DRAFT

Deltares

Activity Plan 2024 SITO Institute Subsidy

Contents

Executive summary

This 2024 SITO Institute Subsidy Activity Plan sketches the outline of the mission-driven Strategic Research that Deltares will conduct in 2024 with the SITO institute subsidy. It outlines how the Deltares Strategic Research aim to contribute to designing innovative and sustainable solutions for the complex and urgent challenges facing society. These challenges are more urgent than ever and are addressed in international and national agendas and missions. Deltares has adopted these agenda's and missions as the basis for our programming to make a positive impact on society. To focus our research activities, we have grouped the missions and agendas into five moonshots providing the direction for all of our research activities. In these moonshots we address the challenges related to climate change adaption, extreme weather events, healthy water and subsurface, biodiversity loss, energy transition, climate neutral deltas and resilient infrastructure through a mission-driven approach, by co-creating and co-developing software, data tools and solutions with stakeholders and research partners to achieve societal impact based on scientific quality.

In this Activity Plan the mission-driven Strategic Research activities for 2024 are described along these Moonshots (chapter 2 to 6). Details of our knowledge facilities (enabling technologies, software and data, experimental facilities) activities are shown in chapter 7. In chapter 8 overviews of the financial framework are presented.

The headlines of the moonshots and knowledge facilities are summarized below. Further details on the 2024 activities can be found in the relevant chapters.

Moonshot 1: Deltas remain habitable *in the context of (extreme) climate change, subsidence and human pressures.*
Comprehensive understanding of water and subsurface systems, the related infrastructure and future changes in densely populated deltas are indispensable to identify the solution space and organize the design task to keep deltas habitable. Additionally, the (unknown) results of this design task will influence large decisions and investments for the coming years. Deltares develops the knowledge base for this design task and innovative measures to keep deltas habitable, while the land continues to sink, erode, and salinize, the sea rises, weather and discharge regimes become more erratic, and biodiversity declines at an unprecedented rate.

To reach our goals, we have structured our strategic research along the following research lines:

1. What are the long-term outlooks for the delta-systems?
2. Which strategies can keep our deltas habitable?
3. How can we support decision makers in the adaptation and transition from now to the future?

Moonshot 2: Making the world safer from flooding.
Hundreds of millions of people worldwide are at risk of flooding from the sea, from rivers and from rainfall, resulting in thousands of casualties and extensive damages each year. Due to population growth, economic development and climate change, these impacts will continue to increase in the future. Through research and innovative product development, Deltares strives to make the world's population safer from flooding and concurrent water-induced hazards.

In this moonshot we target our efforts to support the development of effective and equitable flood risk management strategies; to underpin decision-making with accurate quantification and forecasts of (compound) flood risk; and to provide excellent knowledge on the effectiveness, suitability, and acceptability of solutions to reduce flood risk.

To reach the objectives of this moonshot, we need to understand and quantify the physical processes resulting in floods and concurrent hazards and flood impacts and have knowledge about measures that prevent or mitigate floods, be able to forecast flooding events, and foremost bring all these elements together in flood risk management strategies. Therefore, we have structured our research efforts around the Disaster Risk Management (DRM) Cycle (Figure 3.1) along the following research lines:

1. Effective and equitable flood risk management strategies.
2. Quantification of flood hazards, impacts and risks.
3. Prevention and Mitigation: Effective and sustainable risk-reducing solutions.
4. Preparedness and Recovery: disaster warnings and post-event information.

Moonshot 3: Resilient and healthy water and subsurface systems *for humans and nature.*

Water and subsurface systems are under severe pressure worldwide, throughout Europe, and in the Netherlands, in terms of both quantity and quality. Threats include climate change with sea level rise and more frequent extreme floods and draughts, human activities with changes in use of the system, increasing use of chemicals and increasing demands for water, food, renewable energy, better human health and livelihoods. As a result of these threats the resilience and health of the systems decline, changes are reflected in aridification, salinisation, land subsidence, eutrophication, acidification, pollution, and the decline of biodiversity. Thus, it is difficult to safeguard a healthy environment for humans and nature as well as sustained ecosystem services such as agriculture, fisheries, infrastructure, and water supply.

Deltares strives to contribute to healthy and resilient water and subsurface systems, meaning that systems will be able to deliver services and be ecologically and chemically healthy for life as well, and that systems are able to survive and recover from extremes, so that future generations around the world will be able to use and enjoy them. Deltares' knowledge should facilitate transitional changes in land and water use. This requires in-depth insight and information about the functioning and management of water resources, subsurface and ecosystems. The complex of stress factors, stakeholders and scenarios requires integrated knowledge of the various sub-systems in relation to climate induced developments and human activities. This knowledge is necessary to study future scenarios and assess effects of measures, interventions, climate change and socio-economic developments, and for the design and validation of sustainable solutions for resilient and healthy systems. This knowledge helps to develop policies and management plans, providing instruments, tools, solutions, and advice with perspectives for action. The transformative change in management of water and subsurface is facilitated for stakeholders and decision-makers, on the timescale present-2050 and connecting to the longer time horizon.

Deltares is working along the following research lines:

1. Safeguarding water availability for nature and humans.
2. Preventing further decline of water quality and improving water quality from source to sea.
3. Preventing and reversing the decline in biodiversity and habitat diversity.
4. Improving soil health to ensure provision of services of the soil to nature and humans.

Moonshot 4: Sustainable energy transition. *Water and subsurface will enable sustainable energy and climate neutral deltas.*

The urgency to combat climate change due to greenhouse gas emissions is increasing. Almost 200 countries have committed to the Paris Agreement to limit global warming to a maximum of

2.0 °C and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. Within the EU, there is an agreement to be climate-neutral by 2050 at the latest, to implement this. The Netherlands is also bound by this agreement and has set an interim target for 2030 on the way to achieving this goal for 2050, aimed at reducing greenhouse gas emissions by 60%. This is a huge challenge that requires broad societal transformation.

The overarching goal of Moonshot 4 is the mitigation of greenhouse gas emissions through the sustainable use of water and the subsurface. We are convinced that the only way to this is by integrating with the other transitions and by working together with the actors in the entire energy value chain.

The water and subsurface system can contribute greatly to this intended reduction in greenhouse gas emissions. Water and subsurface provide space for generating and storing sustainable electricity and heat, can act as a transport medium, and as a carbon sink. Think, for example, of generating electricity at sea and inland waters, through wind farms or floating solar fields. Or harvesting heat from surface water for heating of homes, or storage of sustainable energy in the form of heat batteries. At the same time, there is an increasing awareness that water and subsurface generate GHG emissions on the one hand forming a potential source of (emission of) greenhouse gases and a long-term storage of greenhouse gases on the other hand. Smart management of water and subsurface can make a difference here.

Using water and the subsurface for the energy transition has ecological and spatial effects on the water and subsurface system, the negative effects of which must be minimized or mitigated. The challenge will be to safeguard sustainable use and to ensure that spatial assimilation is feasible. This requires designing and construction methods that result in less disruption and fewer costs to society. How can we manage this scaling up with integrated heat and electricity systems and the necessary decision-support tools at the system level?

To make it even more challenging, energy transition is not the only transition we are currently facing as a society. The nitrogen crisis, biodiversity crisis, climate change, water quality problems are major challenges in the physical domain that also have major implications for our country and our way of life. That’s why we’re looking for ways to integrate the energy transition with the other transitions and are working in value chains with a variety of other actors.

We organize our applied research in Moonshot 4 along three lines:

1. Sustainable heating and cooling.
2. Sustainable electricity generation and transport.
3. GHG emissions and storage in land and water management.

Moonshot 5: Resilient infrastructure

Countries and cities around the world face the consequences of substandard infrastructure. While infrastructure networks are the lifeline of society, billions of people lack access to drinking water, energy supply, work or school. In the Netherlands (climate related) infrastructure damages directly harm people’s daily lives, their houses and their environment. The demands to infrastructure change rapidly due to socio-economic factors, climate change and technological developments. At the same time, the quality of the infrastructure is declining due to ageing. While biodiversity and the natural water and subsurface system are under pressure. Under these conditions infrastructure investments are required, based on long-term added value for society.

Deltares feeds transformative solutions towards resilient infrastructures. To increase our quality and impact a significant step in knowledge, experiments and associated tools supporting decision-making is crucial. A step towards (1) embedding infrastructure in the natural water and soil system (2) design options that improve adaptation and recovery from climate related damages (3) connecting object, network and system levels to provide policy information on the transition towards resilient infra. Meanwhile AI and data science techniques will inspire us to rethink our approaches.

By 2030 we have developed and disseminated the capabilities and tools to assess, design, build, transform and maintain infrastructure to cope with current and future challenges, in a nature-inclusive fashion and embedded in other societal and spatial developments.

To reach the goal in 2030 we will work on the following coherent research lines, including knowledge facilities:

1. Transitions and decision-making.
2. Design and embedding.
3. Infrastructure performance assessments.
4. Knowledge Facilities.

Knowledge facilities

Deltares has several unique knowledge facilities at its disposal. They include software, data and experimental facilities and key enabling technologies. The Networks and University Positions Knowledge Facilities support Deltares input for national and international knowledge and policy bodies such as the IPCC and ENW, and fund appointments of professors and senior lecturers at a range of Dutch and foreign (applied) universities. The knowledge facilities support and inspire the mission-driven programmes. Requirements of the mission-driven programmes are supported by the knowledge facilities on the short term. On the other hand, strategic research based on the knowledge facilities aims to inspire the mission-driven programmes by providing new opportunities to generate impact on the longer term.

In 2024, we intend to further boost the effective coordination of the various knowledge facilities, coordination with the mission-driven programmes and the application of enabling technologies. We will continue our efforts to accelerate our digital ambitions (Deltares strategic agenda 2021-2025). Additional attention is required for key scientific positions at (applied) universities as well as the scientific impact of our experimental facilities.

Financial framework

This 2024 Activity Plan was drawn up to apply for the SITO institute subsidy in the context of the subsidy scheme for institutes for applied research of the Ministry of Economic Affairs and Climate (dated 1 February 2018, no. WJZ/17203973). The institute subsidy for the Strategic Research by Deltares has been set with a ceiling of €22.285.000 for the 2024 financial year.

1 Introduction

Challenges

This 2024 Research Plan sketches the outline of the Strategic Research that Deltares will conduct in 2024 with the SITO institute subsidy. With this research plan we aim to contribute to designing innovative and sustainable solutions in the field of water and subsurface for the complex and urgent challenges facing society.

These challenges are more urgent than ever, recent events have reaffirmed this once again:

Intense rainfall events led to flash floods and river overflows in several regions. These floods disrupted daily life, caused property damage, and put lives at risk. The warmer ocean waters fuelled the development of powerful hurricanes and cyclones. Coastal regions were hit by destructive storms, causing flooding, infrastructure damage, and displacement of residents. Last summer saw an increase in the frequency and intensity of heatwaves around the world. Many regions experienced record-breaking high temperatures, posing health risks to vulnerable populations and straining energy resources. Prolonged heat and dry conditions contributed to a rise in wildfires during the summer. Extended periods of drought affected agricultural production and water supplies in various parts of the world. Crop failures and water shortages added to the challenges posed by climate change. In polar regions, the melting of glaciers and ice sheets continued, contributing to rising sea levels and threatening coastal areas. Rising sea levels exacerbated coastal erosion and increased the vulnerability of coastal communities to storm surges and saltwater intrusion. Climate change-related hazards disrupted ecosystems and biodiversity. Species faced challenges in adapting to rapidly changing conditions. Climate-related hazards had significant economic consequences, from damage to infrastructure and property to decreased agricultural yields and increased insurance costs.

Scientists have recently analysed nine planetary boundaries, and it turns out that humans are currently crossing six of them. Staying within these boundaries, often referred to as the safe and just operating space, is vital for Earth's stability. Exceeding these limits can result in severe environmental consequences. To protect the planet's well-being, it's essential to prioritize sustainable practices and responsible resource management.

These hazards and findings once more highlighted the urgent need for global action to address climate change and its far-reaching impacts as emphasized in the recent IPCC reports. They underscored the importance of mitigation and adaptation strategies to protect communities, ecosystems, and economies from the effects of a changing climate. And they underscore the urgent need to act within the safe and just operating space.

Many of these global trends converge within the small, low-lying deltaic area of the Netherlands. Urbanisation, energy transition, infrastructure renewal, intensive land and water use, agricultural transition, the restoration of biodiversity and nature, a sustainable transport corridor with multi modal resilience and not at least the challenge to safeguard our best protected delta against flooding. To ensure the habitability of our delta, we've pushed the boundaries of our water and subsurface systems. The need to adapt to further climate change puts a further increasing pressure on our available water and subsurface system and related ecosystems. Dutch government implemented the transition to a model where water and subsurface play a guiding role in the design and management of our delta, ensuring its sustainability and resilience for the future.

Mission-driven working
All these challenges have been addressed in international and national agendas and missions. In the Netherlands knowledge institutions, companies, governments and civil society organizations are working together in top sectors on 25 Missions for the Future. Deltares puts the global, European and Dutch agendas and missions in a central position in the thinking and activities of our organisation and adopted these as the basis for our programming to make a positive impact on society. To structure and focus our research activities, we have grouped the international and national missions and agendas into five moonshots: inspirational, directive targets to challenge ourselves to go to the limit.

As the urgency is clear, now is the moment to shift our focus from awareness to solutions, offering a more promising perspective. Embarking on the journey of the impact chain involves organizations from various sectors working together to close the gap and connect output, outcome, and impact. We therefore join with national and international partners to pool our knowledge and resources. These connections are crucial, where we grasp the whole picture and not only work from our own individual research activities and working field but bring them together in ‘bold ideas’ to not (only) make incremental or temporary difference, but together fundamentally change the way things have been done.

Introduction to the moonshots and knowledge facilities
In five moonshots we address the challenges related to climate change adaption, extreme weather events, healthy water and subsurface, biodiversity loss, energy transition, climate neutral deltas and resilient infrastructure through a mission-driven approach, by co-creating and co-developing enabling technologies, software, data tools and solutions with stakeholders and research partners to achieve societal impact based on scientific quality:

1. Deltas remain habitable in the context of (extreme) climate change, subsidence and human pressures

2. Making the world safer from flooding

3. Resilient and healthy water and subsurface systems for humans and nature

4. Water and subsurface will enable sustainable energy and climate neutral deltas

5. Resilient infrastructure

For each moonshot the societal challenges, the inspirational and directive targets as well as research lines and activities 2024 are described in chapter 2 to 6. Essential is the interconnectedness of all the various systemic challenges, therefore the coherence in moonshots. In our research we are looking at long-term developments (far ahead) and what it means for the current course of action (accelerating today). There is a cascade of systemic choices with mutual interference and coherence from a national, regional, and local perspective. Switching between comprehensive system approaches and local (and integral) solutions is essential. Natural hazards often affect the most vulnerable individuals and communities, who, in addition, also have the least access to knowledge. Therefore, in the moonshots we specifically pay attention to data-poor deltas, involve a broad representation of residents in the design of solutions, and ensure open access to knowledge and knowledge transfer.

The activities in 2024 contribute to our role as a TO2 institution. TO2 institutions are tasked with conducting applied research, developing relevant knowledge, and promoting innovations. On one hand, these efforts are directed towards addressing major societal challenges and supporting the public execution of tasks. On the other hand, they aim to bolster the economic vitality of the Netherlands through collaboration with businesses.

For our research we cannot do without the unique combination of highly qualified individuals, experimental facilities, key technologies, specialized software, and data products that form the bedrock of the quality and impact of our research. These constitute the most crucial assets, our knowledge facilities, through which our knowledge evolves. Development, management and application of strategic research facilities is a task entrusted to TO2 institutions, Our activities 2024 are described in chapter 7 Knowledge facilities, they are structured around moonshots as the knowledge facilities support and inspire the mission-driven moonshots.

The strategic research activities that Deltares will conduct in 2024 with the SITO institute subsidy, described in this activity plan are strongly entwined with many of our other activities. Embarking on the journey of the impact chain involves organizations from various sectors working together to connect output, outcome, and impact.
This also means connecting our Deltares portfolios from the SITO institute subsidies (strategic research), our applied research programs with ministries (SITO Programmasubsidie), partnerships with private partners and knowledge institutes in the context of the Dutch top sectors (TKI projects), international consortia (EU project, IFI funded project, etc.) and commercial projects. Co-creation means that we ask questions together, discuss research results together, and assess what achieves the highest priority in a collaborative manner. We embrace this as best as we can in our programming while simultaneously realizing that it takes time, learning by doing and that we still have a way to go. We invite you to engage in collaborative thinking with us, as we collectively chart the course towards achieving meaningful impact.

- Under construction is figure / overview of the relationship between the moonshots: In this figure we also indicate the link between the moonshots and the themes under the SITO Programsubsidy, the SDGs and the Dutch missions to elaborate further on these consistencies. Also link to Dutch policy – and implementations programs (DP, IRM, HWBP, BOI, KRW, KRM, Klimaatakkoord, VenR, …–

2 Moonshot 1: Deltas remain habitable

SDG	KIA / MMIP	EU Mission
6, 11, 13, 14, 15	AWF 6, (3)	1

2.1 Description

Deltas remain habitable, even in the context of two metres of sea level rise, subsidence, climate change and human pressures. Deltas worldwide are facing complex challenges due to e.g., land subsidence, overexploitation of resources, sea level rise and changing weather patterns due to anthropogenic and (extreme) climate change stresses. In addition, deltas are dealing with increasing urbanisation, spatial pressure on rural land use and ongoing large investments in infrastructure. These challenges require an integrated long-term spatial planning approach that strikes a balance between living, working, mobility, energy consumption, nature conservation, food production, water availability and flood safety in a changing landscape.

Comprehensive understanding of water and subsurface systems, the related infrastructure and future changes in densely populated deltas are indispensable to identify the solution space and organize the design task to keep deltas habitable. Additionally, the (unknown) results of this design task will influence large decisions and investments for the coming years. Deltares develops the knowledge base for this design task and innovative measures to keep deltas habitable, while the land continues to sink, erode, and salinize, the sea rises, weather and discharge regimes become more erratic, and biodiversity declines at an unprecedented rate.

With a broad range of partners, we collaboratively work on the following ambitions:

The Netherlands knows its critical tipping points and decision moments for various climate and socio-economic scenarios, and the Netherlands possesses a range of strategies for alternative futures that have been evaluated against values such as broad prosperity including healthy ecosystems.

Development of methods to translate future scenarios and strategies to near-future decisions and to assess whether desired local, regional and national investment plans limit future options to reach broad prosperity.

All major deltas in the world – low to high income – have access to information on the impact of climate change and human pressures on their delta system dynamics, and to methods, knowledge and technology needed to collaboratively shape a sustainable, prosperous and inclusive future.

It is internationally recognized that addressing (extreme) climate change and human pressures require interdisciplinary and cross-boundary solutions at the watershed level.

A national and global network of people from the research, private and public sector as well as people from NGO's and local communities with capacity and knowledge is available to jointly keep our deltas habitable for future generations.

2.2 Research lines

To reach our goals, we have structured our strategic research along the following research lines:

1. What are the long-term outlooks for the delta-systems?
2. What strategies can keep our deltas habitable?
3. How can we support decision makers in the adaptation and transition from now to the future?

Within all three research lines, we want to emphasize scenario thinking: as the future becomes increasingly complex, we aim to quantify as many different scenarios as relevant. To this end, we will develop methodologies that fit this purpose and use cutting-edge technology, validated in interdisciplinary, multi-purpose, real-life case studies (at watershed level, as well as more local levels as for example the Rotterdam-Ruhr corridor or the Southwestern Delta in the Netherlands or the Mekong Delta in Asia). Essential element in the context of Moonshot 1 are the economic dimensions, which include the economic costs of the long-term changes ahead and the costs and benefits of taking measures. We will explore how the economic impact can be assessed in collaboration with external parties. We want to provide society and governing bodies with valuable support, utilizing tools such as powerful visualizations to translate our data into relevant information. Working in co-creation with a broad community, we want to ensure a deep and meaningful knowledge dissemination through joint research, and sustainable and long-lasting network connections with (local) stakeholders.

Line 1: What are the long-term outlooks for the delta-systems?
Only if we understand the delta, we can substantiate the bandwidth of the future problems.

To effectively develop solutions and make informed decisions, it is essential to understand the delta's long-term response to climate change and human pressures. In deltas, highly complex dependencies between the response of the natural system (with aspects such as subsidence, salinity intrusion, (geo)hydrological processes, and sediment dynamics) and the anthropogenic delta system (with its cities, hydraulic structures, and transport systems) come into play. With the question of *What are the long-term outlooks for the delta-systems?* we focus on understanding and quantifying the complex and interconnected long-term physical responses and impact on humans and nature and the sustainability and resilience of existing infrastructure and urban areas. Furthermore, we can derive a bandwidth for critical tipping points and decision moments. In collaboration with other institutes, we want to develop the ability to pick up early signs and signals of impending changes and estimate the impact on the delta. This enables timely responses and proactive measures to mitigate potential risks before they escalate.

Quantifying the long-term response of delta system dynamics involves understanding the long-term physical changes (e.g., regional extreme sea levels, discharge patterns, sediment flows, subsidence, salinization and coastline changes) and how they impact our flood risk, freshwater availability, food resources, natural habitats, and transportation.

This requires a set of fit-for-purpose methodologies for evaluating the long-term response of physical processes, their interconnection and impact on humans and nature. They should be designed to evaluate the impact of a range of climate and socio-economic scenarios, as well as prevention and adaptation measures, on our deltas, with the right level of spatial and temporal detail.

For urbanized areas, specific challenges often arise due to the density of human activities and the presence of buildings and hard infrastructure. Focusing on these urban challenges is imperative, as they require specific solutions that consider factors like population density, infrastructure demands, and susceptibility to extreme weather events. For the infrastructure, the long-term reliability, safety, and sustainability needs to be quantified. This involves gauging how well infrastructure will perform under changing conditions imposed by climate change and human activities, in collaboration with Moonshot 5.

Line 2: What strategies can keep the deltas habitable?
We substantiate a wide range of solutions within the solution space and translate the possible pathways into impact on deltas.

Deltas are already under serious pressure due to population growth and increasing urbanization. Climate change will exacerbate the circumstances in the coming decades. To cope with the combined long-term effects, we need a broad range of technical and nature-based solutions. Given the large uncertainties, thinking in a substantiated (broad) spectrum of solutions and future pathways that are translated into impact on society and the natural system is crucial for taking low-regret actions today as to ensure a habitable delta and take responsibility for the environment.

With the question of *What strategies can keep the deltas habitable?* we focus on the actions decision makers can take and the tools and solutions they need to secure an environment within the deltas, in which we can sustain the human population, and at the same time support a balanced relation with the ecosystem.

We need to develop a broad set of future-proof, feasible and resilient engineering and nature-based solutions to cope with the long-term changes ahead. Flexible where possible and robust where needed. Maintaining or adjusting the existing infrastructure as long as possible and considering ‘water and soil guiding’ for adjustments in the infrastructure are crucial strategies. This will be done in collaboration with Moonshot 5. We also want to investigate the effectiveness and scalability of nature-based solutions in urban, rural, and offshore areas in collaboration with Moonshot 2 and 3. Nature-based solutions are mostly long-term solutions, which can be more effective if we have thoroughly investigated possible future scenarios beforehand.

It is important to define the solution space for each challenge[1] while assessing the effectiveness, scalability, and feasibility of possible measures. At the same time increasing complexity of interactions between these challenges will force us to develop integral solutions, addressing multiple drivers, societal functions, and spatial and temporal scales at the same time. Working with local, regional, and national stakeholders, in both the Dutch and the international context, will bridge the gap between theoretical methodologies and applications in society.

Deltares will continue to work on pathways for adaptation and transition for long-term action perspectives. In the community, discussion will be initiated about how we want to assess the

[1] Challenges such as environmental-anthropogenic drivers, flood risk-water security-transport etc., local-regional-national-delta scale, short-long term etc.

impact of these pathways in terms of societal and governmental adaptivity, justice, social welfare, etc. We will develop tools to derive the effectiveness (water availability, flood mitigation, biodiversity, etc.) and the feasibility (availability of natural resources, costs, time, etc.) of pathways. Early signs and signals serve as navigational aids in pinpointing the ideal juncture for adjusting with the most suitable actions. Initiating action prematurely, especially when future sea level rise projections lack reliability, carries the risk of excessive investment or adaptation to erroneous signals. Conversely, commencing action too late may expose one to unfavorable risks.

The time to act is now for mitigating the loss in biodiversity and various resources, for actively managing and reducing the carbon cycle, for climate robust spatial planning, and for overall climate mitigation. We develop insights to work towards a synergy between challenges and policies, seeking out mutual benefits instead of only aiming for trade-offs.

Line 3: How can we support decision makers in the adaptation and transition from now to the future?
We actively bridge science to society and practice.

Climate change requires adaptation and transition. Navigating this path toward the future is complex, given the substantial uncertainties within the climate and socio-economic scenarios. Moreover, the present and future timelines of decisions overlap, as the long-term challenges carry implications for short-term choices. Especially for the Netherlands, a lot of choices and investments need to be made in the coming decades for the energy transition, the reduction of greenhouse gas emissions, the renovation and renewal of infrastructure, resources supply and the water framework directive. But also internationally, many investments will be made. These in turn can significantly influence the future solution space.

With the question *How can we support decision makers in the adaptation and transition from now to the future?* our objective is to assist decision makers in steering the process of adaptation and transition from the present to the future, equipping them with essential information. This encompasses the capacity to translate data into easily comprehensible information, to offer an overview of pivotal decision moments and to formulate climate resilient and feasible development pathways[2]. Additionally, we are planning to develop methods which translate the future changes into present-day decisions. With these methods, synergies and trade-offs can be clearly identified, e.g., between current challenges like the energy transition, the reduction of land-based greenhouse gas emissions, biodiversity conservation and infrastructure renewal/renovation. Furthermore, we aim to offer supporting methods to evaluate the impact of present-day investments on the future solution space.

[2] Climate Resilient Development Pathways (CRDPs) is the integration of adaptation, mitigation and development policies and actions for achieving resilient and just futures under climate change (emphasized by the IPCC's 6th Assessment Report as the needed direction for climate action and sustainable development goals).

Figure 2.1: Adaptation pathways.

Maintaining habitable deltas implies testing future developments against a broad set of values, including social and ecological values. A framework needs to be developed with which transition pathways can be evaluated against these values to support substantive decision-making.

In guiding the transition and enabling an inclusive process, co-creation is needed between stakeholders, decision makers, engineers, and scientists, to translate scientific knowledge into actionable knowledge. For this, we envision developing interactive working methods, including joint virtual and visual design studios and co-creation methodologies.

2.3 Activities 2024

To facilitate and accelerate necessary actions to keep deltas habitable in the face of (extreme) climate change and human pressures, our focus will be on a series of activities that span across the three moonshot-lines. To promote effective progress, we will engage stakeholders right from the start, work in interdisciplinary teams while maintaining in depth research, and experiment with various work-methods such as sprints and hackathons. Additionally, we organize effective knowledge sharing and integration platforms and we keep track of what the outside world is doing. While developing knowledge for the Dutch delta and methodologies and tools for worldwide deltas in general we also consider incorporating a twinning delta case simultaneously, to ensure that what we are developing is robust and applicable to various delta regions. This could involve another delta, such as the Ganges-Brahmaputra-Meghna delta, the Nile, or even a data-scarce delta like the Volta in Ghana.

Adaptation tipping point and decision moment database and analysis for the Dutch Delta – line 1,2, (3)
With increasing climate change and sea level rise short term adaptation options become less effective and are more likely to reach soft or hard thresholds or limits. These are reasons to further adapt by adding or scaling the measure within the current strategy, or by shifting to alternative strategies. Various studies have assessed the effectiveness of measures to reduce risk under different climate change scenarios as well as their synergies and trade-offs with other societal objectives. In the Netherlands, these studies have looked at different objectives related to water and soil (flood protection, water supply and ecosystems) and to opportunities related to maintenance of infrastructure. To date, this resulted in information about when and where additional adaptation would be needed for each objective, but only for a few locations

and adaptation measures. Also, interdependency between the measures for each of these objectives was not further assessed. Here, we aim to integrate and deepen our knowledge on adaptation tipping points to further assess when and where more adaptation is needed and where pivoting decisions, that trigger transformative decisions, are needed. To support such analysis, we develop an adaptation tipping points database with spatial and visual components. We start with conceptualizations based on previous Deltares studies for the Netherlands. We will be piloting this method in the region of the South Western Delta of the Netherlands because of the availability of data and previous work. However, the overall aim is to develop this method further, such that it can be used in any delta in the world.

Solution set – line 2
To cope with the effects of climate change a broad range of engineering and nature-based solutions will be needed. In collaboration with NL2120, a ten-year research program with 29 partners, the feasibility and scalability of nature-based solutions will be investigated. Meanwhile, Moonshot 5 will focus on researching technical solutions such as flexible and resilient water, transportation, and urban infrastructure, as well as next-generation hydraulic structures. Moonshots 3 and 4 will focus on solutions for short(er) term problems regarding flood risks and healthy water and soil systems. Over the course of a decade, we anticipate developing an extensive collection of evaluated and tested innovative solutions, both engineered and nature-based.

Dutch Futures Model – line 1,2 (3)
With the impending changes, we will likely need significant interventions in our system to sustain the livability of our delta. To explore alternative configurations, understand the impacts of such changes on functions (freshwater availability, water safety, ecology, transportation) and values (e.g., overall well-being, healthy ecosystem, social equality) and compare pathways, we require a model that can provide a high-level assessment of these effects on different scales. In this activity, we will explore the possibility of collaborating with the financial sector to express the effects also economically. In 2024, we want to develop a blueprint of the model in co-creation with the Rethink the Delta community and other governmental organizations. This model complements existing models utilized in the Delta Program and the Sea Level Rise Knowledge Program, which mainly address the isolated impacts of climate change within the current setup of our delta. However, these models are generally not designed to evaluate the interconnected effects of alternative configurations for our delta.

Path dependency – line (2), 3
There is a knowledge gap between the future need for an alternative configuration of our delta and the current challenges and investments related to renewal and renovation of infrastructure, housing, agriculture, energy transition and nature restoration. Uncertainties on how solutions on long-term challenges (e.g. sea-level rise) will look like, hamper decisions for investments needed earlier. A systematic approach is required to be able to derive and discuss the influence of current decisions on the solution space for the future Delta on one hand; and to be able to include knowledge about the uncertain future in short term decisions on the other hand. This activity involves the set-up of an adapted method for adaptation policy pathway analysis to align present challenges with the future demand for a redesign, with changing system requirements in time. This approach aims to bridge the gap between the future perspective and imperative short-term decisions, while offering directives for current investments and providing focus by identifying crucial decisions. We aim for an interdisciplinary approach with system and infrastructural knowledge, governance and adaptation, theoretical methods, and local practical knowledge. By 2024, we aim to have formulated and tested the method on two Dutch cases (Zuidwestelijke Delta, Rijnmond- Drechtsteden) in co-creation with the stakeholders. In addition, we aim for a trial in another delta.

Toekomstatelier ruimtelijke transitie Rethink the Delta – line 3

The Rethink the Delta Community plans to create a permanent spatial transition hub to integrate and activate scientifically validated knowledge. In most urbanized regions, there is more spatial demand than available space. Mapping and visualizing solutions, expected phenomena, and/or planned interventions accelerate and enhance joint knowledge production and community building. The learning community engages in meaningful discussions regarding the assessment of action perspectives in terms of desirability and feasibility. By organizing broader support, this allows society to take steps towards a robust, resilient, prosperous, and more enticing future more quickly and with greater enthusiasm. Co-creation and inclusiveness are both necessary for long-term sustainable developments and actual change, testing and developing methods to organize this is part of the hub.
This hub not only explores complex spatial decisions and transitions but also unites users, interests, values, and facts. It considers cross-sectoral connections and stakeholders, such as nature, water management, finance, insurers, households, and industry. In 2024, we aim to launch this hub with Rethink the Delta partners. SITO-IS will contribute by fostering interdisciplinary collaboration, visualizing outcomes, and facilitating discussions about the Netherlands' future solutions. We hope more parties will join in the following years, forming a knowledge network to co-create, gather, develop, and translate knowledge for adaptation and transformation.

Future International Delta Toolset – line 1, 2, (3)

To enable effective action, demonstrating and quantifying the joint (long-term) effects of climate change and human influences on the delta, along with measure effectiveness, is essential. To achieve this, we are developing an integrated fit-for-purpose toolset, that can quantify the long-term physical changes of water and soil dynamics in coastal regions (e.g. subsidence, salinization, erosion, flooding, drought) and their impacts (e.g. on water security, flood risks, navigation, health, food productions, biodiversity and poverty). It should be designed to quickly, and with the right level of temporal and spatial detail, quantify the long-term uncertainty of the future, in order to evaluate in an integral way the impact of a range of climate and socio-economic scenarios on major deltas, as well as the effectiveness, scalability and feasibility of possible measures. In 2024, we will continue to develop and improve the set of models and apply the compound effect of these physical changes and impacts through practical cases like the Mekong, or the Ganges-Brahmaputra-Meghna delta, establishing a foundational version and highlighting required advancements. The results will be made accessible via the International Delta Portal. Our main collaborators on this activity are various Dutch universities and the TKI program ShorelineS.

Figure 2.2: Delta Portal.

International Delta Portal – line 1, 2, (3)
An increasing number of future delta state projections and region-specific measures are becoming available. Through the International Delta Portal, we will provide access to existing and upcoming projections for everyone. This includes broad global projections on processes like erosion and flooding, as well as detailed regional projections, alongside with possible solutions. In 2024, we plan to expand on the 2023 version of the Delta Portal, by incorporating all existing Deltares projections into the viewer, providing regional “future state of the delta” reports and setting up a format to identify and visualize suitable region-specific measures. In the following years the portal should become a central hub for all future projections and solutions.

2.4 Knowledge facilities

In collaboration with the Knowledge Facilities, we are initiating technology exploration sessions for (a selection of) the following topics:

- Establishing a robust and flexible tipping point and decision moments database with solutions (data platform)
- Developing a strategy to quantitatively co-create adaptation and transformation pathways for the Dutch Delta with external stakeholders (digital twin of the future delta, multi-resolution models, co-creation approach modeled in a data platform).
- Creating an international delta portal to visualize changes and solutions (data platform).
- Developing approaches for the Toekomstatelier ruimtelijke transitie Rethink the Delta

Furthermore, we continue with the work on text mining of innumerable PDFs, such as existing Deltares reports, on relevant long-term physical changes in water and soil dynamics and their impacts in coastal regions. The results will be implemented into the International Delta Portal database.

3 Moonshot 2: Making the world safer from flooding

SDG	KIA MMIP	Sendai
3, 5, 10, 11, 13, 17	AWF 6, (3)	1, 2, 3, 4

3.1 Description

Hundreds of millions of people worldwide are at risk of flooding from the sea, from rivers and from rainfall, resulting in thousands of casualties and extensive damages each year. Due to population growth, economic development and climate change, these impacts will continue to increase in the future. Through research and innovative product development, Deltares strives to make the world's population safer from flooding and concurrent water-induced hazards.

In this moonshot we target our efforts to support the development of effective and equitable flood risk management strategies; to underpin decision-making with accurate quantification and forecasts of (compound) flood risk; and to provide excellent knowledge on the effectiveness, suitability, and acceptability of solutions to reduce flood risk.

We contribute to keeping the Netherlands the safest delta in the world. Our country is at the forefront of protecting its people against flooding through a combination of infrastructure, nature-based solutions, policy, governance, knowledge, funding and organisation. To keep the Netherlands well-protected now and in the future, levees are being reinforced and strengthened to make them compliant with the legal safety standards; (storm-surge) barriers are being re-evaluated and adapted if needed; and room for the river is maintained as much as feasible. The task of upgrading the Dutch levees is challenging due to scarcity of means, capacity and regulations for nature conservation.

Internationally, populations in flood-prone areas are exposed to multiple types of hazards of extreme surge, waves, rainfall and river discharges, with in many cases ineffective and inequitable flood mitigation solutions and compounded by pressing socio-economic and environmental issues.

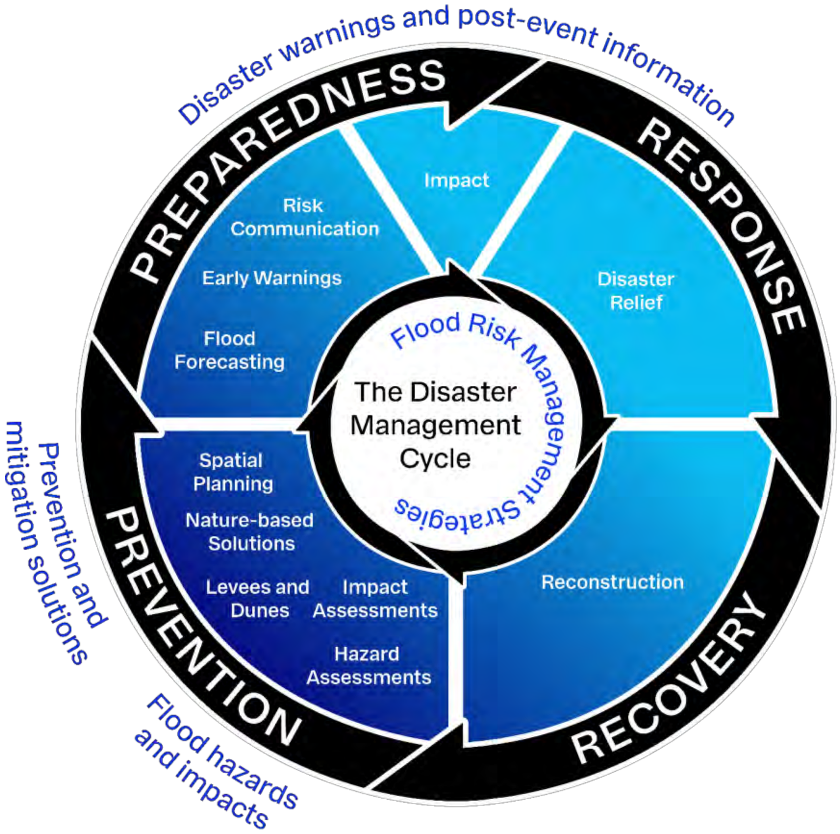


Figure 3.1: The Disaster Management Cycle, describing four phases. In the Prevention stage, risks are identified, and structural measures are implemented to reduce flood risks. In the Preparedness stage, early warning systems and evacuation plans are made to deal with an impending disaster. The Response phase deals with the immediate aftermath of a disaster. In the Recovery stage, an impacted area is rebuilt, preferably to a state which is more resilient to the next impact event.

3.2 Research lines

To reach the objectives of this moonshot, we need to understand and quantify the physical processes resulting in floods and concurrent hazards and flood impacts and have knowledge about measures that prevent or mitigate floods (including for the Netherlands knowledge about levees and innovative flood protection measures), be able to forecast flooding events, and foremost bring all these elements together in flood risk management strategies. Therefore, we have structured our research efforts around the Disaster Risk Management (DRM) Cycle (Figure 3.1) in four lines:

1. **Effective and equitable flood risk management strategies:** Develop effective, equitable and sustainable flood risk management strategies for flood-prone areas which encompass all phases of the DRM cycle in an integral way.
2. **Quantification of flood hazards, impacts and risks:** Obtain better knowledge and quantification of the physical processes that contribute to flooding and concurrent hazards in our current and near-future climates, and develop methods to quantify impacts in the Prevention phase.

3. **Prevention and Mitigation: Effective and sustainable risk-reducing solutions:** Assess and prioritise measures to reduce flood risk, such as levees, seawalls, hybrid and nature-based measures, as well as adjusted building codes and flood-proofing as part of the Prevention phase.
4. **Preparedness and Recovery: disaster warnings and post-event information:** Enable flood forecasting and early warnings to reduce the exposure and vulnerability of people to flooding in support both the Preparedness and the Recovery phase of the DRM cycle.

Each line contains a number of topics and associated activities that Deltares will undertake in 2024. For brevity we limited the number of activities in this text. Each line also contributes to the annual moonshot goal of 2024 to set up a flood forecasting and impact assessment system that covers one of the world's regions such as East Africa.

3.3 Activities 2024

Line 1: Effective and equitable flood risk management strategies
Deltares is committed to develop cost-effective, suitable, sustainable and equitable strategies to reduce flood risk, so that societies can prosper even in flood-prone areas. As risk is the combination of the probability of a flood hazard, the exposure of people and property and their vulnerability, we develop integral and tailored approaches that can help reduce each of these elements. We carry out research on integrated flood risk management strategies at different scales, varying from the country or watershed scale to the scale of cities, and small islands. We also investigate how we can make flood risk strategies more equitable while dealing with implementation challenges.

Flood-resilient landscapes.
Due to an increasing pressure on limited space and competing land use interests, especially but not only in the Netherlands, it is important to develop a flood risk management strategy which is tailored towards the characteristics of the hazard and the landscape and its use To that end, Deltares has developed the concept of 'flood-resilient landscapes' in which we research ways to enhance the flexibility of flood defences, making them more resilient to effectively mitigate the impact of flooding by minimizing potential breaches and their resulting consequences. We detect current and future narratives related to flood risk management. For each narrative, landscape 'building blocks' are derived that contribute to an adaptive flood risk management strategy.

In 2024, Flood-resilient landscape concepts will be developed for several flood hazard cases. In the built environment of Zwolle, The Hague, Den Helder and Rotterdam, the study focusses on multi-functional land use as well as long-term spatial planning which includes climate change effects, CO_2 emissions, circularity and biodiversity in the city. In the case studies in rural areas, i.e., river levees in Rivierenland and coastal levees along the Waddenzee, additional focus is placed on ecosystems and nature- based solutions.

Flood-resilient cities.
A climate resilient city must adapt the functioning of its infrastructure to long-term climate change and be prepared to remain functional during weather disasters and to recover quickly afterwards. This requires not only knowledge about the potential impacts of extreme weather and the functioning of individual networks, but also about the interaction between networks and citizens.

Using the CRIDA framework (Climate Risk Informed Decision Analysis Approach), in 2024 we are building a software environment with (automated) methods and tools (open source, and free to use) to support three stages of resilience 1) urban resilience analysis, where we use innovative software, monitoring and sensor technologies to analyse, map and monitor systems in urban regions; 2) Planning where we combine information from science, governance and design to integrate objectives and interests into a spatial plan or planning process, and 3) Implementation where we focus on measures for resilient delta cities, their implementation and performance. In 2024 we develop stress tests to identify flood-prone areas as input to master plans containing measures to better protect cities. For risk assessments, we develop workflows that can be applied to both global data for low-resolution models and local data for high-resolution models. In addition to cost-benefit models, we develop methods that provide insight into the equitable distribution of risks.

Flood-resilient Small Islands.
Small Islands Developing States (SIDS) are prone to multiple compounding hazards which may cause large damages, sometimes larger than a country's GDP. Keeping these islands habitable will become an even larger challenge due to climate change, sea level rise and population growth. Therefore, the islands require innovative, integrated solutions to protect the people and assets against flooding and erosion, and to ensure a sustainable, healthy and clean freshwater supply for people and ecosystems.

To achieve this impact, we develop a 'Resilient SIDS framework' which includes process-based modelling, Earth Observation, data-model-driven tools, and a set of mitigating measures to deal with current and near-future hazards such as sea level rise, storms, droughts and climate change. It will be used to develop suitable solutions in the short and medium term (years to decades) with a look at their long-term resilience through adaptation pathways.

In 2024, this framework will be further developed and scaled up to the national level and made available for different regions around the globe. It will be provided to stakeholders such as governments and funding organisations so that resilient flood management investments can be prioritised.

Incorporating inclusivity and equity in flood risk management.
Undesired impacts of flooding events around the world have shown how past prioritizations of plans and solutions – driven by economic and political interests – have come at the expense of the lives and livelihoods of the vulnerable and marginalized populations. For instance, farmers and fishermen in informal settlements, which are often located in the flood prone areas, are more vulnerable to and are slower to recover from disasters than other societal groups. Their vulnerability is often exacerbated by unplanned urbanization, climate impacts, land subsidence, and flood risk management programs that to not cater to their specific needs.

To ensure flood mitigation and adaptation solutions become more equitable, we need to better understand existing inequities, how climate and socio-economic changes will affect these inequities and how potential solutions can improve them. There is a strong need among government agencies for methods to accurately identify social vulnerability and incorporate it in the evaluation of flood mitigation and adaptation solutions, but these methods are in their early phases and are rarely implemented in practice.

Deltares is committed to learning about the complexities of inequities during and after flood events. In collaboration with stakeholders such as national and local government decision-makers, community organizers, NGOs and university researchers we develop and improve governance approaches, planning tools and impact models to better absorb indicators of social vulnerability, use that data in determining impacts to welfare both during and after flood events, and visualize and communicate the impacts in terms of equity targets that can be used in decision-making. We make these methods accessible by incorporating them in open-source decision-support tools for these stakeholders to use.

Concretely, Deltares launched the decision-support tool FloodAdapt, which makes information on compound flood risks and mitigation measures accessible to decision-makers, to enable the development and implementation of fair and sustainable solutions. In 2024, Deltares will further develop FloodAdapt to make it applicable to a wider range of flood prone areas and to make it available to a wider group of stakeholders.

Bridging the implementation gap.
Floods are managed by a variety of agencies and the national and local level with different capacities and levels of development. In Deltares, we focus in breaking silos in flood risk management by identifying and strengthening the linkages between these actors. We look at the overall enabling environment for implementation, including legal and institutional frameworks, inter-agency collaboration, whole-of-society approaches, social inclusion and sustainable financing. We do so by identifying real-life examples and lessons learned, and by developing methods and approaches based in practice. We are working with more than a dozen governments across three regions to analyse their governance systems for the combined management of floods and drought and inform multiannual World Bank investment programs in water and disaster risk management.
In 2024 for the Netherlands, we are focusing on the governance of flood-resilient landscapes, based on recent legal developments on land management, by bringing together different sectors such as water, DRM, agriculture and environment to have a concerted approach to building and managing green and grey infrastructure. We are also considering leveraging more advanced flood risk management systems to the management of droughts in the Netherlands, focusing on observation, land management, investment in infrastructure and inter-institutional collaboration.

Line 2: Quantification of flood hazards, impacts and risks.
Developing flood risk management strategies requires robust understanding of disaster risk drivers and reliable quantification of current and future climate risks. Climate change, population growth in flood-prone areas, and compound flood drivers such as storm surges, river discharge, and extreme precipitation make this task extremely challenging. Therefore, Deltares aims to develop and provide knowledge and locally appropriate methods to quantify the risk of compound flood events. In this we consider both flood risk management settings that are data-rich, such as the Netherlands, as well as settings in data-poor environments, such as much of the Global South, and utilize shared learning from each to improve our data, tools and models. These developments are captured in three topics:

***Quantification of compound flood and concurrent hazards and drivers**.*
This research focusses on quantifying the occurrence probabilities of sources (e.g., cyclones, storms) and pathways of compound flooding and concurrent water-related hazards such as rainfall-induced landslides and event-driven erosion. Within the Dutch legal flood safety framework, we develop and provide methods to determine hydraulic boundary conditions such as water levels and wave conditions. Internationally, we collaborate with partners to quantify the probability of extreme meteorological events such as tropical cyclones and atmospheric rivers. We analyse data and develop numerical models and tools to describe the pathways of (compound) flooding, e.g., of pluvial, fluvial and marine origin, and concurrent hazards that can be applied in data-rich and data-poor environments.
In 2024 we will improve methods to estimate (uncertainty in) hydraulic boundary conditions for the Dutch flood safety framework, for instance for offshore and nearshore wave conditions, and provide the discharge extreme value distributions for the Dutch rivers based on the KNMI'23 scenarios.

Internationally, we will research uncertainty estimates in cyclone risk assessment, and will collaborate with key partners on climate attribution of extreme events in the EC-funded COMPASS project. We will study the physics of flood pathways, including the *sponge effect,* which stores rainwater temporarily, for instance in the deep underground and which may have a reducing effect on flood risk as well as drought risk. We will furthermore continue development and validation of data-driven and numerical models such as SFINCS, wflow, and BEWARE to improve quantification of (compound) flooding in complex environments, and models such as XBeach, MPM and LHAT to quantify concurrent erosion and landslide hazards. We will develop and test new remote sensing methodologies and datasets to improve flood risk assessments (e.g., in the ESA-funded EOatSEE project), improve open-source modelling frameworks such as HydroMT and GHIRAF (Globally applicable High-resolution Integrated Risk Assessment Framework), and combine these in digital twins and multi-hazard assessment frameworks, for instance in the EU-funded InterTwin, MEDIATE and CLIMAAX projects.

Figure 3.2: Still photograph of an XBeach simulation of flooding in Ft. Meyers Beach due to Hurricane Ian (September 2022).

Quantification of flood impacts.
Floods and concurrent hazards cause damages or impacts on communities, assets (e.g., infrastructure, buildings) and ecosystems. To assess building damages, we cast our knowledge into the FIAT tool, which we will make applicable for quicker assessments. With regards to infrastructure, we make the RA2CE (Resilience Assessment and Action perspective for Critical infrastructurE) tool further applicable to assess road and transport disruption and to perform accessibility analyses during and after a flood. RA2CE will be developed to incorporate equity principles, uncertainty analyses and cost-benefit analyses in the future. Furthermore, standing flood waters can be breeding grounds for (tropical) diseases, which may cause more casualties than drownings. Specifically, we will expand estimates of flood-induced disease risks from waterborne diseases to encompass vector-borne diseases and risks of impacts on health services and embed this in the FloodAdapt tool. Furthermore, we will make an integrated analysis and advocacy ‘cookbook’ for the social and physical situation in flood-prone informal settlements to foster decision-making on resilience and wellbeing. All of these impacts may affect vulnerable populations disproportionally, which we address in Line 1 above. One extreme consequence of repeated flood impacts is that populations migrate to higher ground or even other countries. We support an ongoing project with the Free University in Amsterdam by casting our knowledge on people behaviour in a so-called agent-based model.

Quantification of compound flood risk.
Development of effective flood risk management strategies requires understanding of what flood risks communities face and how they are affected by environmental change and risk reduction measures. This assessment is particularly difficult in locations with concurrent and compound flood drivers, such as combinations of extreme rainfall, river discharge, surge, waves, and tide.

Traditionally, these flood drivers have been assessed individually. However, this will underestimate flooding and flood risk. The goal of this research line is to accelerate the uptake of compound flood risk assessment in practice by making probabilistic compound flood methods accessible to a wide community of practitioners. To achieve this, in 2024 we aim to develop an open-source toolkit for practitioners to derive compound flood event sets (synthetic compound events and their probabilities) for a diverse range of physical environment typologies, including coastal regions, transition zones between coastal and inland regions, inland river-dominated locations, and river-lake systems. Deltares will furthermore contribute to the development of a ‘manual on compound flood risk’, an initiative of the American Society of Civil Engineers.

Quantification of failure probabilities
Accurate estimation of flood and failure probabilities of levees is essential for the development of integrated flood risk management strategies. In the Netherlands there is a lack of confidence in the failure probabilities which were estimated during the periodic levee safety assessment, as some of these probabilities are clearly implausible. In 2024 Deltares aims to obtain more reliable flood failure and flood probability estimates for policy making. This also includes deriving flood probability maps of flood-prone areas, this topic is becoming increasingly relevant since there are discussions on introducing 'water risk labels’ to residences, and to use flood risk information in spatial planning.

Line 3: Prevention and Mitigation: risk-reducing measures
Flood risk can be reduced by implementing measures that reduce the flood hazard, exposure, or vulnerability. This research line focusses on prevention of flooding by applying and maintaining water retaining infrastructure such as levees, dams, dunes, and through mitigating measures such as foreshores or nature-based solutions.

In the Netherlands, the Flood Defence Act of 2017 requires that all levees must comply with the legal safety standards in 2050. The Dutch government is responsible for providing a framework to perform this safety assessment (BOI - assessment and design framework). The Dutch Flood Protection Programme (HWBP - HoogWater Beschermings Programma) is responsible to design and carry out strengthening projects to achieve the legal safety standards. New legislation on nitrogen emissions, nature conservation and a shortage on physical space, capacity (of people) and funds make this task even more challenging.

For both safety assessments as well as optimal design of reinforcement projects it is essential to be able to quantify the loads and strength of water retaining infrastructure such as dikes, dunes, dams and foreshores (including nature-based solutions). The main failure mechanisms are structure specific, i.e., levees (erosion incl. revetments, piping, macro-instability), dunes (erosion and breaching), and storm surge barriers (structural failure due to various mechanisms or non-closing). The understanding of the interaction between water retaining structures and hydraulic loads (waves or high-water levels) is a key element in this research line. Specifically, research on erosion of clay, on piping and on macro stability may significantly reduce uncertainties on failure probabilities or reduce the required strengthening of levees.

In SITO-IS 2024 we put emphasis on three topics:

Quantifying the effect of erosion of clay on failure probability.
Many levees have a grass cover with an underlying layer of clay which has 'no strength' in calculation tools, potentially resulting in severe overestimation of the failure probability. This may lead to unnecessary or over-dimensioned dike reinforcements with accompanying costs, and spatial and environmental burden. In 2024, we will start developing a toolbox that will be able to include the presence of the underlayer of clay in determining the failure probability of a dike under wave loading. We anticipate integrating this toolbox on a longer term with other toolboxes related to the design and assessments of revetments.

We will also conduct studies about a fundamental change in the design and construction of levees. The idea is to split the watertightness function and the erosion function in the levees. On the outside only erosion resistance and in the core of the levee an impermeable vertical layer. This is closer to international dam-design and the change is to build environmentally friendly levees that allow beaver burrows and are also potentially more resistant against long dry periods.

Quantifying the effect of Nature Based Solutions and foreshores on hydraulic loads. Foreshores may lower water levels and wave heights on water retaining infrastructures. At the same time, vegetated foreshores (nature-based solution) potentially lead to increased biodiversity and spatial quality. However, we need to be able to quantify the load reducing effect. In 2024, we will integrate the available knowledge related to foreshores, including vegetated foreshores and, together with our stakeholders, identify the need for future tools and knowledge requirements.

In the international context, Deltares is helping to quantify the effectiveness of (tropical) nature-based solutions to lower coastal flood risk. In 2024, Deltares will host experiments in the Delta Flume examining strategies for coral reef-lined islands, such as those in the Pacific and Indian Ocean, to naturally adapt to sea level rise and flooding, and aims to help quantify the role of nature-based solutions such as beach and reef restoration in coastal flooding and island adaptation. Deltares is also aiming to aid planning and decision-making relating to other vegetation-based flood risk reduction measures, such as mangrove forests and coastal marshes, through quantification of their effects in rapid risk assessment tools in the GHIRAF framework, such as SnapWave and SFINCS.

Quantifying erosion of dunes on failure probability.
Sandy beaches and dunes protect approximately one third of the world's coastline, including much of the Dutch North Sea coast. While providing substantial protection against marine flooding, wave attack during extreme events erodes the dune face and can lead to breaching of the dune system. In this topic we study processes affecting event-driven dune erosion using laboratory and field observations in collaboration with international partners. We capture this knowledge in process-based models, such as XBeach, to support safety assessment in the Netherlands and abroad. In 2024, we aim to facilitate a fully probabilistic assessment of the failure probability of Dutch dune systems through development of a rapid AI meta-model of XBeach.

Figure 3.3: Impression of research on erosion of grass revetments with underlayer of clay under wave loading in the Deltares Delta Flume. Obtained empirical data will be combined with physical understanding, numerical modelling and integrated into a toolbox that be used to quantify the failure probability of revetments including underlayers of clay.

Line 4: Preparedness and Recovery: disaster warnings and post-event information
Lifesaving information in the form of flood forecasts and post-event information can save lives. With accurate forecasts people can be evacuated in time and valuable assets can be temporarily reinforced. Information about how the flood waters will recede can help first responders in determining how vulnerable people can be reached. We focus in 2024 on the following topics:

Global to local multi-hazard forecasts.
In the Preparedness Phase, Early warnings can significantly help reduce the impact of extreme flooding events. Forecasting systems with global coverage and using global data can contribute to the UN and Sendai Framework goals of making early warning available to all. This motivates Deltares to further develop globally applicable, locally relevant forecasting systems, including GLOSSIS and GLOFFIS. Based on these systems Deltares works towards a service-based dissemination of globally available multi-hazard forecasts, as well as automatically produced locally relevant information. This can provide a significant contribution to enhancing the protection of people living in flood-prone areas, especially in regions where this information is currently lacking. These systems can also be used to assess the situation after a disaster strikes to provide information that can be used for emergency relief. In 2024, we will further develop the global forecasting systems for storm surge and flooding, with special focus on adding relevant physics for compound flood inundation such as river discharge and waves, optimizing computational time by using fast numerical models in the cloud, dissemination of the results through Deltares Global Data services, and downstream applications such as automatically generated local flood forecasts based on global forecast. We will also showcase a full cloud-based demo and further brainstorm its service uptake, for example in the WMO's Early Warning 4 All initiative.

Urban and flash flood forecasting.
By 2050, nearly 70% of the world's population is expected to live in urban areas. Hence, flood forecasting in urban areas is needed to enable early warnings there where most people live. Generating useful flood warnings for urban and flash flood prone areas poses requirements on the forecasting process that clearly differ from those in the large-scale, global approach. Both input data and underlying models need to be of high resolution. In addition, these systems are typically characterized by a fast response to meteorological forcing, with lead times being short (in the order of a few hours) and thus requiring forecasts within minutes in order to be useful. As current weather models and urban hydrodynamic models cannot provide the required combination of high-resolution and timely forecasts, alternatives have to be investigated.

In 2024, Deltares will work on three topics. On rainfall observations: in line with WMO's Early Warning 4 All initiative, Deltares will investigate the use of attenuation information from commercial microwave links in our cellular communication networks to obtain high-resolution rainfall data. On forecasting, Deltares will further develop hybrid and machine-learning rainfall nowcasting approaches to better capture high-intensity rainfall due to thunderstorms. And on urban flood modelling, Deltares will investigate the use of computationally fast regression-based or machine-learning applications of existing detailed urban hydrodynamic models.

3.4 Knowledge facilities

To fulfill the aims of this moonshot, we need advanced, robust and validated software that can be used to deliver projects. It is equally important that the software can also be used by partners and clients, so that the models can continue to be managed and used.
The software we use consists of hydrodynamic software such as Delft3D-FM and SFINCS, morphodynamic models such as Xbeach, wave models such as SWAN and HurryWave, and impact models such as FIAT for damages and RA2CE for road disruption. We apply Geosoftware such as the D-Series and KRATOS. We use and contribute to open-source nowcasting models such a pysteps and regression-based urban flood nowcasting models such as HybridUrb. In our research projects we make sure that the software is validated against available data, and the results are published in the open literature.
For the urban environment, we will commit to the (further) development of urban software to model, analyse and improve water systems in megacities at a detailed scale (0.5 x 0.5 m) to reduce flood risk.

Regarding Data, we use publicly available global and local data, and make tools to incorporate these sources in our models and advice products. We also generate data with our software which needs to be visualized such that clients and end users can understand it.
We will collect and expose relevant coastal data in a unified manner by making the data products cloud-based, FAIR, and easily accessible. This then allows for automatically extracting data for user-defined regions and themes, followed by a high-level description of these combined data products. Such a Global Coastal Atlas can deliver high-level climate risk sheets for policy makers but can also deliver data required for setting up models and for perform a reconnaissance of a new region.

Regarding Experimental Facilities, this moonshot will support two Delta Flume experiments relating to nature-based flood mitigation. In one experiment, the failure mechanisms and resilience of mangroves to extreme conditions will be examined to improve our understanding of the reliability of mangrove forests in terms of flood mitigation. The other experiment focusses on the adaptation capacity of coral reef-lined islands to flooding and sea level rise and will study the effectiveness of nature-based solutions, such as beach and reef restoration, in reducing coastal flooding and increasing resilience of reef-lined coasts. In these, we use the SITO-IS resources to initiate new experiments, which are typically funded from external or SITO-PS sources.

4 Moonshot 3: Resilient and healthy water and subsurface systems

SDG	KIA MMIP	EU Mission
3, 6, 11, 13, 14, 15, 17	AWF 3, 5	1, 3, 5

4.1 Description

Water and subsurface systems are under severe pressure worldwide, throughout Europe, and in the Netherlands, in terms of both quantity and quality. These systems include surface water, groundwater, soil, sediment, both in marine and freshwater environments as well as socio-economic aspects and governance. Threats include climate change with sea level rise and more frequent extreme floods and draughts, human activities with changes in use of the system, increasing use of chemicals and increasing demands for water, food, renewable energy, better human health and livelihoods. As a result of these threats the resilience and health of the systems decline, changes are reflected in aridification, salinisation, land subsidence, eutrophication, acidification, pollution, and the decline of biodiversity. Thus, it is difficult to safeguard a healthy environment for humans and nature as well as sustained ecosystem services such as agriculture, fisheries, infrastructure, and water supply.

Nationally and internationally the urgency for improving ecosystem health is increasing. In many cases societal and ecological boundaries are reached or transgressed. Water resources are not managed respecting environmental limits. The Netherlands and many other EU countries will fail to fully comply with Water Framework Directive (WFD), Marine Strategy Framework Directive (MSFD), and the Natura 2000 legislation (*https://environment.ec.europa.eu/index_en*). Policy objectives, agreements, and legal targets regarding ecological quality of aquatic and subsoil environments are increasingly becoming showstoppers for various human activities. Examples of such showstoppers are the nitrogen crisis where permits for economic activities can no longer be issued in the Netherlands and problems surrounding PFAS. These boundaries force regulators to search for integrative solutions where ecosystem services are optimized and negative impacts on the environment are minimized.

A transition to more sustainable, integral, inclusive, and adaptive management and use of water and subsurface is needed to secure quality and quantity of resources for nature and future generations. Human activities should not lead to the depletion of groundwater and surface water, to poor water quality, to biodiversity decline and to land degradation and loss of soil health. To achieve such a transition, all relevant actors and stakeholders need to be involved. Also, it is vital that water and subsurface are the guiding principles in spatial planning of land and sea.

Deltares strives to contribute to healthy and resilient water and subsurface systems, meaning that systems will be able to deliver services and be ecologically and chemically healthy for life as well, and that systems are able to survive and recover from extremes, so that future generations around the world will be able to use and enjoy them. Deltares' knowledge should facilitate transitional changes in land and water use. This requires in-depth insight and information about the functioning and management of water resources, subsurface and ecosystems. The complex of stress factors, stakeholders and scenarios requires integrated knowledge of the various sub-systems in relation to climate induced developments and human activities. This knowledge is necessary to study future scenarios and assess effects of measures, interventions, climate change and socio-economic developments, and for the design and validation of sustainable solutions for resilient and healthy systems. This knowledge helps to develop policies and management plans, providing instruments, tools, solutions, and advice with perspectives for action. The transformative change in management of water and subsurface is facilitated for stakeholders and decision-makers, on the timescale present-2050 and connecting to the longer time horizon.

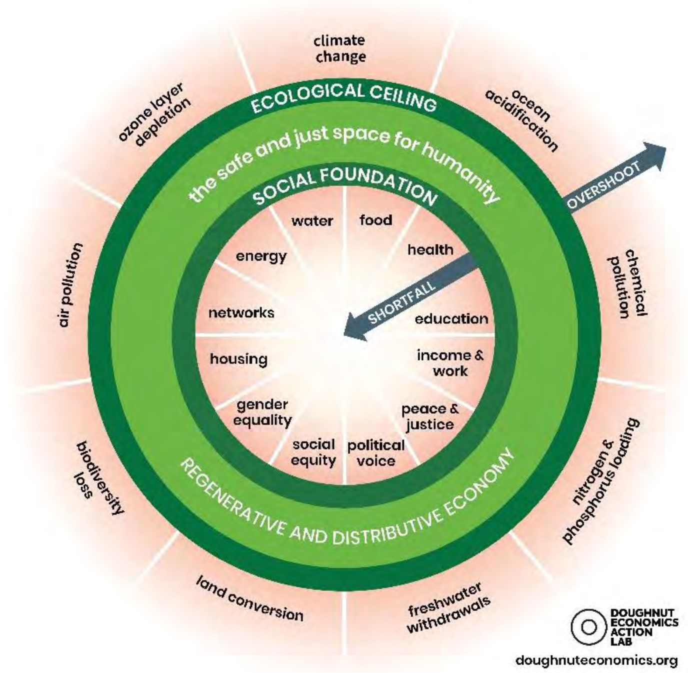


Figure 4.1: The Doughnut of social and planetary boundaries. (credit: Kate Raworth and Christian Guthier. CC-BY-SA 4.0. Citation: Raworth, K. (2017), Doughnut Economics: seven ways to think like a 21st century economist. London: Penguin Random House).

4.2 Research lines

Deltares is working on the following research lines:

1. Safeguarding water availability for nature and humans.
2. Preventing further decline of water quality and improving water quality from source to sea.
3. Preventing and reversing the decline in biodiversity and habitat diversity.
4. Improving soil health to ensure provision of services of the soil to nature and humans.

Hereto Deltares provides its expertise, knowledge networks, modelling, software, data, and experimental facilities.

Important questions to scope our work are: How can we support and inspire decision makers, planners, designers, implementers and other actors in management of water and subsurface, to address the needs for a resilient and healthy water and subsurface system in co-creation?; What happens in the near future (2023-2050) with water and subsurface systems under global change, taking into account the longer term developments, local conditions and context of the system, including natural, socio-economic and governance aspects?; What can we do to keep and/or make the water and subsurface systems resilient and healthy with sustainable solutions? The research efforts are structured in four lines:

Line 1: Safeguarding water availability for nature and humans
Stakeholder awareness of the risks of climate change, drought, water scarcity and water-related conflicts are key towards a fair and sustainable use of water resources. The full economic impact is difficult to quantify, but according to the EU's Joint Research Centre (JRC), the current average cost of drought for the EU and UK alone is nearly €9 billion per year. The recent IPCC report on climate change notes that in some areas – including the Mediterranean, southern Africa, and north-eastern Brazil – droughts are rapidly increasing in scope, duration and intensity due to climate change. The 'Ice and Glacier melt' study in 2022 from the International Commission for Hydrology of the Rhine Basin has shown that under the influence of a warming climate the surface of glaciers in the Alps is rapidly shrinking and will impact the water availability in the Rhine River basin significantly. The intricate connection between water, energy, industry, food, and ecosystems (nexus) shows how these sectors compete which often results in insufficient water allocation to support aquatic ecosystem functioning and biodiversity. Water, peace and security are interlinked and insight in water and subsurface will help to reduce risk. Addressing these challenges effectively requires cross-border, cross-sectoral, and cross-institutional approaches and cooperation. Deltares´ research is committed to catalyse collaborative actions. These actions are based on a good description and understanding of the system, scenarios, and the exposure and vulnerability of water users and identified risks. The information is tailored to decision makers' needs and helps, planning, and implementation of projects in the transition to healthy and resilient systems.

A predictive information system is needed before and during drought periods, which offers insight into the various risks and impacts of a drought at different scales and offers perspectives for action. This applies to the Netherlands, but certainly also internationally. Deltares´ knowledge and expertise are used to develop operational systems for preventing impacts of droughts, increasing insight into droughts and effectiveness of measures.

Nature-based solutions (NBS) are being promoted and supported widely for their ability to integrate different landscape functions and sustainable designs, providing both human wellbeing and biodiversity benefits. Governments, investments banks, NGOs along with many others embrace NBS as a key ingredient for making the world safer and more sustainable, as they contribute to multiple goal achievement. Yet, to ensure NBS that will be successful a deeper understanding that critically reflects on where and in what way NBS are possible, and how they can combine with other types of solutions in overarching water and subsurface management strategies. Deltares works on the design of Nature-Based Solutions that contribute to enhancing the sponge functioning and restoration of the hydrological cycle at landscape scale, connecting NBS to societal goals and multifaceted challenges including biodiversity, social inclusion, carbon and nitrogen cycling, droughts, floods and more. These challenges are faced around the world, and in the Netherlands in the NPLG (programs for rural areas) and ´Water en bodem sturend´ (water and subsurface as a guiding principle for developments). Deltares wants to quantify effects, to provide perspective on where NBS are feasible solutions, and where not, and to assess what is needed to enable implementation. Therefore, assessments are expanded from the single-location application towards the NBS in relation to an entire landscape scale system, including socio-economic aspects and ecosystem services. For this, Deltares is constantly further developing its data, experimental and software facilities, to study solutions well in the water and subsurface setting.

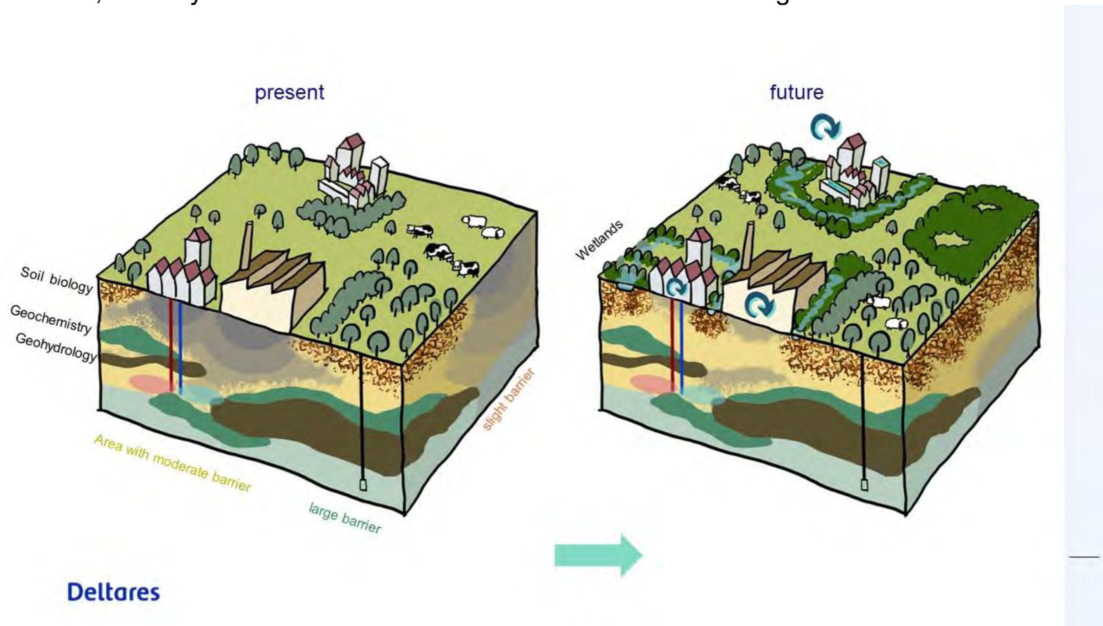


Figure 4.2: Protection of groundwater quality. From: Integrale Grondwaterstudie Nederland, Deltares & WUR 2023.

Line 2: Improving Water Quality from Source to Sea

The quality of groundwater, surface water, and marine systems is fundamental for the health of humans and ecosystems. It is the purpose of the EU WFD and the MSFD to protect water quality and ecosystems. Population increase, economic and industrial growth increases the concentrations of nutrients, anthropogenic substances, and plastics in water and subsurface, and also affects microbiological quality. Pollution occurs both locally and more diffuse and is caused by present and historic contamination. Climate change affects water quality via droughts, floods, and salinisation. Also, adaptive and mitigating measures may have effects on water quality like in green cities, water conservation, nature-based solutions, managed aquifer recharge, re-use of wastewater, independent water cycle. The impact of insufficient quality is large, with health issues and permits for economic activities that can no longer be issued. Issues occurs around the globe and insights in the quality issues are increasing, with improving monitoring of (emerging) substances, findings on the relations between water quality and human and ecosystem health. The Zero Pollution Action Plan (EC, 2021), as part of the European Green Deal (EC, 2019), expresses the EU’s commitment to reducing pollution. The plan defines a zero-pollution vision for 2050 as “air, water and soil pollution are reduced to levels no longer considered harmful to health and natural ecosystems and that respect the boundaries our planet can cope with, thus creating a toxic-free environment”.

Deltares aims to contribute to zero-pollution and protection of water quality and associated ecosystems. Prevention of pollution is only possible if substances releases can be unambiguously and transparently quantified. This insight will contribute to more effective implementation and improvement of the existing policy frameworks. If prevention is not (yet) feasible, a good quantitative understanding of leakages and their pathways to surface waters and subsurface helps to minimise and control the pollution. As a last option, Deltares can contribute measure to eliminate and remediate local and large scale (historic) pollution, where both technical and nature-based options are considered.

The Source to Sea approach of Deltares provides knowledge on pollution, from its generation in discharges and leakages from sources to the fate and transport pathways in rivers, sediments, soils, groundwater, to the place where pollutants accumulate in water, land and sea.

Deltares is approaching environmental quality in a holistic way, by assessing the water and subsurface system and its development with modelling, smart and innovative monitoring tools and strategies, and experiments in the laboratory and in the field, and developing knowledge to underpin and design sustainable, nature-based, solutions, and feasible strategies to improve water quality, with the ultimate goal to reach zero pollution and drinkable rivers.

Line 3: Reverse the decline of biodiversity and habitat diversity
Despite ongoing efforts, biodiversity is deteriorating across the world, and this decline is projected to worsen with business-as-usual scenarios. The UN Biodiversity Conference COP15 in Montreal, Canada has been gathering governments and decision-makers from around the world to discuss a new set of goals for nature over the next decade through the Convention on Biological Diversity. The EU Biodiversity Strategy for 2030 expresses ambitious goals for enhancing biodiversity values in Europe and these goals are strengthened with the proposed Ecosystem Restoration Law. The Netherlands and other European countries are struggling to comply with the ecological goals of EU Nature2000, Birds and Habitats Directive, WFD and MSFD. Biodiversity stabilizes ecosystems and makes them more resilient to pressures such as climate change or human interventions. Many questions exist on how climate change will affect ecosystem functioning. Droughts, extreme rainfall, temperature, and sea level rise have a thorough effect on water quality and biodiversity.

Deltares provides ecosystem understanding which is essential for improving and restoring biodiversity. Deltares develops tools and approaches to better understand ecosystem functioning and identify restoring measures. Deltares provides system knowledge, instruments, and tools to explore scenarios of ecosystem functioning under various climate conditions and with proposed adaptation measures. Hereby, Deltares collaborates with knowledge partners, and combines knowledge on the abiotic system (i.e. hydro-morpho-dynamics, chemical water quality, structure) with knowledge on ecosystem function and species response to changes in the abiotic system. Scenarios can show how an ecosystem will evolve, how to keep ecosystems resilient under climate change, what environmental goals can be achieved and which of the ecosystem services can be sustained for the future and what the maximum biodiversity potential for specific water and subsurface systems will be, in rivers, lakes, coastal systems, wetlands, elevated sandy soils and groundwater dependant terrestrial ecosystems.

Deltares wants to create awareness of the positive or negative impact of projects on biodiversity and stimulates that projects aim for a positive effect on biodiversity. Take for example the hydraulic infrastructure in water systems designed to provide safety for people living in delta areas or for safekeeping freshwater for drinking water or irrigation. Up to now, biodiversity has been often neglected in these types of projects or is only addressed via mandatory

Environmental Impact Assessments late in the project development chain. By providing knowledge and dialogue to assess the impact of these structures on biodiversity Deltares aims to contribute to a net-positive biodiversity gain, for example through nature inclusive designs. For Deltares projects, Deltares´ Biodiversity Core Team is providing support to colleagues working in different fields of interest in the dialogue of how their projects affect biodiversity and how they can start up conversations on how to include biodiversity in these projects.

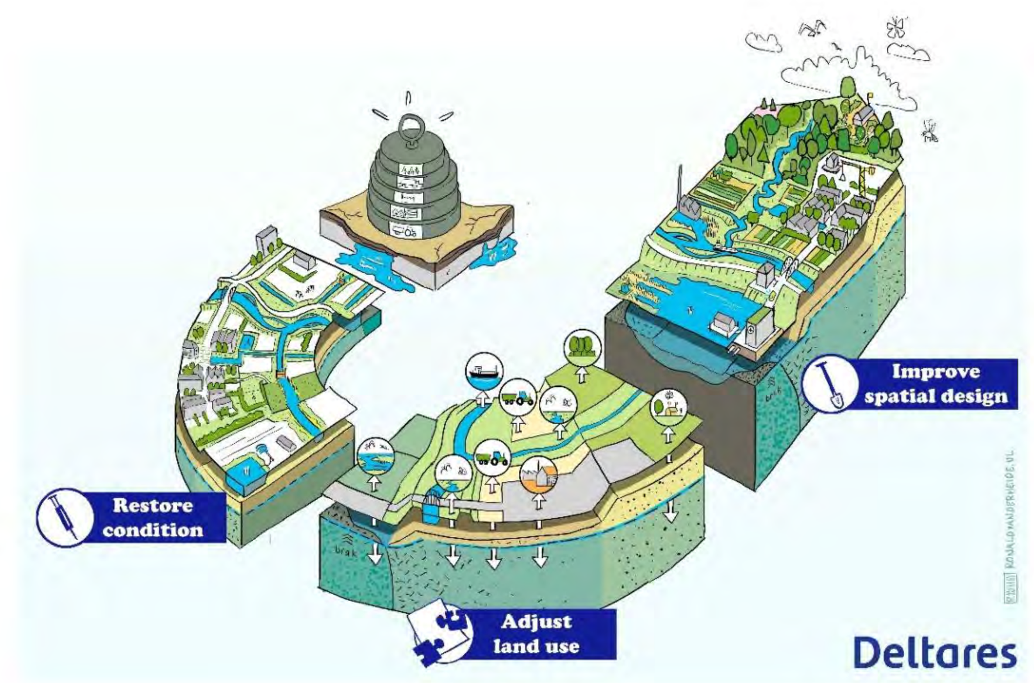


Figure 4.3: Deltares' approach to Water and subsurface-based planning and design. It is vital that water and subsurface are the guiding principles in spatial planning of land and sea. From: https://www.deltares.nl/expertise/onze-expertises/droogte/herstel-bescherming-en-beter-gebruik-van-water-en-bodem.

Line 4: Improving Soil Health to ensure provision of services to nature and humans
Soil health is defined as the physical, chemical, and biological condition of a soil, determining its ability to function as a vital living system and to provide ecosystem services. These services comprise: carrying functions for land use; water storage and discharge; natural buffer for polluting substances; food production capacity and habitat for flora and fauna. In 2020, the EU Soil Mission was launched as 1 of the 5 European missions, with its own research and innovation program. The European soil strategy (EU soil strategy for 2030) is renewed, as "key deliverable" of the EU biodiversity strategy for 2030, part of the EU Green Deal. In 2023, a proposal was made for a European Soil Monitoring Directive. The aim is to have started the transition to healthy soils by 2030 and to have healthy and resilient soils everywhere in Europe by 2050.

Knowledge is needed to shape this European policy and legislation and translate it to concrete action plans for Member States to achieve these objectives. Deltares has expertise in the field of soil system functioning, scenarios, transitions, and interactions with human activities. Deltares is committed to work on knowledge development to assess soil health, assess stressors and threats to soil health, understand and forecast the provision of ecosystem services from soils, identify key conditions for healthy soil systems, and work on concrete, cost-effective and widely applicable solutions and interventions to achieve healthy soils in Europe.

With this understanding, existing nature-based solutions and sustainable land management solutions can be optimized to specifically address soil health and soil vitality and help to achieve healthy soils.

4.3 Activities 2024

In 2024 and the coming years, Deltares wants to strengthen system understanding, scenario thinking, software, tools, experimental facilities, and solution design to accelerate the realisation of resilient and healthy water and subsurface systems for humans and nature. This will be done via contributing to knowledge projects in the Netherlands, Europe, and the world, together with knowledge partners, stakeholders and clients such as ministries, cities and other authorities, European Commission, and the IFIs.
Deltares Sito-IS 2024 will invest in realising bold ideas to create more focus and impact. Hereby, expertise will be integrated and Deltares will collaborate in co-creation with stakeholders, knowledge partners and companies in rural, coastal, and urban areas that are under pressure. International and national experience will be combined, optimally making use of available expertise. Knowledge on transition management, social, economic, and legal hindrances and incentives will be included to speed up transition processes. Some of the bold ideas are described below. This list of bold ideas will be developed and expanded together with our partners.

Large-scale managed aquifer recharge (´Water battery´)
Creating a large-scale managed aquifer recharge (MAR) in elevated sandy areas, together with stakeholders, to adapt to climate change, to be prepared for drought and flood events, to restore desiccated nature areas, to improve water quality and to create reserves to safeguard water availability to agriculture and drinking water production. Addressing large-scale circular use of water resources, linking to the ambition of the Netherlands to be a fully circular economy by 2050 (this includes water -and soil- resources). *Goal: implementing intrusive climate adaptation measures with co-benefits for nature and ecosystem services.*

Innovations for upscaling nature-based solutions
Validation of NBS at field scale through close cooperation with; land-users and field monitoring experts. Use innovative techniques in an efficient innovation pipeline, to tackle complexity to predict and realize effects of NBS for improving water quality, water availability and biodiversity at a regional scale. To optimize co-benefits from solutions. Make optimal use of high-tech and low-tech sensors in the laboratory and in the field, experimental set-ups, artificial intelligence, computational technologies, data science. *Goal: illustrate the true value of nature-based solutions to make them economically attractive.*

A voice for nature
Create awareness of the urgent necessity to improve resilience and health of the water and subsurface system. Giving water, subsurface and ecosystems a voice by means of digital technology (e.g. digital twins, digital tool to apply doughnut economics mapping) so we know and can communicate what is needed to restore biodiversity and ecosystem health. Providing insights in what is happening in the water and subsurface system, why that is an urgent problem, and what can be done about it, and to inspire to take action. Demonstration sites in rural and urban areas. Education material, serious games. *Goal: include all stakeholders to achieve drinkable rivers.*

Urban living lab to improve soil health
Evaluate, develop, test solutions in practice with stakeholders to enhance soil vitality and health, to enable to provision of ecosystem services from subsurface systems, including interactions with the water system. Doing this in a living lab context enables community involvement, learning by doing and allows for the inspiration and capacity development of

practitioners and communities in cities, while raising awareness on the importance of soil health for urban life. Inclusiveness and community involvement is crucial for an effective transition. *Goal: Transition to resilient and healthy urban soils.*

The list of bold ideas will be developed and expanded in the coming period together with our strategic partners, to come to impactful activities. Other ideas are on: Scenarios for a resilient and healthy Wadden Sea; Integrated area approach for healthy and resilient rural areas in the Netherlands; Knowledge impact for the issues of water-related migration and social stability; Transformative transboundary water cooperation for healthy water systems in large river basins worldwide; A healthy holomicrobiome in water and subsurface; Clean-up plastics from water and subsurface.

4.4 Knowledge facilities

Deltares software and data in the fields of Water quality and ecosystems, Hydrology and Hydromorphology are important to study the relation between causes and impacts on resilience and health of water and subsurface systems. Numerous datasets and data science techniques are available to study the systems. Impact modules and a scientific toolbox for modelling chemical and biological processes in water and subsurface is developed. Developments in this area are to create smoother linkages between the surface water systems and the groundwater domain, the water quantity, water quality and ecological status assessments, and to further develop data-driven modelling. The goal is to create an integrated set of instruments to easily calculate the effects of scenarios and strategies and to provide an accessible knowledge-based tools for cocreation with stakeholders.

The **experimental laboratories and field facilities of Deltares**, including the Laboratories for Microbiological, Geochemical and Physical experiments, Geohal and Hydrohal, and a monitoring trailer, provide unique research opportunities on a lab, pilot and field scale for Moonshot 3 and other Moonshots. Here, Deltares develops smart measuring and monitoring techniques, system knowledge about the distribution and breakdown of substances and the development of nature-based (remediation) solutions. We conduct lab and field experiments on sludge, where, in addition to the physical behavior of particles, we also look at the influence of chemistry and microbiology on sludge behavior. Also, these in these facilities, the integration between Moonshots is important. For example, Moonshot 4 activities in the laboratories, generate knowledge about the opportunities and risks of sustainable (underground) energy solutions in the context of resilient and healthy water and subsurface system, improves system knowledge about the emission and sequestration of greenhouse gases in natural expand systems, and investigate methods to capture CO_2.

5 Moonshot 4: Sustainable energy transition

SDG	KIA MMIP	EU Mission
7, 9, 11, 13, 14, 15	E&S: A, B, C; AWF: B, C2, E1	1, 4

5.1 Description

The Moonshot has evolved in 2023 to "Water and subsurface will enable sustainable energy and climate neutral deltas".

The urgency to combat climate change due to greenhouse gas emissions is increasing. Almost 200 countries have committed to the Paris Agreement to limit global warming to a maximum of 2.0 °C and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. Within the EU, there is an agreement to be climate-neutral by 2050 at the latest, to implement this. The Netherlands is also bound by this agreement and has set an interim target for 2030 on the way to achieving this goal for 2050, aimed at reducing greenhouse gas emissions by 60%. This is a huge challenge that requires broad societal transformation.

The energy transition is happening slowly but at the same time picking up speed. It's a huge challenge to both accelerate and scale up. Also, there is a peak demand usually in winter and a peak supply in summer. This mismatch must be overcome.

The water and subsurface system can contribute greatly to this intended reduction in greenhouse gas emissions. Water and subsurface provide space for generating and storing sustainable electricity and heat, can act as a transport medium, and as a carbon sink. Think, for example, of generating electricity at sea and inland waters, through wind farms or floating solar fields. Or harvesting heat from surface water for efficient heating of homes, or storage of sustainable energy in the form of heat batteries. At the same time, there is an increasing awareness that water and subsurface generate GHG emissions on the one hand and a long-term storage of greenhouse gases on the other hand. Smart management of water and subsurface can make a difference here.

Using water and the subsurface for the energy transition has ecological and spatial effects on the system, the negative effects of which must be minimized or mitigated. The challenge will be to safeguard sustainable use and to ensure that spatial assimilation is feasible. This requires designing and construction methods that result in less disruption and fewer costs to society. How can we manage this scaling up with integrated heat and electricity systems and the necessary decision-support tools at the system level?
To make it even more challenging, energy transition is not the only transition we are currently facing as a society. The nitrogen crisis, biodiversity crisis, climate change, water quality problems are major challenges in the physical domain that also have major implications for our country and our way of life. That's why we're looking for ways to integrate the energy transition with the other transitions and are working in value chains with a variety of other actors.

The overarching goal of Moonshot 4 is the mitigation of greenhouse gas emissions through the sustainable use of water and the subsurface. We are convinced that the only way to achieve this is by integration with the other transitions and by working together with the actors in the entire energy value chain. Our activities are aligned with IPCC WG3 recommendations to support rapid transformations.

5.2 Research lines

We organize our applied research in Moonshot 4 along three lines:

1. Sustainable heating and cooling.
2. Sustainable electricity generation and transport.
3. GHG emissions and storage in land and water management.

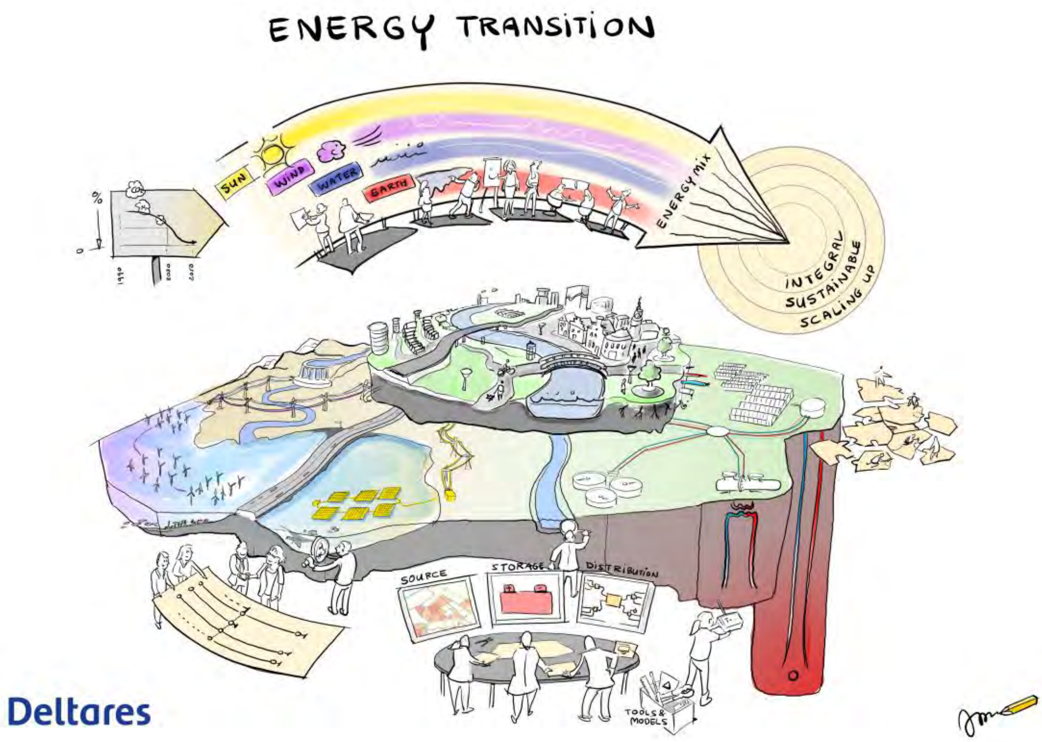


Figure 5.1: Overview Moonshot 4 with respect to Energy Transition.

Within the research line Sustainable heating and cooling we're working with and aim to support the energy sector, governmental bodies like ministries, waterboards and municipalities, housing cooperations and other stakeholders with design innovations, capacity building and decision support on cost-effective, acceptable and sustainable heating and cooling solutions.

Our Sustainable electricity generation and transport portfolio addresses design innovations, environmental impacts and decision support. The research line on GHG emissions and storage in land, water and sediment management investigates nature-based solutions that minimize GHG emissions (especially methane and CO_2) and maximize storage in water systems and agricultural areas. Within alle three lines our strategic research activities require co-funding, next to SITO-IS.

All research lines share the following three focus points:

1. **System potential, integration, acceleration and upscaling:** This concerns the development of integrated water and underground systems' models for assessing the potential for heat and electricity production, as well as for carbon sink. It also concerns the integration of heating and electricity systems to support the further scaling up of energy production and storage, as well as the development of transition paths and decision support instruments that contribute to responsible choices and considerations in energy policy. Also, it covers enabling of sustainable upscaling of offshore energy.
2. **Spatial and ecological consequences and multifunctional use**: Insights into the spatial and ecological consequences of large-scale application of energy services in water and subsurface systems (aquathermal, geothermal, wind and floating solar energy, hydropower, heat and cold storage, high-temperature storage), integrated design and construction methods with considerations for multifunctional use and strengthening biodiversity. Attention is also paid to the implementation of legislation and regulations.
3. **Integration of energy transition with other societal transitions:** Integration will take shape through the elaboration of area-based tasks. In this way it will contribute to spatial policies and planning processes (in the Netherlands: in relation to the "Omgevingswet").

5.3 Activities 2024

Line 1. Sustainable heating and cooling

Challenge: The Netherlands and the world are facing a major challenge in terms of decarbonizing the heating and cooling demand in the built environment, which accounts for approximately 70% of the final energy demand in the built environment and for 25% of the global final energy demand. This transition from fossil-based heating and cooling to renewable heating and cooling is very complex for multiple reasons: 1) The existing fossil-based heating technology delivers a high comfort level, because very high peak demands can be delivered at acceptable costs, 2) There is competition between individual and collective solutions, 3) The future cooling demand in urban areas is very uncertain, especially in regions with insignificant cooling demand in the past (e.g. North Western Europe) and 4) many stakeholders are involved in the development of collective solutions.

Deltares ambition: One of the goals of the Dutch Climate Agreement is to decarbonize 1.5 million homes in 2030. It is anticipated that sustainable district heating system will account for 700.000 homes. The water and subsurface systems can play a major role in these decarbonization efforts. In addition, we want these systems to use smart design, construction and control methods. We will scale up and accelerate the heat transition through cooperation with all actors and a strong knowledge ecosystem. Joint efforts are required from various government levels, businesses, consultancies, housing corporations and citizens. With this we want to strengthen the heat value chain of sustainable collective heating and cooling systems.

Using water and the subsurface for the heat transition has ecological and spatial effects on the system, the negative effects of which must be minimized. The challenge will be to safeguard sustainable and cost-efficient use and to ensure that spatial integration in the urban area is feasible. This requires construction methods that result in less disruption and fewer costs for society. Deltares will supply knowledge and expertise to design and manage sustainable collective heating systems, firstly in the Netherlands and increasingly in the rest of Europe.

We develop solutions for the sustainable use of water and subsurface as a source and for the storage of heat and cold. We will take a leading knowledge position in upscaling, making sources and storage more sustainable, in cost-efficient construction and optimal integration via demand response strategies and power-2-heat system integration.

Smart design of aquathermia systems could also have a positive impact on water systems, such as cooling surface water in summer, creating circulation, and filtering of unwanted materials. Deltares will develop knowledge and expertise to stimulate these positive impacts.

Figure 5.2: Construction of a heating network.

Activities 2024: In 2024, our activities will focus on:

1. Low-temperature and ultra-low temperature heating and cooling grids, especially the feasibility and design of LT-heating and the increasing cooling demand in existing neighborhoods.
2. The WarmingUP Design Toolkit will be further developed in collaboration with TNO and The People Group.
3. Furthermore, we will develop heat transition pathways for municipalities to identify tipping points in the concurrent development of individual and collective heating/cooling solutions. Possible tipping points include the (likely) occurrence of grid overload with many individual heat pumps or insufficient participation in a collective heating solution.
4. The challenge for the upcoming years is to integrate collective heating and cooling systems with solutions for climate adaptation, urbanization, healthy and biodiverse ecosystems creating habitable and resilient cities. We will work on an integrated modelling framework, to estimate the future heating and cooling demands and urban heat island effect taking into account green-blue measures in public spaces and building measures. Such a modelling framework enables the evaluation of integrated 5^{th} generation heating and cooling solutions.
5. By introducing high temperature heat storages in heat systems, the demand for peak electricity can be reduced, especially in winter times with less supply of sustainable electricity from wind and sun (Dunkelflaute). Several ways of high-volume HT storage will be explored.

Deltares is actively engaged in updating educational programs for the MSc track Heat in the interfacultary TUDelft Master program Sustainable Energy Technology and for institutes for higher education via the Knowledge Dissemination project in NieuweWarmteNu!.
Deltares will strengthen the entire knowledge cycle for sustainable heating and cooling of the built environment. Working with parties from the heat value chain with their specific experiences and knowledge, guarantees direct testing and using of the products and tools. Broad implementation will be facilitated in the national development program (Nationaal Groeifonds) NieuweWarmteNu! (2022-2027).

Line 2. Sustainable electricity generation and transport
Challenge: To combat climate change, we need to replace existing fossil sources of electricity, while considering the increase in demand due to electrification in mobility, increasing use of heat pumps and demand for green hydrogen. This leads to a high demand for cost effective sustainable energy production and transportation through wind and solar both on land and water. We expect a steady increase in solar and wind farms both on inland waters, hydropower reservoirs and offshore. These developments have significant impacts on the water and soil systems, including physical, chemical, spatial and ecological processes.

Deltares ambition: Within this subtheme we aim to develop decision support tools based on an integrated approach which include sustainable, nature-inclusive and multi-functional designs for solar and wind both on inland waters and offshore. Also, we develop innovative, cost-effective foundation technologies for offshore wind turbines and for power cable protection.

Activities: In 2024, Deltares will focus on the following lines:
1. Continue working on innovative solutions for generating electricity (solar and wind) with the realm of sea and inland water. We focus on integrated approaches encompassing sustainability, nature-inclusive design, cost and risk reduction, multi-use, and optimization (safe and affordable scaling up).
2. We will e.g., study proof of concepts (in demonstration pilots) of new nature-inclusive foundation technologies (installation and decommissioning), guidelines and manuals for sustainable design and concerning 'scour' and erosion.
3. Offshore power cable protection, insights and knowledge about failure opportunities and mechanisms of offshore transport cables.

Sustainable refers also to insights into the spatial and ecological consequences of offshore and inland energy services in aquatic ecosystem (focus point 2). This is done in multiple national and EU projects looking at the environmental impact of offshore wind and solar plants and the overall ecosystem. We will further consider synergies with other transitions.

For an acceleration in the developments of the energy transition, it is crucial to integrate the heat and cooling subtheme and electricity. In 2024, further steps will be taken towards this integration by investigating Deltares contribution to the hydrogen industry, storing electricity in the form of heat and connecting supply and demand of energy.

Line 3. GHG emissions and storage in land, water and sediment management
Challenge: To prevent exceeding the 1.5 degrees Celsius global warming goal of the Paris Agreement, European and Dutch climate law require a reduction of 95% of the GHG emissions by 2050 (respective to GHG emissions in 1990). Emission of GHGs like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) due to human activities are at the core of the climate change crisis, but that does not rule out that part of the solution can be found in natural processes and nature-based solutions impacting the carbon cycle. The water- and subsurface systems have a dual role, either they emit GHGs, or they serve as long-term GHG storage. Smart management of water- and subsurface with respect to the carbon cycle can make the

difference here. Furthermore, dredging activities are increasingly complemented with innovative sediment management in order to improve the GHG balance of dredging.

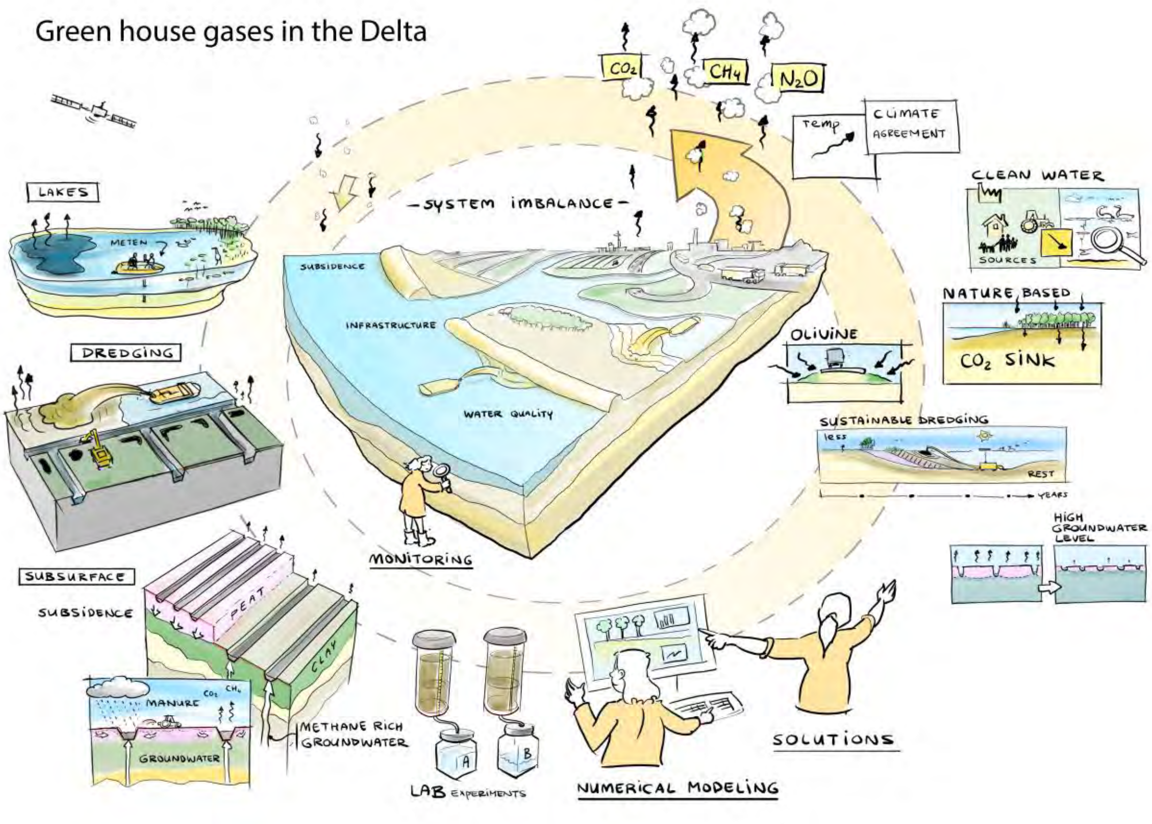


Figure 5.3: Green House Gases in the Delta.

In 2031 the IPCC includes the agricultural GHG balance in the LULUCF regulation (Land Use, Land Use Change and Forestry). By 2036 the aim is that the LULUCF sections combined, are net negative in terms of GHG emission, meaning they store more carbon than they emit as GHG. This alone requires massive rethinking of our water and subsurface management, to limit emissions and maximize carbon storage.

Deltares ambition: Our ambition within this subtheme is to develop cost-effective, carbon-inclusive water-, subsurface and sediment management strategies to enable climate-neutral deltas.

Activities 2024: To achieve this goal Deltares will work on the following lines in 2024:

1. Expand system knowledge and mechanistic understanding on which the subsurface and waters have a high potential to act as sources of GHG and which have a high potential to store GHG for the long term.
2. Continue to gather and develop knowledge on smart water- and subsurface management strategies to minimize GHG emissions and maximize GHG capture and long-term storage. This includes the water and land management sector (mostly central governments), the dredging sector (contractors, ports and waterboards) and landscape planning (lower governmental bodies). But also carbon capture technologies and storage solutions that are safe and which contribute to climate neutrality of delta systems. This includes the development of Carbon credit methodologies based on system impact (and not only point based sources). Ultimately, these developments lead to carbon inclusive delta protection, that is sustainable, with robust water resources and climate resistant.

3. Contribute to carbon inclusive Land use planning for agriculture and nature. How do we arrange the landscape so that carbon storage is maximized? How do we restore ecosystems so that the carbon storage potential is optimized. All to contribute to a climate-neutral or even carbon net-negative agriculture and nature sector.

5.4 Knowledge facilities

The mitigation of greenhouse gas emissions through the sustainable use of water and the subsurface cannot do without digitization and e.g., the use of large datasets. Examples are the determination of the remaining life and maintenance needs of offshore infrastructure, the system integration in sustainable collective heating and cooling systems (e.g. through the design tool kit), and the safe and (cost)efficient management of wind farms. We see applications of a digital acceleration for the energy system that will become largely dependent on wind and sun. Short-term forecasts in terms of chain matching (supply and demand and responding to imbalance and buffering) become important. Better regulations and well-developed energy security systems will guarantee the stability of our energy supply. In addition, the integration of the heat transition and the electrification is so complex that digital acceleration will be able to offer a solution here.

By working on system innovations in which both technical and social components have a place, we can contribute to upscaling and acceleration. Key technologies (AI and ML, digital twinning) are needed to properly integrate all links in the chain. We are working on tools that use the latest technologies and at the same time have user-friendly user interfaces. Within the research program, large datasets and software techniques are being developed for image processing, linking measurement data and models, processing extreme amounts of terabytes, innovative measurement techniques, etc.

The Deltares experimental facilities play a prominent and indispensable role in the research within the moonshot and will continue to do so. Physical experiments provide a valuable contribution to the development of knowledge needed for the energy transition and for GHG balance from water and the subsurface and is reflected in the various program lines and ongoing/future projects. This is in providing input to develop and validate solutions, further develop, and validate numerical models, provide data and test and validate proof of concepts of innovative solutions. An example of the latter is the intensive use of all the geo and water-soil flume over the last years for testing innovative silent foundation installation methods for offshore wind-turbines, which are less costly, more ecological and environmentally friendly (e.g. the SIMOX research program).

6 Moonshot 5: Resilient infrastructure

SDG	KIA MMIP	Sendai
9, 11, 13	AWF 6, 3	1, 2, 3, 4

6.1 Description

Countries and cities around the world face the consequences of substandard infrastructure. While infrastructure networks are the lifeline of society, billions of people lack access to drinking water, energy supply, work or school. In the Netherlands (climate related) infrastructure damages directly harm people's daily lives, their houses and their environment. The demands to infrastructure change rapidly due to socio-economic factors, climate change and technological developments. At the same time, the quality of the infrastructure is declining due to ageing. While biodiversity and the natural water and subsurface system are under pressure. Under these conditions infrastructure investments are required, based on long-term added value for society. Not only to foster economic growth, but also to improve well-being and prosperity. These investments offer the opportunity to connect long-term challenges to the design and implementation of infrastructure. Smart infrastructure, fueled by AI and data analytics, enables real-time monitoring and adaptive responses. Sustainable materials and new construction techniques reduce environmental impact, support the carrying capacity of the water and subsurface system and enhance long-term resilience of infrastructures. With uncertain changing demands to infrastructures and with many stakeholders in delta regions involved, transformative approaches and solutions are a necessity: a transition towards resilient infrastructures is required.

Deltares feeds transformative solutions towards resilient infrastructures. To increase our quality and impact a significant step in knowledge, experiments and associated tools supporting decision-making is crucial. A step towards (1) embedding infrastructure in the natural water and soil system (2) design options that improve adaptation and recovery from climate related damages (3) connecting object, network and system levels to provide policy information on the transition towards resilient infra. Meanwhile AI and data science techniques will inspire us to rethink our approaches.

By 2030 we have developed and disseminated the capabilities and tools to assess, design, build, transform and maintain infrastructure to cope with current and future challenges, in a nature-inclusive fashion and embedded in other societal and spatial developments.

Deltares contributes to infrastructures for which performance is influenced by the water and subsoil system: Hydraulic structures, roads and railways, harbours and inland shipping infrastructure, urban infrastructures, cables and pipelines, on object, system and network level.

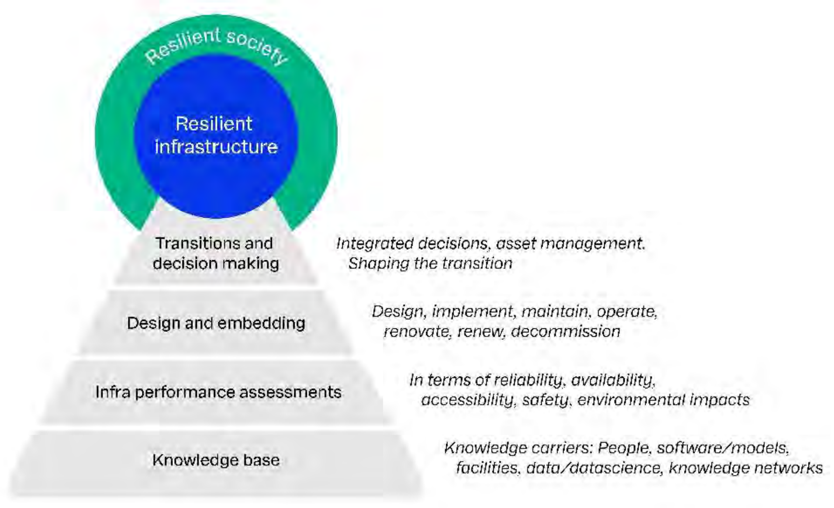


Figure 6.1: Coherent goals towards Resilient infrastructure.

(inter)national agenda's
The transition towards resilient infrastructure is adopted in many national and international agendas and policies. In response to the COVID pandemic the OECD (The Organisation for Economic Co-operation and Development) gave input to the G20 summit with their strategies for strengthening infrastructure resilience. Financial institutions such as the World Bank and the Asian Development bank state that investing in resilient infrastructure is sound and profitable, leading to economic opportunities and more prosperous futures for people. In the Netherlands the Deltaprogramme on Spatial Adaptation aims to make vital and vulnerable infrastructures climate proof by 2050 (Programma Vitaal en Kwetsbaar) while paying attention to the guiding principles of water and subsurface in spatial planning. The Dutch Mission Driven Innovation policy also encompasses the transition towards resilient infrastructure, in for instance the MMIP Levensduur verlenging gebouwde omgeving (KIA Energy and Sustainability) and the missions C & F under the KIA LandbouwWater Voedsel.

6.2 Research lines

To reach the goal in 2030 we will work on the following coherent research lines, including knowledge facilities:

1. Transitions and decision-making: We are able to facilitate informed decision-making towards the resilience of infrastructure.
2. Design and embedding: We are able to provide measures and design options to bridge the gap towards resilient infrastructure.
3. Infrastructure performance assessments: We are able to assess infrastructure objects, networks and systems in terms of risks, performance and resilience under current and future circumstances.
4. Knowledge Facilities: To improve and inspire the scientific quality and the uptake of our work, Deltares develops a base of expertise, models, experiments and networks.

6.3 Activities 2024

Line 1: Transitions and decision-making

Why is it important?

Infrastructure networks typically last for decades. The management of these networks is aimed at maintaining or improving their functioning. Because of the longevity of civil structures and networks, these transitions often take decades, and require thorough decision-making that involves many stakeholders. Effective strategic decision-making is facilitated by transition pathways to make infrastructure resilient, and involves integrating climate change, socio-economic dynamics, and cutting-edge technology.

Towards which goals do we work?

The key goal is to bridge the gap between technical research in the other research lines of this moonshot and practical (long term) decision-making for enhancing resilience of infrastructure. By translating technical information effectively and on the right asset management level, decision-makers are enabled to make informed choices with a positive impact on the living environment by improving infrastructure resilience.

To improve infrastructure resilience, it is key to understand how the functioning of infrastructure objects contribute to the service that infrastructure networks and systems provide to society. Decision-makers and infrastructure planners need to identify criticalities, vulnerabilities and how these evolve over time. They also need to plan for contingencies and ensure that disruptions in one part of the infrastructure do not lead to cascading failures in the system. This requires system integration, and involves linking infrastructures, the actors (operators) involved and their perceptions.

Finally, within this research goal, development perspectives will be developed. Development perspectives explore a range of potential futures by considering the current situation, the physical conditions, the expected developments and the manager's ambitions or tasks. We will derive scenarios and pathways, by combining the information from the development perspectives with the outputs of the other research lines linked to design, adaptation, embedding in the surroundings as well as performance of infrastructure. Aim of these scenarios and pathways is to provide guidance in the development of future proof infrastructure that enhances resilience of society.

Which topics do we address?

In this line we will define a transformative project on long term infrastructure adaptation, connecting object and network/area information on a specific infra (asset) type. In this project we will focus on the translation of technical intelligence knowledge into policy information. We will explore how this information influences decision making under deep uncertainty and which decision criteria are being used. This project will incorporate path dependencies with other long term delta developments and explore interventions to break out suboptimal paths.

The following main activities are foreseen:

- Develop methods and tooling for resilient multimodal transport networks and systems: Strengthening the approach from object – through network – towards system level and scale up towards multi-modal approaches. By developments of RA2CE towards a multi-modal application, and exploring/developing methods and tools in TKI (digital twin vaarwegen) or Horizon Europe projects (Clarion, Miraca).

Line 2: Design and embedding
Why is it important?
Coherent, low-impact and effective measures need to be designed to bridge the gap from now towards a sustainable system of infrastructure networks. Measures need to be based on the current infrastructure performance and resilience (goal 3) considering future demands and within the carrying capacity of the water and soil system. This includes the embedding of measures in a changing (natural and built) environment. To enable the transition towards a resilient infrastructure system (goal 1) it is vital to design a coherent set of adaptable and sustainable measures, making optimal use of the scarce resources.

Towards which goals do we work?
The key goal is to design coherent, low-impact and effective measures to bridge the gap between the current infrastructure system and a (more) resilient infrastructure system. There is a need to offer design options which fulfill society's changing demands regarding infrastructure cost-effectiveness, reliability in performance and environmental impact, now and in the future. Finally design options need a systemic translation into guidelines, methods and standards to support transparent and smooth decision-making.

Which topics do we address?
In this line we will define a transformative project on assessment of adaptive and nature inclusive solutions. It will focus on climate related damages and reduced performance of objects and networks. As we need to organize outcome and at the end impact, we need to understand how asset owners can use our results. Therefore this project will be carried out in close cooperation with asset owners.

The following main activities are foreseen:

- Increase the portfolio of validated climate resilient and nature based design options:
    - Climate resilient breakwaters (TKI climacs project),
    - Sustainable sediment management (Dutch coastline challenge)
    - Exploration of biodiversity-inclusive functional performance of hydraulic structures (Kennisprogramma natte kunstwerken
    - Measures to deal with the negative outcomes of subsidence (NWA loss).
    - Tool development for (re)designing hybrid grey-green drainage systems (EU REACHOUT)
- Quantification methods and tools for broad prosperity indicators as enrichment of cost-effectiveness indicators, to offer design options that fulfill society's changing demands.

Line 3: Infra performance assessment
Why is it important?
Performance information under current and future conditions is essential for asset management, design and interventions in infrastructure objects and networks. Reliability,

availability and resilience information using relevant metrics are the indicators used to assess infrastructure performance in a changing environment. Under uncertain changing conditions real time diagnosis and prognosis become more important while enabling technologies allow for improved forecasting and eventually digital twinning of infrastructure performance.

To which goals do we work?
The principal objective of this research line is to provide and apply methods and tools to assess technical and functional performance for infrastructure objects and networks in terms of reliability, availability, risks (hazard, exposure & vulnerability), resilience and (residual) lifetime. Making use of the increasing amount of condition and performance data, the potential of data-driven approaches and methods dealing with a lack of data, will be crucial herein. Performance assessment integrates knowledge of the technical and physical aspects of infrastructure with elements of reliability, risk and resilience. We will apply test and integrate data, methods and tools to infrastructure objects (e.g., ports, hydraulic structures), networks (e.g., roads, railways, waterways) and systems (e.g., transport, energy, cities), including interdependencies between infrastructures. Performance assessment and indicators, and hence the associated tooling, will increasingly need to include societal priorities such as environmental and climate impacts or social equity.

Which topics do we address?
Approaches to assess infrastructure performance, both quantitative and qualitative, will be further developed to provide optimal decision information for assessment, design and embedding of infrastructure. The various approaches will be aligned and enriched making use of the experiences, methods and tools from different types of infrastructure (cross-benefitting). The methods and tools will be developed and designed to provide actionable information to decision makers, that can be seamlessly used in design, adaptation, replacement or change of use analyses (goal 1 and goal 2), as well as in studies on transitioning infra systems to being more resilient and future-proof (goal 1).

In this line we will define a transformative project on risk-based assessment of infrastructure performance. In this project we will connect object and network information on a specific infra (asset) type. The focus will be on data-driven uncertainty-based modeling and will be aligned with the enabling technologies program.

The following main activities are foreseen:

- Methods and tools to assess infrastructure performance (objects and networks) in terms of resilience, reliability and risk: For instance the NWA LiveQuay (2023-2027) project: Live Insights for Bridges and Quay Walls. The overall aim of the project is to improve decision-making to maintain the current safe operational conditions of existing infrastructure, by assessing the remaining useful life span and the potential need for measures on quay walls and bridges in urban environments.
- Development of an innovative framework for renewal and renovation using Reinforcement Learning by efficiently balancing risk, cost, and performance indicators, to optimize decision-making for engineering asset management. Research will focus on applying the decision-making framework on case studies of quay walls.
- Further develop (Open-source) tools for performance analysis of networks and/or objects, e.g. RA2CE and PTK, both for diagnosis of current as prognosis of future performance. The analysis of the network performance also covers the link between the technical and functional performance of underlying assets.
- Use of multi-source data to assess and validate the exposure and response of infrastructures to (climate) hazards.
- Contribute to standards and guidelines for assessment, e.g. Eurocodes, NEN, ASCE, PIANC, CROW, public authorities.

6.4 Knowledge facilities

Why is it important?
The activities under the knowledge facilities inspire our objectives, improve scientific quality and improve the uptake of our work. In line with the moonshot objectives, the activities in the knowledge base will focus on the transition towards resilient infrastructures.

Towards which goals do we work?
The knowledge developed in our physical model facilities mostly relates to infrastructure *objects* rather than networks or systems. In the facilities we focus on simulating (climate related) loads on infrastructure objects, new object designs, new building techniques or possible (nature based) adaptations of existing objects. In addition, we monitor infrastructure condition and performance in field labs. These activities serve to improve the assessment of technical and functional performance (line 3).

Complementary to our physical model facilities, we develop detailed engineering software (validated with physical model data), digital twins and data-driven techniques in our infrastructure assessments. In this way we are able to design on various levels (system, network, object and component) and ensure the reliability of solutions and the resilience of infrastructure objects.

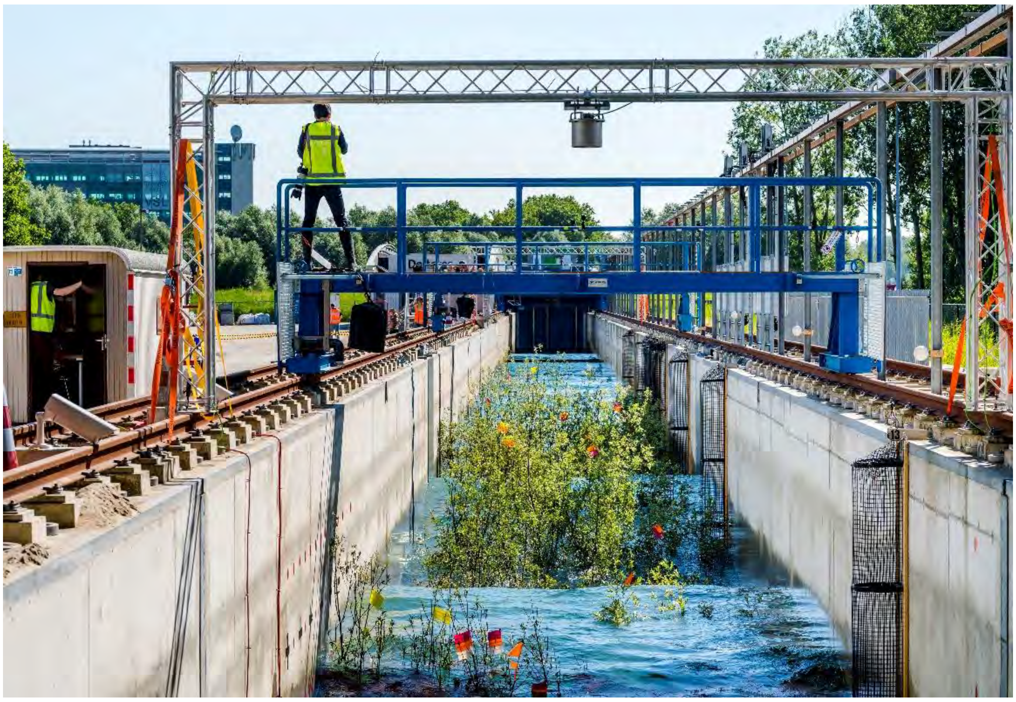
We publish our monitoring data, validated methods and tools in journal and conference papers to embed the quality of our work and share the software. To have a solid knowledge base we need to invest in people and skills. Additional attention is required for key scientific positions at (applied) universities in both system analysis as well as in the technical and engineering related disciplines. We engage our stakeholders to organize outcome and at the end impact: by mainstreaming pilots and by embedding methodologies. Therefore, we are involved relevant networks and ecosystems. In scientific networks we disseminate our insights and obtain inspiration on the latest developments in the field.

Which topics do we address?
The following main activities are foreseen:

- Theoretical and experimental research into (among others):
  - Soil-structure interaction (including pipelines).
  - Detailed hydraulics (a.o. hydraulic loads on coastal, offshore and other hydraulic Structures such as locks, sluices and weirs) to support performance assessments on e.g .salinization, bed protections and discharge.
  - Stability and reliability of road and railway embankments.
  - Storm surge barriers: learning from the past, looking ahead and exploring international experiences.
- Software and tool development.
- Support (part-time) positions at (technical) universities.
- Active participation in knowledge networks and standardization bodies, such as:

  CEN / NEN / Eurocodes, PIANC / PIARC, CROW PAR, ISSMGE, SMARTPORT, CEDA, Urban drainage knowledge programme, TU-Delft and Rioned

7 Knowledge facilities



Deltares has several unique knowledge facilities at its disposal. They include software, data and experimental facilities and key enabling technologies. The Networks and University Positions Knowledge Facilities support Deltares input for national and international knowledge and policy bodies such as the IPCC and ENW, and fund appointments of professors and senior lecturers at a range of Dutch and foreign (applied) universities. The knowledge facilities support and inspire the mission-driven programmes. Requirements of the mission-driven programmes are supported by the knowledge facilities on the short term. On the other hand, strategic research based on the knowledge facilities aims to inspire the mission-driven programmes by providing new opportunities to generate impact on the longer term. In 2024, we intend to further boost the effective coordination of the various knowledge facilities, coordination with the mission-driven programmes and the application of enabling technologies. We will continue our efforts to accelerate our digital ambitions (Deltares strategic agenda 2021-2025). Additional attention is required for key scientific positions at (applied) universities as well as the scientific impact of our experimental facilities.

7.1 Enabling Technologies

Description

The objective of Enabling Technologies is to support our mission Enabling Delta Life by testing key technologies in data science, modelling and (remote) sensing and proto-typing solutions and products which make use of these technologies. Technological innovations in these fields can increase the impact of solutions Deltares is working on. For example, the speed at which data currently becomes available in increasingly higher spatial and temporal resolution offers huge opportunities to increase the value and scale of solutions in the realm of ‘Enabling Delta Life’.

The Program Enabling Technologies therefore contributes to all the moonshot objectives. It creates opportunities to increase the impact either by offering new concepts which can be used to scale-up or opportunities to increase reliability and trustworthiness of the solutions. The Program’s way of working is by facilitating and inspiring Deltares’ Moonshots and research programs. Facilitation will take place through co-opted projects. Inspiration is generated through educational and networking activities. Since the program focusses on cutting edge technologies, it pays attention to additional aspects of innovation relevant for Deltares’ mission areas. Testing of new innovations and technologies is done in projects built around short innovation cycles with room for failure or unexpected results.

In order to achieve this the program is structured around four enabling technologies:
1. Data Science
2. Computational technology and modelling
3. Sensing and monitoring
4. Earth Observation

The innovations in Enabling Technologies will help drive its impact by enabling speed-up of modelling and data analysis, improve data sets and parameter estimations and increase the scale of our solutions. These are all in high demand by our clients. The program ‘Enabling Technologies’ therefore focusses on testing and prototyping applications supporting Deltares’ missions through technologies enabling:
- Decreased modelling lead time – i.e. how to shorten the time needed to set all steps in the modelling pipeline, from data acquisition, through model set-up and analyzing model results.
- Increased computational speed up – i.e. how to significantly accelerate computations either through ICT-technology, emulation or data-driven solutions.
- Increased automation and scale-up of data-acquisition from local to global – i.e. how to increase scale in measuring and processing sensor information while improving spatial and temporal resolution.
- Increased value of information in sensing and monitoring – i.e. how to improve accuracy, precision and measure relevant parameters at systems level.

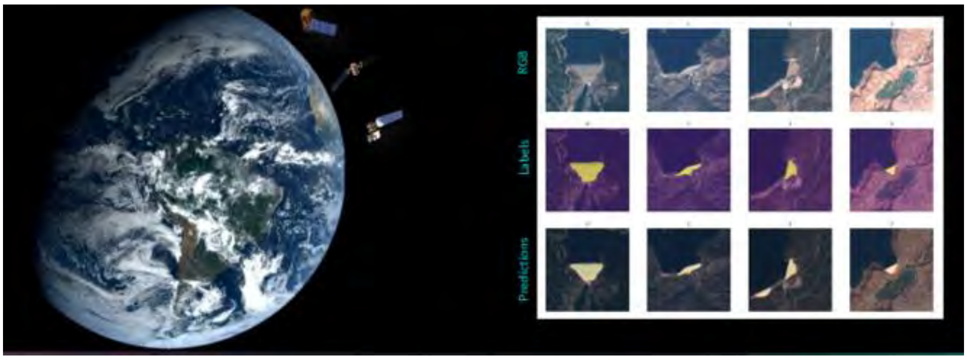


Figure 7.1: Segmentation of dams and reservoirs from Satellite Images using Machine Learning algorithms.

ET will contribute to all five moonshots. These contributions will be further detailed in co-operation with the Moonshots and translated into projects:
- Moonshot 1: Enabling Technologies can contribute to solutions which enable to increase the spatial detail of scenario-analyses by delivering innovations in processing (earth observation) data sets relevant for coastal lowlands (e.g. DEM’s, infrastructure and habitation, coastal morphology) and innovations in data science and computational technology for fast modelling and scenario-analysis.
- Moonshot 2: Enabling Technologies can contribute to solutions for real-time forecasting which enable situational awareness through new monitoring and sensing technologies, by increased automation of processing (earth observation) data sets relevant for flooding

and innovations in data science and computational technology for fast modelling and scenario-analysis.

- With these new advances, lead time for flood early warning systems can be tremendously reduced and therefore trigger early actions which save lives and reduce damages from flooding. New sensing and monitoring technologies will also contribute to design, construction and maintenance of water defence structures.
- Moonshot 3: Enabling Technologies can contribute to monitoring and predicting the state of water systems through new monitoring and (remote) sensing technologies and data analysis which offer capabilities of scaling and coverage of large water bodies.
- Moonshot 4: Enabling Technologies can contribute to solutions for monitoring the impact of energy storage in water and soil systems through new monitoring and sensing technologies and with innovations in data science and computational technology for fast modelling and scenario-analysis.
- Enabling Technologies can contribute with innovative data science solutions to provide new insights into improving the cost efficiency and optimizing the design of heat networks by integrating available datasets (from energy companies, geodatabases, etc.)
- Moonshot 5: Enabling Technologies can contribute to solutions for monitoring the state of infrastructure systems through new monitoring and (remote) sensing technologies and through innovations in data science and computational technology for the analysis of infrastructure data about status, risks and interdependencies, with focus on climate extremes and natural disasters. Digital twins allow us to share data between different infrastructure networks and providers. Such trans-project learning encourages cooperation and the sharing of data, knowledge and experience across the various infrastructure networks. Finally, strong computational facilities (e.g. using cloud) enable us to analyze massive amounts of data that are necessary to represent the interconnectivity of infrastructure networks at a larger network level.

Figure 7.2: Deltares IDlab.

Activities 2024
Programming of Enabling Technologies specifically takes aim at bringing together low TRL-ideas considering the objectives of Deltares' Moonshots. We develop our program taking into account:

- Plans of the Moonshots and demands for Enabling Technologies.
- Results and prospects of the project plan of 2023, including multi-year commitments.
- Future Trend Report of the Young Science Council.
- Results of Horizon Scans.

Based on the goals and ambitions of the Moonshots we will develop a detailed planning of the pillars on Future Modelling, Data Science, Future Sensing and Earth Observation.
Possible topics to be addressed are:

- Artificial Intelligence
  As the Future Trends report has shown and ET's activities and reviews have shown the current state of Artificial Intelligence has the capacity to disrupt important workflows and products within our field of expertise. In 2024 the Enabling technology program will particularly focus on scanning and testing the applicability of AI for achieving the goals of the Moonshots.
- Data Services and Data Platforms
  The Future Trends report has signaled the importance of the development of data services and data platforms. Apart from the fact that these will come with different revenue models, they will also serve as instruments for development of new services and applications for climate adaptation, water management or flood forecasting. Solutions to solve the challenge of multi-resolution modelling are needed.
- Digital Twins
  Digital Twin technology becomes increasingly important in fields of asset management but also in relation to earth system management and climate policy. There is a broad range of technologies that contribute to Digital Twins. Merging of various, heterogeneous data sets through data fusion is an important component. On the other side of the spectrum, visualization and user experience through immersive or virtualization is becoming more and more important.
- Monitoring
  Model validation and field observation are essential in understanding the extremes in climate and system changes that we are facing. This is what Deltares develops and employs its research infrastructure for. Technological advancements assist in this process. The possibilities and applications for measurement and monitoring continue to expand. Keeping up with, experimenting with, and utilizing these technologies for tasks such as multi-scale, long-term, and integrated monitoring enables us to interpret the mentioned changes.

These topics might also be addressed through an Open Call for proposals through Deltares' Ideas Platform.

The development of the program will be further supported through inspirational activities which will be partly also relate to the above-mentioned topics and serve to disseminate knowledge within the organization. These activities comprise:

- Brown Bag lectures and an annual ET 'Get Together'
- Moonshot Hackathons
- Forging of knowledge networks with academia, offering opportunities to students through cooperative projects.

7.2 Digital Transformation in Software and Data

Description

In order to create impact on the complex societal issues with our domain knowledge, we need the smartest people, all relevant technologies and co-creation with national and international stakeholders and partners. As stated in the Deltares Strategic Agenda 2021-2024, this requires an acceleration in updating our main software products, in strengthening our capacity in data driven technologies and in our data management and cloud infrastructure. And in addition, this requires a newly designed way of co-creation between Deltares and other knowledge institutes, private parties in the water and subsurface sector and governmental stakeholders.

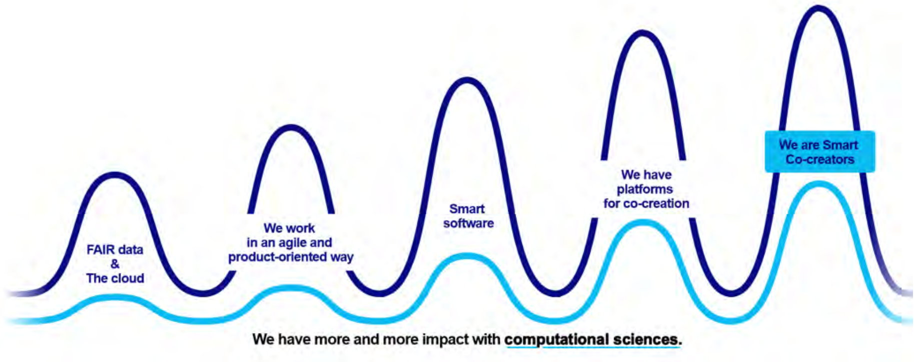


Figure 7.3: Co-creation process.

The implementation of our digital transformation roadmap started in 2022 with the first priority to improve of our data management following the FAIR principles, and the extension of our cloud infrastructure. Moreover, we introduced a more agile way of organizing the maintenance, development and renewal of our software products. In 2024 we will focus on the use of these improvements: renewal of parts of our software to make it smarter, collaborate with partners to share and co-create with data on a jointly to be developed platform, and further integration of data driven modelling in our mission drive work. Below we will elaborate on each of these topics.

Software

Deltares' software, most of which is open-source, has been world-leading in several application areas for decades and an important part of our knowledge base. In order to maintain this position parts of our software need to be upgraded and renewed in order to integrate with new applications and new developments in computational sciences relevant for our knowledge domains, like Machine Learning approaches, Earth observational techniques (spaceborne, airborne, terrestrial), faster computational algorithms and meta models, Cloud Computing, high performance computing, web services and data driven modelling. Moreover, we aspire to develop and maintain the software much more in co-creation with others. This also makes demands to the software.

For some products this implies major changes or even renewal of large parts of the software code. A challenge Deltares is facing here, is that the current products have to be maintained while the new versions are being built. This requires extra capacity of specialists and financial sources. To face this challenge, we aim to co-operate with other parties, further prioritize in our activities, and find multiple financial sources. On both of these topics we are having dialogues with our stakeholders.

We organized our software development in 5 Product Lines: Hydrodynamics & Morphology, Catchment Hydrology, Geotechnics and Flood defences, Water Quality & Ecology and Operational Systems. All product lines have developed a vision and roadmap for the coming years.

Activities Software 2024

The main activities in 2024 are:

- Hydrodynamics and Morphology software: software renewal, in co-creation with public and private partners. In 2024 we will start with technical experiments and first building activities.
- Geotechnical and Flood defences software: in 2024 we will continue the development of KRATOS in co-creation with CIMNE Barcelona and continue with data driven experiments.
- Hydrology Software: in 2024 we will continue the development of MODFLOW6 in co-creation with USGS and continue to further professionalize the development of a high quality hydrology software suite of interoperable modules, supporting uniform modeling workflows. Focus in 2024 will be on module couplers.
- Water Quality and Ecology software: focus in 2024 will be on Development of a D-Hydro 1D2D Water Quality module, Operationalisation of the D-Emissions module, and further development of D-Eco Impact, in cocreation with scientific partners. The overarching goal is to realise three software lines:
    1. Scientific Toolbox, for modelling chemical and biological processes in surface waters and sediment,
    2. Ecological Impact Modules, for modelling the impact of measures on aquatic ecosystems; and
    3. Accessible knowledge-based tools for cocreation with stakeholders.
- Operational systems: The roadmap for Delft-DFEWS aims at further improving software quality and easily connecting to external data sources, other software applications and communication tools. In 2024 focus will be on continuation of the development of the FEWS Web operator client, improved data handling and simplification of the software use.

Data

As the amount and diversity of data is growing, and the techniques for analysing data develop rapidly, the FAIR management of data facilities plays an important role in the digital transformation. In this way we can meet the growing demand for (global) data: on the one hand by providing high quality data and information, as well as information developed using data engineering and data science, and on the other by developing data-driven methods and software.

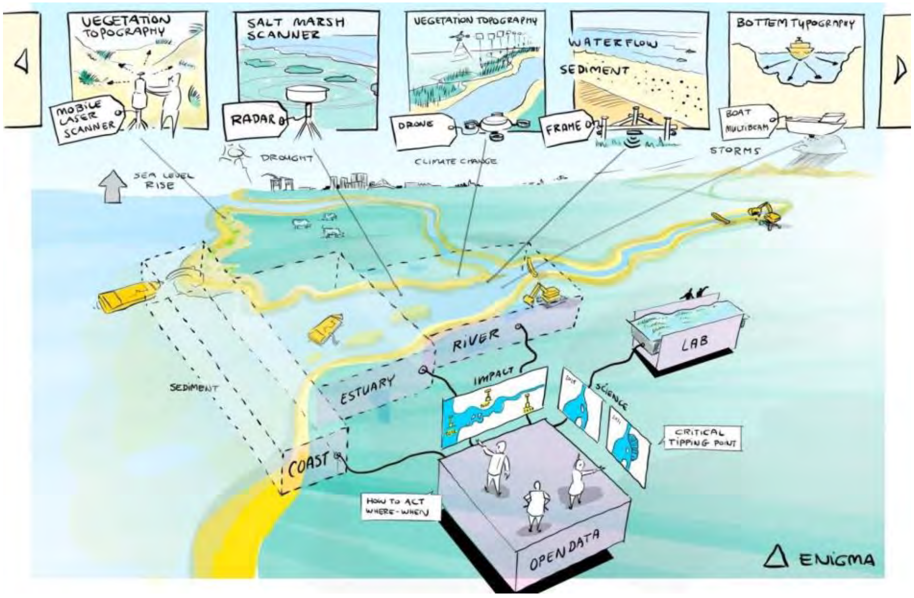


Figure 7.4: NWO project Δ-ENIGMA project.

Activities Data 2024

The main activities in 2024 include:

- **The best studied delta in the world**
  Through the NWO project Δ-ENIGMA, Deltares is contributing to the development of the best studied delta in the world; The Dutch Delta. In the Danubius-NL consortium Utrecht University, Technical University of Delft, University Twente, Wageningen University & Research, NIOZ, Deltares and TNO are working together.
  Deltas and coastal plains are attractive places to live: fertile, flat, open to the sea. These lowlands are, however, also vulnerable to climate change and sea level rise. To better predict how deltas will develop in the future we need a thorough understanding of how organisms, currents, waves, water and sediment together shape the delta landscape. This so-called biogeomorphology lies at the heart of Δ-ENIGMA. The program provides measurement infrastructure for intensive observational and experimental research of the Dutch Delta. This will improve our ability to predict future development of our delta in times of climate change, to ensure safe and sustainable living for the generations to come.
  Δ-ENIGMA forms a crucial element in the DANUBIUS-NL strategy to strengthen data-driven science in the field of water management, and it will bring the Netherlands globally in a forefront position regarding research infrastructure for studying biogeomorphological processes in engineered deltas.
- **Interoperable experimental facility data**
  The availability of accurate and reliable data is essential for knowledge development. To this end, we are taking the next steps to improve access to data from our experimental facilities. This will allow us to conduct further data analysis and improve our numerical models such as compare and validate our models against the experimental data with less effort.
  Together with the other TO2 institutes, we proposed for funding for the so-called TO2 DigiLab. This would be federated platform to share data, in particular data from experimental research. When this funding is granted, the implementation of the platform will start in 2024.
- **Global Coastal Atlas**
  For the Coastal Atlas we will collect and expose relevant coastal data in a unified manner by making the data products cloud-based, FAIR, and easily accessible. This then allows for automatically extracting data for user-defined regions and themes, followed by a high-level description of these combined data products. Such a Global Coastal Atlas can deliver high-level climate risk sheets for policy makers but can also deliver data required for setting up models and for perform a reconnaissance of a new region. The Global Coastal Atlas is based on the BlueEarth Data developments of Deltares.
- **NL2120**
  Climate change, loss of biodiversity and resulting declining economic use space pose an increasing threat to the prosperity and well-being of current and future generations of Dutch people. In order to maintain and increase our earning capacity, and to be able to live and work safely and healthily in the Netherlands in the future, fundamental adjustments are needed in our land use and soil and water management. In this transition, Nature Based Solutions (NBS, integrated solutions that use the power of nature for, among other things, the future-proof reduction of climate and environmental problems) will play an important role, as is also internationally recognized. In order to achieve the transition, it is necessary to store and make the data accessible of the various aspects of our land use and soil and water management in a future-proof and effective manner. Deltares, in collaboration with the consortium members, will play an important role in unlocking and connecting the various data sources.
  The NL2120 consortium consists of: Stichting Ecoshape (partnership between knowledge institutions, NGOs and the business community, including Arcadis, Boskalis, HKV, RHDHV, Sweco, Van Oord, Witteveen+Bos), the province of Friesland, the

municipalities of Dordrecht and Rotterdam, Staatsbosbeheer, the knowledge institutions Deltares, DRIFT, Stichting Wageningen Environmental Research, Wageningen University, TU Delft, TU Twente, Utrecht University and a wide range of NGOs (St ARK, St De Noordzee, IUCN, IVN, Natuur & Milieu, Natuur & Milieu Federaties, Natuurmonumenten, SoortenNL, Vogelbescherming and the WWF) and the training institutions Hogeschool van Hall Larenstein, HZ UAS and Yuverta/Aeres.

Impact with digital technology
Now that our data management improves, our cloud infrastructure is largely in place and our organisation of software development has been updated, we recognise that the way we manage our innovations towards common use by us and others can be further improved. In cooperation with the Enabling Technologies Program, we analyse our working process through the different TRL levels and find ways to further smoothen it. We experiment with different working forms to activate and focus the creativity and innovative power of experts from Deltares and partners to challenges that come up from our moonshots. We connect teams and working processes to each other to make sure that new knowledge and technology flows towards the software product teams and the projects that contribute to our moonshots. And we offer our experts training programs to strengthen their skills on digital technologies and on co-creating with partners.

7.3 Experimental Facilities

Description
Experimental facilities are an essential asset of Deltares. Our high-quality experimental research and specialist consultancy are recognized internationally. Our experimental facilities (Hydro-geo-chemical-bio facilities) provide opportunities to provide evidence-based input for many societal issues. Many of our experimental facilities are the best of their kind and using them for research on relevant societal problems offers unique possibilities to deliver high quality and high impact results. Deltares has a good diversity of facilities, competence to create valuable measurement set-ups, and perform and analyze experiments. Technological breakthroughs and innovative solutions often arise from experiments in these facilities. In 2024, the use of Deltares' experimental facilities by our researchers for selected topics, related to the ambitions of the moonshots, will be stimulated.

Strategic experimental facilities
Deltares has three clusters of (physical) facilities. The first cluster consists of our wave and flow facilities. This includes our 300-metre-long Delta Flume where we can simulate waves of more than 4.5 meters high. In order to adapt hydraulic structures along coasts or at ports to changing circumstances, or to build new ones for this purpose, it is important to test them first. Within this cluster the focus is on water related issues.

The second cluster consists of our geofacilities. This includes our GeoCentrifuge, in which we reduce processes in the subsurface that in reality take years, to hours. In the geofacilities we conduct research into issues relating to the subsurface. We study the effects that occur when we intervene in the subsurface. For example, if you are going to build or to improve a tunnel or a road in or on soft (deltaic) soils. Within this cluster the focus is on the subsurface in all its manifestations.

Figure 7.5: Deltares GeoCentrifuge setting up an experiment.

The third cluster consists of our Biological, chemical and physical facilities for water, soil and sediment. The quality of water, soil and sediment is important for quality of life. For example, we investigate possible solutions for sufficient space for dredged material and the presence and effects of pollutants.

Figure 7.6: Deltares Delta Flume experiment.

Strategic research
Model validation and field observation are essential in understanding the extremes in the climate and system changes that we are facing. This is what Deltares develops and employs its research infrastructure for. We use experiments as a key to gain new insights, validate methods and mechanisms, and implement them, for example, in predictive models.

Additionally, monitoring and observational methods are used to interpret long-term trends and gain insight into behaviour and conditions. Technological advancements and digitalization spark opportunities to achieve greater impact in the moonshots.

Deltares conducts high-end experiments in state-of-the-art research infrastructure (both in the lab, experimental facilities, and the field), using reliable and verifiable measurement techniques, and applies in our mission enabling delta life. We achieve this by utilizing a broader range of research infrastructure as an institution and leveraging new technologies, as well as by contributing to, accelerating, and strengthening collaborations and networks.

Our ambition is to study phenomena, validate methods, and generate verifiable experimental datasets. We do this at three levels. We conduct research on phenomena and their applications in our moonshots. Additionally, we validate and implement methods through experimental research in concrete applications and fields, ensuring knowledge transfer to a wide group of experts in the sector. Finally, we aim to play a role in networks and partnerships in this regard.

In 2024, the focus of Experimental Facilities is on increasing and broadening the added value of these facilities in our research. Based on the great societal challenges, we explore whether new state-of-the-art facilities can contribute to research into them. We achieve this by promoting the use of new facilities, applying them to new knowledge fields, and implementing new or improved measurement methods in experiments. This is done while considering the challenges in our moonshots. Regarding the digital transformation, experimental facilities have a role in validating data and models, utilizing new technologies. Attention will be given to making datasets available and connecting experiments to models.

When making choices regarding activities from Experimental Facilities, we keep in mind that we contribute to Deltares' activities in two ways. On one hand, we provide support for the work carried out within the moonshots. On the other hand, we challenge the moonshots to expand or revise their approaches and methods and enhance their understanding through experiments.

Experimental facilities will contribute to all five moonshots. These contributions will be further detailed in cooperation with the Moonshots and translated into projects:

- Moonshot 1: EF can contribute with solutions such as observation and long-term monitoring, as well as developing facilities and conducting experiments under (changing) extreme conditions.
- Moonshot 2: EF provides the facilities for researching (changing) failure mechanisms and condition assessment of water defence infrastructure for load and strength and offers data for forecasting and prediction of the risk of flooding. The Delta Flume is an important facility in this context.
- Moonshot 3: EF develops facilities for conducting phenomenon research and conducting experiments and contributes to monitoring the water and soil system. The Biological, chemical and physical facilities for water, soil and sediment play an important role in this moonshot.
- Moonshot 4: EF develops state-of-the-art research facilities where experiments are conducted for phenomenon research and model validation. This enables system transformation and the transition to it.
- Moonshot 5: EF contributes to monitoring to assess the state of the infrastructure and provides insight into the impact of the changes that this infrastructure systems undergo. Our geofacilities and, especially, our GeoCentrifuge, are important assets to realize the ambitions of this moonshot.

Activities 2024
In 2024, we will connect the use of the strategic facilities, such as our Delta Flume and our Geocentrifuge, closely to the moonshots and use them in such a way that they will contribute maximally to realizing our ambitions in the moonshots.

Experimental facilities will develop its program in more detail, demand driven, taking into account:
- Plans of the Moonshots and demands for Experimental Facilities. In close cooperation with the moonshot teams, it will be determined which research has priority in order to realize the ambitions of the moonshots.
- Intermediate results and prospects of the project plan of 2023, including multi-year research activities and commitments.
- The program will be adjusted based on the Future Trend Report of the Young Science Council and Mid-Term review of the Science Council.

Main Topics:
- <u>Including the experimental facilities in digital twinning and hybrid modelling.</u>
  As the Future Trends report of the Young Science Council and the Mid Term Review of the Science Council call for, we will look for opportunities to increase the quality and impact of our activities by making greater use of physical modeling in our experimental facilities in combination with numerical modeling and/or machine learning techniques (hybrid modeling).
- <u>Keeping up excellent research infrastructure</u>
  As the Mid Term Review of the Science Council calls for, stimulate the use of our experimental facilities for research by our own experts, as well as involvement of new staff. The Science Council proposes to stimulate the use of Deltares' experimental facilities by our researchers for selected topics to increase our scientific credibility and visibility, to create opportunities to broaden the knowledge base of our experts in physical modelling, and to enable our experts to make use of the scientific opportunities that our unique facilities provide.
- <u>New monitoring methods and facilities</u>
  The aim is to increase the contribution from experiments by validating and applying new measurement methods and introducing new facilities for changing challenges. Model validation and field observation are essential in understanding the extremes in climate and system changes that we are facing. This is what Deltares develops and employs its research infrastructure for. Technological advancements assist in this process. The possibilities and applications for measurement and monitoring continue to expand. Keeping up with, experimenting with, and utilizing these technologies for tasks such as multi-scale, long-term, and integrated monitoring enables us to interpret the mentioned changes.

Additionally, efforts are made to integrate the facilities into knowledge networks, fostering collaboration and knowledge exchange within them, such as involving students in joint projects.

7.4 Networks and university positions

Alliances with universities
To achieve the goals and ambitions of Deltares moonshots, active alliances with universities and institutes of higher education are essential. These close relationships are seen, on the one hand, in shared chairs, associate professorships, lecturers, PhD students and postdoctoral appointments and, on the other, in the joint development of projects and research in NWO/TTW programmes, NWA and European research programmes. We will intensify and expand these

relations by facilitating new chairs and appointments, e.g., in the fields of geotechnics, water quality, data science, water resource management, and land and water management in the context of carbon cycling.

Through the SITO funding, Deltares will facilitate the appointment of more than 12 professors (full-time or part-time), 17 university and college lecturers and 80 doctorate students. The financing/co-financing and substantive supervision of the PhD students is organised through the research projects in the programmes. The guiding principle remains that Deltares participates only in projects that match the objectives of its own research programmes and the knowledge questions related to the Deltares moonshots. Through this program, we facilitate long-term collaboration with universities and universities of applied sciences (HBOs) through the exchange of staff targeting the development of the core disciplines through joint scientific research for the purpose of developing and maintaining the knowledge base of the mission-driven programmes. The positions are at a range of Dutch universities (Delft University of Technology, Utrecht University, Radboud University, the University of Amsterdam, VU Amsterdam, University of Twente, Wageningen University and Research Centre), Dutch Universities of Applied Sciences (HBOs) of Saxion, Hogeschool Zeeland and Hanze Hogeschool, and at international institutions (University of Illinois). The alliances focus on the disciplines of hydraulic engineering, geo-engineering, hydrodynamics, hydrology, morphology, ecology, water quality and health, hydro-informatics, informatics data science, climatology and climate adaptation.

Networks

To maintain the knowledge base and to exchange of knowledge, the Deltares knowledge facilities finance broad-based networks with research institutes and the private sector. These networks have a cross-programme coverage and are of strategic importance in facilitating the development of mission-driven research. The networks operate on a national, European or global scale. The projects arising from the network activities are financed by one of the 15 research programmes.

At the national level, these are networks in areas such as river research (NCR), coastal research (NCK), flood risk management (ENW), underground construction (COB) and digital innovation in the water sector (Digishape).

At the European level, they are mainly networks that target collaboration in research and the definition of the knowledge agenda for policy-making and support in the field of water, climate services, environment and geo-engineering such as Water Europe, Euraqua, Sednet, ELGIP, NICOLE and NORMAN. The European network activities focusing on strengthening the position of Deltares in the Horizon Europe research programmes. In 2023, this resulted in a large number of new EU projects.

At the global level, network activities are supported in the field of climate (IPCC), hydraulic engineering (PIANC), meteorology (WMO), nature-based solutions in water management (Ecohydraulics) and the Collaborative Modelling community of practice. A new network initiative is the International Panel for Deltas and Coasts (IPDC) that will be launched during the UN-Water 2024.

8 Financial framework

This 2024 Activity Plan was drawn up to apply for the SITO institute subsidy in the context of the subsidy scheme for institutes for applied research of the Ministry of Economic Affairs and Climate (dated 1 February 2018, no. WJZ/17203973). The institute subsidy for the implementation of Strategic Research by Deltares has been set with a ceiling of €22.285.000 for the 2024 financial year.

The 2024 Activity Plan is in line with the knowledge and innovation agendas of the relevant ministerial departments and Top Sectors. The contribution to societal themes - as set out in national and international agendas - has been elaborated and explained in the previous chapters. This chapter provides an indication of how the subsidy contributes to the Mission-Driven Top Sectors and Innovation Policy (MTIB).

Our estimate is that Deltares' turnover will consist of, at least, 60% of non-economic activities. The institute subsidy will not be used for economic activities. As in previous years, the rates for activities covered by the 'institute subsidy' and as described in the 2024 Activity Plan will be submitted to the Ministry of Economic Affairs and Climate (EZK) in December 2023 together with an auditor's report.

8.1 Commitment to mission-driven working

In 2024, approximately two-thirds of the institute subsidy (approx. €14.8 million) will be used directly for activities that contribute to the national missions and international agendas as described in the KIAs. Approximately €6.8 million of the total institute subsidy will be used for activities relating to the knowledge facilities.

The first table shows the indicative budget allocation per moonshot, for the Knowledge Facilities and for the Programme Management.

	Indicative budget Euros x 1,000
Moonshot 1 – Deltas remain habitable	3,600
Moonshot 2 – Hundreds of millions better protected against flooding	2,900
Moonshot 3 – Resilient and healthy water and subsurface systems for humans and nature	3,600
Moonshot 4 – More energy from water and the subsurface	2,000
Moonshot 5 – Resilient construction and replacement in 2030	2,700
Sub-total Moonshots	**14,800**
Knowledge facilities:	
- **Enabling Technologies**	1,000
- **Digital transformation: software and data**	2,800
- **Experimental Facilities**	1,300
- **University Positions**	1,000
- **Knowledge Networks**	350
- **Emerging topics**	300
Sub-total Knowledge facilities	**6,750**
Programme Management	732
Total in euros x 1,000	**22,282**

Table 8.1: Budget distribution SITO-IS 2024.

The next table shows how the budget is allocated at the level of the KIAs. The largest share goes to the Agriculture, Water and Food KIA (AWF KIA).

	KIA1 E&S	KIA2 AWF	KIA3 H&C	KIA4 S	KIA5 ET	KIA6	Total contribution of KIAs
Moonshot 1 Deltas remain habitable		**					
Moonshot 2 Hundreds of millions better protected against flooding		**					
Moonshot 3 Resilient and healthy water resources in 2030		**					
Moonshot 4 More energy from water and the subsurface	**	*					
Moonshot 5 Resilient construction and replacement in 2030	*	**					
Enabling Technologies/ Digital Transformation		**			**		
Total in euros x 1,000	**2,250**	**10,000**	**0**	**0**	**1,250**	**0**	**13,500**

Table 8.2: Budgets located to the KIAs.

8.2 Commitment to collaboration with the private sector

One of the tasks of Deltares is to strengthen the innovative capacity of Dutch business. Private partners therefore play an important role in articulating needs and questions, and in the application of knowledge, both as financiers and co-creators. The most important private sectors work in construction or hydraulic engineering, or they are consultancy and engineering firms from both the Netherlands and other countries.

Nevertheless, the government remains the largest purchaser and user of the knowledge and innovations in the field of delta technology. The private sector is expected to contribute approximately €10 million annually to the applied research conducted by Deltares. This contribution is made to JIPs (joint industry projects), PPPs (with and without TKI subsidy) and Horizon Europe projects. Deltares is also making its own contribution to European research projects amounting to approximately €2 million of the institute subsidy.

Deltares is committed to multiple types of alliance – such as those mentioned above, but also new activities - that specifically target SMEs and start-ups. Deltares interacts with many Dutch SMEs. Those contacts involve transferring knowledge to SMEs, acquiring knowledge from SMEs or working together on applied knowledge development. Over 200 SMEs call annually on Deltares (and vice-versa) for their projects. In addition to this project-related collaboration, there are also innovation projects that are executed without invoicing or by using external funding. Since 2019, we have a service desk for SMEs and start-ups. SMEs and start-ups can also make use of the ‘Technology Consult’ (a one-day consultation) free of charge and Deltares is providing increased access to the experimental research facilities (using quarterly SME vouchers) for the testing and validation trials of SMEs and start-ups. In this way, Deltares aims to make its knowledge and expertise more accessible to these entrepreneurs. The Deltares strategy for start-ups and scale-ups is to establish links with incubators and accelerators. Agreements to this end have been signed with PortXL and SBIC, for example.

T

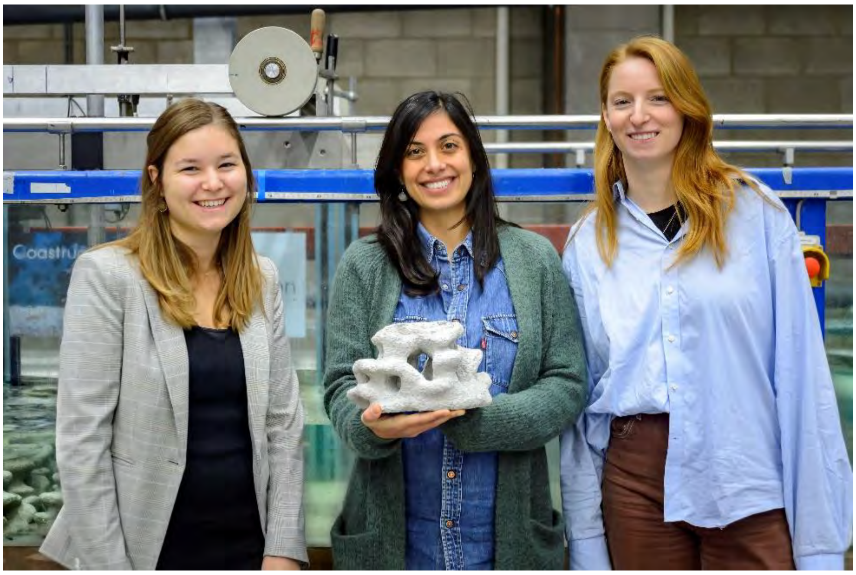


Figure 8.3: Testing of 3D-printed artificial reefs in the Wave Flume in collaboration with SME.

A Appendix A: KIA, missions and MMIPs

Mission		MMIP	Description
KIA AWF (Agriculture, Water and Food supply)	C		Climate-resilient rural and urban area
		C1	Climate- and water-resilient rural areas
		C3	Climate- and water-resilient urban areas
		C4	Improving water quality
KIA AWF	E		Sustainable North Sea, oceans and inland waters
		E1	Sustainable North Sea
		E3	Sustainable rivers, lakes and intertidal areas
KIA AWF	F		The Netherlands is the best protected delta
		F1	Sustainability and cost control in operational water management projects
		F2	Adaptation to accelerated sea level rise and increasing weather extremes
		F3	Netherlands Digital Waterland
		F4	Energy from water
KIA Energy Transition and sustainability	A	1	Renewable energy at sea
	B	4	Sustainable heating and cooling in the built environment
UN Sustainable Development Goals	3		Good health and well-being
	6		Clean water and sanitation
	7		Affordable and clean energy
	9		Industry, innovation and infrastructure
	11		Sustainable Cities and Communities
	13		Climate Action
	14		Life below Water
	15		Life on Land
EU Missions	1		Adaptation to climate change
	3		Restore Oceans and Waters
	4		100 Climate Neutral and Smart Cities
	5		Soil Deal: living labs for Healthy Soils
Sendai Framework for Disaster Reduction	1		Understanding disaster risk
	2		Strengthening disaster risk governance
	3		Investing in disaster risk reduction for resilience
	4		Enhancing disaster preparedness for response and recovery

B Appendix B: Abbreviations

Abbreviation	Dutch	English
ADB		Asian Development Bank
AFDB		African Development Bank
AGWA		Alliance for Global Water Adaptation
APFM		Associated Programme on Flood Management
AWF	Landbouw, Water en Voedsel	Agriculture, Water and Food supply
BOI	Beoordelings- en Ontwerp Instrumentarium	Assessment and Design Instrument Suite
BuZa	Ministerie van Buitenlandse Zaken	Ministry of Foreign Affairs
BZK	Ministerie van Binnenlandse Zaken en Koninkrijksrelaties	Ministry of the Interior and Kingdom Relations
C40		C40 Cities Climate Leadership Group
CEDA		Central Dredging Association
CEN		European Committee for Standardization
CMCC		Centro Euro-Mediterraneo sui Cambiamenti Climatici (IT)
DGWB	Directoraat-generaal Water and Bodem	Directorate-General Water and Subsurface
DHS		Department of Homeland Security (USA)
DPRA	Deltaplan Ruimtelijke Adaptatie	Delta Plan Spatial Adaptation
E&S	Energietransitie en Duurzaamheid	Energy Transition and Sustainability
EA		Environment Agency (UK)
ECMWF		European Centre for Medium-Range Weather Forecasts
ENW	Expertise Netwerk Waterveiligheid	Expertise Network Flood Safety
ESA		European Space Agency
EU	Europese Unie	European Union
EUR	Erasmus Universiteit	Erasmus University Rotterdam
EWEA		European Wind Energy Association
EZK	Ministerie van Economische Zaken en Klimaat	Ministry of Economic Affairs and Climate Policy
FEMA		Federal Emergency Management Agency (USA)
GNS		GNS Science (New Zealand)
HWBP	Hoogwater Beschermingsplan	Flood Protection Programme
HZ	Hogeschool Zeeland	Applied University of Zeeland (NL)
IADB		Inter-American Development Bank
IAHR		International Association for Hydro-Environment Engineering and Research
ICOLD		International Commission on Large Dams
IenW	Ministerie van Infrastructuur en Waterstaat	Ministry of Infrastructure and Watermanagement
IHE		IHE Delft Institute for Water Education
IMEC		Interuniversity Microelectronics Centre
INRAE		French National Institute for Agriculture, Food and Environment
IPCC		Intergovernmental Panel on Climate Change
ISSMGE		International Society for Soil Mechanics and Geotechnical Engineering
I-STORM		International network for storm surge barriers
IUCN		International Union for Conservation of Nature
JRC		Joint Research Center of the European Commission

KIA	Kennis en Innovatie Agenda	Knowledge and Innovation Agenda
KICT		Korean Institute of Civil Engineering (SK)
KIM	Kennisinstituut voor Mobiliteitsbeleid	Netherlands Institute for Transport Policy Analysis
KNMI	Koninklijk Nederlands Meteorologisch Instituut	Royal Dutch Meteorological Institute
KWR		KIWA Water Research
LNV	Ministerie van Landbouw, Natuur en Voedselkwaliteit	Ministry of Agriculture, Nature and Food Quality
MMIP	Meerjarige Missiegedreven Innovatie Programmas	Meerjarige Missiegedreven Innovatie Programma's
NBS		Nature-based Solutions
NGI		Norwegian Geotechnical Institute
NIOZ	Nederlands Instituut voor Onderzoek der Zee	Royal Netherlands Institute for Sea Research
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium	Royal Netherlands Aerospace Centre
NSTT		Nederlandse vereniging voor Sleufloze Technieken en Toepassingen
OECD		Organisation for Economic Co-operation and Development
PBL	Planbureau voor de Leefomgeving	Netherlands Environmental Assessment Agency
PIANC		World Association for Waterborne Transport Infrastructure
PIARC		World Road Association
RCN		Resilient Cities Network
RUG	Rijksuniversiteit Groningen	Groningen University
RVO	Rijksdienst voor Ondernemend Nederland	Netherlands Enterprise Agency
RWS	Rijkswaterstaat	Rijkswaterstaat (Directorate-General for Public Works and Water Management)
RWS-WVL	Rijkswaterstaat Water, Verkeer en Leefomgeving	Rijkswaterstaat Water Traffic and Environment Services
SDG		Sustainable Development Goals
SPC		Secretariat of the Pacific Community (Fiji)
STOWA	Stichting Toegepast Onderzoek Waterbeheer	Foundation for Applied Water Research
TNC		The Nature Conservancy (USA)
TNO		Netherlands Applied Research Organisation
TU/e	Technische Universiteit Eindhoven	Eindhoven University of Technology
TUD	Technische Universiteit Delft	Delft University of Technology
USACE		United States Corps of Engineers
USGS		United States Geological Survey
UT	Universiteit Twente	University of Twente
UU	Universiteit Utrecht	Utrecht University
VEI		Vordenbaum Engineering
VU	Vrije Universiteit Amsterdam	Free University of Amsterdam
VU-IVM	Instituut voor Milieuvraagstukken	Institute for Environmental Studies
WB	Wereldbank	World Bank
WEFE		Water, Food, Energy Nexus
WMO		World Meteorological Organization
WUR	Wageningen University & Research	Wageningen University & Research
WWF		World Wildlife Fund