fully utilized
Inspection	- Flexible adaption of inspection intervals - Optimized use of life span - Collection of data/information on degree of wear - Plannable costs in the long-term	- Costs for inspections

To organize maintenance efforts for flood protection assets as economical as possible a combination of advantages of the above-mentioned maintenance strategies is required.

3 Methodology

To advance existing strategies and processes a three step approach is applied. First it is essential to assess and understand the existing maintenance processes and strategies. In a second step these findings will be analyzed and then, finally, used to derive consequences and improve maintenance of flood protection assets. This paper presents first results of the inventory of the as-is state.

The system analysis for current maintenance practice in the NSR was conducted within FAIR for all partner countries - *the Netherlands (NL), Belgium (B), Germany (GER), the United Kingdom (UK), Denmark (DK), Sweden (SWE)* and *Norway (NOR)*. Semi-structured interviews with asset owners and asset operators were executed with the key institutions in the respective partner countries in order to identify the interaction between maintenance, operation and panning of flood protection assets.

Within the study using a two-step analysis the focus of the semi-structured interviews was on both the strategic and the operational perspective (see Tab. 2). With regard to strategic maintenance aspects such as responsibilities, legal framework, funding or organizational structure are being addressed. The operational part is dedicated to actual maintenance processes such as servicing, inspection, repairs and upgrade. In the first step, presented in this paper, the analysis of the as-is state in the NSR points out responsibilities and organizational structures. Identified common challenges for successful maintenance of flood protection assets are presented and best practice examples from across the FAIR partnership are given.

In a next step the interviews will then be used to analyze the potential room for improvement of maintenance strategies and processes regarding for example the execution of individual maintenance steps, the documentation of the process, the legal framework or maintenance efforts and expenses.

Tab. 2. The catalogue of criteria for the systematic analysis of the maintenance of flood protection assets (Fröhle et al. 2018).

MAINTENANCE OF FLOOD PROTECTION ASSETS	
STRATEGIC PERSPECTIVE	OPERATIONAL PERSPECTIVE
Organization - Legal framework - Responsibilities - Funding arrangements - Status & position of the maintenance unit in the overall asset management - Interactions of maintenance staff with other units - Specific features & issues	Maintenance process - Specific guidelines - Time & frequency of maintenance procedures - Responsibilities - Maintenance procedure (step-by-step) - Inspection procedure (step-by-step) - Effort (Time, personnel, costs) - Documentation - Interaction or exchange with other maintenance departments or relevant units
Conflict potential - Conflicts within the institution - Affected parties (public, industry, etc.)	Basic data - Types of assets - Ownership - Specific features & issues

4 Analysis of maintenance strategies and processes

4.1 Legal frameworks

With the exception of Sweden the legal frameworks are seen to be sufficient across the countries in the NSR. Nevertheless, consequent implementation of existing regulations is required. At the moment in Sweden there is no legal framework regarding flood protection or maintenance of flood protection structures because problems with coastal flooding are relatively new.

4.2 Organization & responsibilities

Regarding the organization of flood protection asset management and of the maintenance of assets in particular there are heterogeneous approaches across the NSR. Countries either have a centralized or a decentralized governance structure.

In the Netherlands, Belgium and the United Kingdom the main responsibilities with respect to maintenance are centralized. Big governmental bodies and agencies, such as Rijkswaterstaat (NL), MDK (B) or the Environment Agency (UK), are in charge of the flood protection assets throughout the whole country. Only the responsibilities for smaller, local assets like river dykes are dispersed amongst several other organizations, e.g. the Dutch Regional Water Authorities. Centralized approaches ease the compliance with nationwide, uniform standards and methods but can also carry the danger of losing track of comparatively smaller measures.

The Scandinavian countries have a long history of decentralized governance. In Denmark, Norway and Sweden local municipalities or even private citizens are in charge of 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 decentralized approach has its 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 of the matter.

The German approach represents a mix of centralized and decentralized 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 the Free and Hanseatic City of Hamburg.

4.3 Common challenges & best practices

The following strategic and operational challenges for successful maintenance of flood protection assets were identified during interviews across the FAIR partnership. Some interviewed institutions are struggling with these common challenges, others found creative ways to successfully manage them. Best practice examples from one or several partner institutions are given to illustrate the point.

4.3.1 Strategic challenges

Manage costs and explore various funding options. Maintenance budgets are usually tight around the NSR. Most organizations have to prioritize their planned projects and are only able to implement projects from the top of their lists. Smaller measures often do not make the cut. These are usually located in more rural areas and affect far less people than in the urban regions. In the United Kingdom, the Environment Agency introduced so-called 'partnership funding' a couple of years ago. Based on a cost-benefit analysis the Agency tries to find funding partners for all their flood protection projects. These can be municipalities, companies or even private citizens profiting from the assets. By sharing the costs for the assets, more budget is available for smaller measures of lower priority. Supervised by the Environment Agency, the funding partners which are often the landowners may even be responsible for the maintenance of the assets.

In many cases only maintenance measures targeting the structural integrity of assets are being realized. Works which are merely aiming at esthetics can usually not be funded. Therefore, in Belgium it is common practice that construction and maintenance of flood protection structures are funded by the government as well as the local municipalities. In this partnership the governmental agency MDK is responsible for the basic, protective structure, whereas the municipalities finance the architectural touches and aspects appealing to tourists, since the municipalities are profiting from tourism in their region.

Build knowledge and capacity in-house instead of outsourcing capacities. Due to political decisions most governmental bodies in the partner countries were reduced in staff over the last decades. More and more tasks that were originally conducted in-house were outsourced to private contractors. Following this strategy of contracting and taking maintenance works on the markets a lot of knowledge regarding the assets, the areas and the execution of maintenance measures got lost in the responsible institutions. Nowadays, many authorities and agencies try to regain this lost expertise. The municipality of Helsingborg (SWE) for example is using the FAIR project for orientation and capacity building. Since they only experienced problems with flooding in recent years, there are no flood protection assets, yet. The municipality's employees who will plan and manage future assets are now participating in the FAIR project to benefit from the experience of others and get feedback on their planning from international asset managers and flood protection specialists.

Link strategic local and operational planning. In order to conduct operational maintenance as efficient and economic as possible the responsible institutions need to know when and where which measures have to be taken. To be able to plan maintenance in the long-term it should be incorporated in the strategic local planning at the coasts. Like all Danish municipalities in 2013, the municipality of Esbjerg was required to establish climate adaptation plans including e.g. urban development, wastewater management and environmental issue as well as erosion and flood protection. These plans, which are updated continuously, incorporate possible future climate scenarios and adaptation options for the flood protection assets and their maintenance. Hence, when local planning decisions are made, different operational maintenance options are also taken into account to achieve the targets set.

4.3.2 Strategic & operational challenges

Make room for innovation. Uncertainties and risks regarding valuable assets of high importance for the security of coastal communities restrain asset managers from pursuing innovative and possibly promising new technologies, inspection methods or asset management approaches. Following the well-known inspection routines, maintenance measures and maintenance plans feels like the safe way to continue. But keeping in mind the uncertainties and changes due to our changing climate and the probable sea level rise risks cannot be avoided forever and responsible institutions should rather learn to manage them now. Therefore, it is necessary to investigate new techniques and strategies in the

maintenance of flood protection assets. An example for an innovative approach is given by the Midden-Nederland district Zuid branch of Rijkswaterstaat (NL). The maintenance unit for the Amsterdam-Rhine Canal is experimenting with 360° photography of the dyke to detect changes on the surface as well as infrared measurements to detect seepage. Inspections are executed from the crest of the dyke (see Fig. 2) and by boat. From the boat the experts are able to measure the dips of wave troughs to make recordings of the intertidal zone of about 0.5 to 1.0 m.

Fig. 2. 3D Laser Scanning vehicle for the inspections at the Amsterdam-Rhine Canal (Lievens 2018).

Regarding strategic innovation the Environment Agency (UK) launched the Thames Estuary Asset Management 2100 project (TEAM2100) (Thames Estuary 2100, 2012) to develop a long-term tidal flood risk management plan for the whole estuary until the year 2100. The Focus of TEAM2100 is on maintenance and refurbishments of the tidal flood defences in London and the outer estuary in the first 10 years, taking into account the changing boundary conditions and allowing the compensation of climate change related uncertainties through adaptive solutions. Furthermore, TEAM2100 is developing a management system for the assets over the next 100 years.

Sensitize maintenance staff and the public to care for the assets and get them involved. Thanks to well designed and well maintained flood protection assets most people today never experienced or were affected by a major flood event at their living place. Especially rigid assets like dykes or embankments are easily overlooked by the public as active working structures which are protecting their lands. This lack of awareness of the assets' importance can result in an incomprehension of the need to actively work on them, maintain them and constantly spend money for them to keep up the security level. Therefore, it is important to keep the public informed. In the municipality of Trysil (NOR) a stone flood monument (see Fig. 3) with past flood marks and information boards along the protective dam, which is also a popular recreational area, educate the public about the assets function and its benefit for their lives. Walkers in the area now care about the dam and are actively participating in inspections when alerting the municipal government about damages or shortcoming.

Fig. 3. Flood monument in Trysil, Norway (courtesy Trysil Municipality).

To get the own personnel to care about the flood protection assets and consider them 'their' responsibility the Environment Agency in the United Kingdom educates its own staff to become licensed inspectors. After an externally credited training and a period of supervised inspections these inspectors are assigned 'their' assets in an area. As long as they work as inspectors for the Environment Agency they will usually stay in charge of the same assets. Thus, they get very experienced and accumulate an extensive knowledge of the assets and the area over time and they feel connected to and responsible for the assets under their supervision. Most inspectors tend to do the job for several years.

4.3.3 Operational challenges

Use frequent low-effort checks for crucial assets or units. On the one hand there are flood protection assets like dykes or flood walls which are in use every day protecting their hinterland from flooding at high tide. But on the other hand there are also numerous assets like barriers or flood gates which are only in use for a couple of times a year during severe storm surges. These often automatically

controlled assets have crucial functions in protecting the land from flooding. Since their failure would have catastrophic consequences their reliability in the rare events of operation has to match the highest standards. To ensure this, inspection and testing is crucial. Due to these assets' complexity inspection and testing is often very complex and of high effort and/or costs and therefore only conducted annually or semi-annually. To allow for more frequent inspections of these assets the effort has to be reduced while still ensuring that the assets functional efficiency can be assessed. Hamburg's LSBG (GER) is managing and maintaining 40 flood gates within the city, many of those are operated automatically. Since the full testing of the gates requires a lot of effort, manpower, time and the closing of main roads in the city LSBG can only afford to do this twice a year. To enhance the gates' reliability, gather more data and gain more experience in the operation of the gates LSBG came up with a monthly test routine. During these monthly tests the gates are only closed partially, more or less for the first meter (see Fig. 4). Thus, the effort is kept low and the closing of roads is unnecessary but the gates' drives are tested and, if the test goes well, it can be assumed that a full closure would have succeeded, too.

Fig. 4. Left: regular semi-annual testing of gate 'Brooksbrücke' in Hamburg (courtesy TUHH). Right: Low-effort partial testing of gate 'Niederbaumbrücke' in Hamburg (courtesy TUHH).

Define objective criteria for the assessment of the status of structures. All interviewed institutions in the NSR rely on the inspection strategy to regularly assess the status of their assets and derive subsequent maintenance measures. Although the importance of inspections is widely appreciated many institutions do not have any inspection schemes in place. The thoroughness and the way of executing an inspection strongly depends on the individual inspector. The classification of inspected assets is subjective and dependent on the inspector's personal experience. Therefore, it is difficult to compare assessed failures or damages, exchange experiences with the assessment or start off as a flood protection asset inspector without orientation or guidelines. In the United Kingdom the Condition Assessment Manual (CAM) (Environment Agency 2012) gives such objective criteria for visual inspections. The CAM provides a grading from 1 (very good) to 5 (very poor) for various flood protection assets or asset's units. It includes pictures, a specific description and key features for each grade as an orientation for the Environment Agency's inspectors. Based on the CAM the inspector determines the grades for all relevant elements, e.g. berm, crest, inner and outer slope for a levee, and an inspection tool determines the asset's overall score taking into account different weightings of the elements. This overall score is the determining factor for decision-making and planning of further maintenance.

In the Netherlands two digital tools which give objective assessment criteria are available. Web-based Digigids gives several exemplary pictures for elements of various assets dividing the categories good, reasonable, moderate and bad. With the app Digispectie inspectors of Rijkswaterstaat or the Water Authorities can even upload geo-referenced pictures of inspections while they are on-site. The app also shows examples for the different ratings to help assigning a score to the pictured damages.

4.4 Communication

In order to continuously advance flood protection assets it is crucial that maintenance and planning units interact with each other. Possible design flaws or construction details which hinder a maintenance-friendly management of on asset often surface in the operation phase during inspections, maintenance works or repairs. To avoid these mistakes in the design of future assets or to improve existing ones, feedback from the maintenance unit has to be incorporated in the work of the planners. Hamburg's LSBG (GER) is pursuing this strategy since a couple of years with their so-called 'maintenance-friendly construction agreement' which is concluded between their planning, construction and maintenance units. It is supposed to accompany new projects from beginning to completion.

Communication with the public is also of great importance to create awareness for the importance of maintenance and an understanding for the need to continuously spend money on flood protection assets. Although - or especially because - most people in the NSR never witnessed a severe flood they need to be aware of the crucial functions of the assets and the fact that they require maintenance to be in good shape. A good example is the Danish Coastal Authority which puts a lot of effort into publicity giving radio interviews, providing informative websites and publishing newspaper articles.

New practice can originate from interacting and communicating with others. In FAIR peer2peer meetings were introduced as a way to facilitate honest communication between partners facing similar challenges. Amongst other constellations LSBG (GER), Rijkswaterstaat (NL) and some of the Dutch Water Authorities met several times during the FAIR project to discuss and develop their maintenance strategies and processes for flood protection assets. In an open environment changing experts from the mentioned institutions discussed maintenance intervals, risk-based maintenance approaches, data collection and information management as well as future developments in flood protection and their effects on maintenance efforts.

5 Discussion of the preliminary results

National laws and regulations on flood protection asset management are, with exceptions, seen to be sufficient even though they often do not give specific details regarding maintenance. An inter-European approach or even strategy for asset management is not in place, yet.

Regarding the responsibilities and institutional structures maintenance is organized either centralized or decentralized, both of which approaches come with advantages and disadvantages, depending on the number, type and size of assets.

All interviewed institutions pursue the inspection strategy as described above. The FAIR partners handle inspections and testing of their flood protection assets very differently, ranging from contracting all measures to performing inspections and repairs themselves or from supervising every inspection to just assisting and giving advice. In spite of these differences most FAIR partners struggle with common challenges. Costs and funding of maintenance, capacity building and knowledge management as well as operational planning in long-term strategies pose common strategic challenges. Of both strategic and operational character are innovation and the involvement of people and creation of awareness for the importance of flood protection and its maintenance. Inspection efforts and objective assessment criteria pose common operational challenges across the NSR.

Communication, internal as well as external, is widely considered to be the key to successful asset management. Communicating with other maintenance experts, other institutions and other nationalities widens the personal horizon and can help to improve maintenance processes and strategies by looking at challenges from a different perspective. The FAIR project promotes this active interaction and offers a platform to share knowledge and experiences from all countries bordering the North Sea.

6 Conclusions & Outlook

The developed interviewing method could be applied to analyze the maintenance processes and strategies for flood protection assets in the FAIR partner countries across the NSR. Common challenges could be identified through the interviews with the responsible institutions in the

Netherlands, Belgium, Germany, the United Kingdom, Denmark, Sweden and Norway. At the same time best practice examples for these challenges were found in one or several countries as depicted in this paper.

These results are expected to help the asset owners and responsible institutions to reflect on their current maintenance practices and strategies. To improve their asset operation and management in the long run they are pointed to other institutions in the FAIR partnership who are either facing the same challenges or already found their way to tackle these challenges. Through the active and open FAIR network, during project meetings or peer2peer talks, these common challenges can then be approached together and lessons can be learned from each other.

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- Agency for Maritime and Coastal Services (MDK), April 2018, Ostend, Belgium.
- Agency of Roads, Bridges and Waters (LSBG), May 2018, Hamburg, Germany.
- Esbjerg Municipality, May 2018, Esbjerg, Denmark.
- The Danish Coastal Authority (DCA), May 2018, Lemvig, Denmark.
- Rijkswaterstaat, June 2018, Utrecht, the Netherlands.
- Helsingborg Municipality, June 2018, Helsingborg, Sweden.
- County Board of Skane, June 2018, Helsingborg, Sweden.
- Trysil Municipality, September 2018, Trysil, Norway.
- Norwegian Water Resources and Energy Directorate (NVE), September 2018, Oslo, Norway.
- Environment Agency, February 2019, London, United Kingdom.
- Jacobs Ltd., February 2019, London, United Kingdom.