Deltares

Adaptation Catalyst eTool

User guide and background information

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1 Introduction

The Adaptation Catalyst is an e-Tool designed to support planners and decision-makers overcome the ‘implementation gap’ in delivering local action that builds adaptive capacity. The Adaptation Catalyst is a decision support tool that focuses on how adaptation measures can be delivered in uncertain environments, through incremental and integrated (multi-functional and mainstreamed) actions. The tool supports stakeholder knowledge building and the ability to participate in ‘future-proofed’ decision making through the co-creation of adaptation pathways.

The Adaptation Catalyst was developed as part of the STAR2Cs project, which seeks to stimulate real change in how organizations overcome barriers to building adaptive capacity across the 2 Seas area, by implementing adaptation in the timeliest and most cost-effective manner, tailored to local scenarios. The STAR2Cs project is funded by the European Regional Development Fund – Interreg VA 2 Seas Program.

In the STAR2Cs project, implementation pathways will be realized in 8 pilot areas to demonstrate the success and cost-savings of using integrated and incremental actions to increase adaptive capacity for wider roll-out of the Adaptation Catalyst tool. By building climate change adaptation into decision-making processes, STAR2Cs seeks to encourage ‘future-proofed’ decision-making that will avoid ‘lock in’ to a particular course of action, under uncertain future conditions.

Reading guide
This document consists of three main sections. Chapter 2 contains a description of the scientific background that forms the basis for the design and functionality of the Adaptation Catalyst (AC). Chapter 3 consists of the user guide for the tool. And chapter 4 describes the application of the AC in two different cases.

Summarizing, key messages are placed in text boxes

2 Enabling adaptation through insightful planning

2.1 Challenges for traditional planning and investment under uncertain conditions

Planning, investment decisions and asset management are traditionally based on optimizations of predicted future conditions, such as river flows, precipitation patterns and population growth (Van Den Berg et al., 2015). Climate change is making future conditions increasingly uncertain and unpredictable. In this context, traditional prediction-based planning has become untenable and risks exist of both over and under investment, as well as of ill-timed actions. At the same time, climate change requires new ways of planning that create flexible and resilient systems for different possible futures. This is particularly challenging, as planning decisions are often traditionally characterized by long life spans with potential for ‘lock-in’ to solutions that may become unsuitable or inefficient (Muller, 2007).

In planning, decision makers have long relied on economic assessments like Cost Benefit Analysis (CBA), to compare alternative investment options under a particular scenario. In the current planning context, however, traditional decision-making processes, such as CBA, can lead to sub-optimal outcomes over time and under different futures. In its traditional application, CBA and similar methods of economic assessment overvalue early returns on investment and undervalue flexibility and the ability to change course to meet new or unexpected conditions (Haasnoot et al., 2019). A more pro-active and adaptive approach to planning and decision-making focuses on ensuring that service levels and system objectives are maintained under different futures, while avoiding inefficiencies and lock-in over time (Haasnoot et al., 2013; Kwadijk et al., 2010; Lawrence and Haasnoot, 2017).

Tools can support adaptive planning for more climate resilient urban areas in a way that integrates stakeholder participation in urban planning processes, with meaningful information for decision making (McEvoy et al., 2018).

> *Traditional methods for planning and decision making regarding asset management and infrastructure investments are ill-suited to the uncertain conditions brought on by climate change. Therefore, the Adaptation Catalyst tool is based on adaptive planning that supports decision making in a multi-stakeholder context.*

2.2 Adaptive planning of climate adaptation

Dynamic Adaptive Policy Pathways (DAPP) is a planning approach that aims to support the development of adaptive plans that are able to deal with conditions of deep uncertainty (Haasnoot et al., 2013). DAPP was developed by Deltares and Delft University of Technology, and has been applied in the Dutch Delta Programme, as well as in local-scale planning, in Greater Wellington, New Zealand (Lawrence and Haasnoot, 2017) and Dordrecht, the Netherlands (Gersonius et al., 2016), amongst others. A DAPP analysis involves the creation of ***adaptation pathways***, which depict different ways of ensuring a system’s level of service, or objectives, are met under future conditions. Building adaptation pathways involves multiple stakeholders in identifying and connecting possible short-term actions and long-term options that will ensure that the desired level of service or system objective is maintained in a variety of future scenarios (Walker et al., 2013). Adaptation pathways are a central component of an adaptive plan, as they facilitate exploring different futures and different possible responses over time. ***Scenarios***, as opposed to predictions, are used to represent different futures and to explore different sources of uncertainty. For instance, scenarios can reflect a range of climate change effects and rates, directions of social and economic development, political changes or even wild-card events, like a natural disaster.

To further support the development of adaptive plans, DAPP encourages the identification of ***adaptation tipping points***, or the conditions under which a particular action will no longer meet the system objectives. Since a new action should be taken before a tipping point is reached, a DAPP analysis also emphasizes the need to identify ***signals*** for when a new action or decision should be taken. This promotes decision making processes that are proactive and adaptive to changing conditions (Haasnoot et al., 2013).

A simplified illustrative example of the main concepts of adaptation pathways, scenarios tipping points and signals comes from the issue of sea level rise in the Netherlands. The coastal city of Scheveningen decides to explore the effect of three sea level rise ***scenarios*** from 2020 to 2100: no sea level rise, one meter of sea level rise and two meters of sea level rise. Their assessments indicate that current protections will no longer meet safety requirements after 50 centimetres of sea level rise. This is their first ***adaptation tipping point***. Now, the city can decide on a number of actions. They could decide to invest in a sea wall of two meters, which would protect them in all scenarios. This is one ***adaptation pathway***, but it is expensive and does not give them flexibility if sea level rise turns out to be less extreme. Another pathway is to add more sand to the dunes, which add protection up to one meter of sea level rise. If sea levels exceed one meter, a second adaptation tipping point is reached and the city may have to invest in the sea wall after all. This represents a second pathway to ensuring the city is protected if sea level rises to two meters. A third pathway could be to retreat if sea level rises beyond two meters. A fourth could be to add still more sand. It is clear that there are different options that may be more suitable to under different futures. Since it takes time to decide and implement each action, the city could choose a signal of 20 centimetres below each tipping point sea level as an appropriate ***signal*** for taking a new action. This would mean that for the first tipping point, 50 centimetres, sea level rise of 30 centimetres (50-20) would be the signal to take action.

Dynamic Adaptive Policy Pathways (DAPP) is a tool to explore different future conditions and potential responses, in a way that avoids the trap of optimization-based decisions that rely on predictions of the future, which may prove incorrect. Instead of planning for a "most likely scenario" DAPP frames plans as pathways that can be adapted as the future unfolds. This supports more adaptive decision making around investments and asset management. The Adaptation Catalyst tool is based on the DAPP approach.

2.2.1 Dynamic Adaptive Policy Pathways (DAPP)

A DAPP analysis is an iterative process that comprises six steps. These are outlined in Figure 1 and elaborated below.

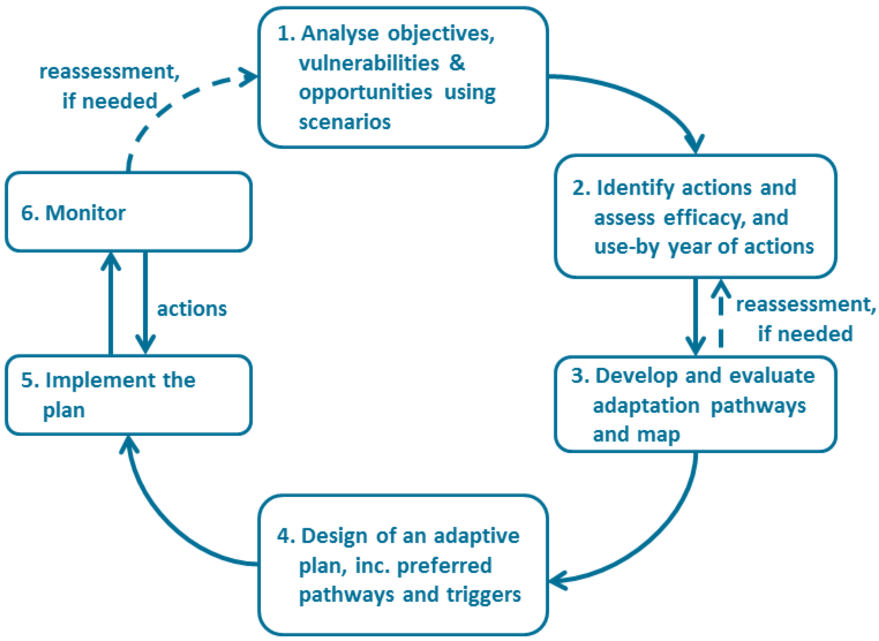


Figure 1 The steps of a dynamic adaptive policy pathways (DAPP) analysis (simplified from Haasnoot et al. 2013)

Before describing each step in the analysis, it is useful to note that DAPP can be applied at different levels of detail and quantification, depending on the data and resources that are available for the analysis. The three levels range from qualitative narrative-based analyses (Level I), through expert-based analyses (Level II), to fully quantitative model-based studies (Level III). The three levels of analysis and how they can be applied are described in more detail in paragraph 2.2.5. It is also useful to note that different types of stakeholders can participate in a DAPP analysis, from technical experts to local decision makers, system users and community members. Diversity in the knowledge and views included in the analysis adds value to the planning results.

Six steps for a Dynamic Adaptive Policy Pathways analysis (Figure 1)

1 DAPP begins with the identification of objectives, constraints, and uncertainties that are relevant for decision-making about a given system. The uncertainties are then used to generate an ensemble of futures. These futures are compared with the objectives to see under which conditions the system will continue to perform, and if vulnerabilities or opportunities arise. Identifying when the system may no longer meet a given level of performance or objective, determines when actions may need to be taken.

2 Based on the vulnerabilities and opportunities identified in step 1, suitable adaptation actions are identified. The performance of each of the actions is assessed in light of the defined objectives, in order to determine when it fails to meet the given level of performance.

3 Promising adaptation actions are used as the building blocks for sequences of actions called adaptation pathways, which are presented in adaptation pathways maps. A scorecard is used to record the costs and (co)-benefits of each of the pathways (Figure 4).

4 Based on the scored pathways, one or more preferred pathway can be selected to be developed into an adaptive plan. The aim of this plan is to identify a pathway (sequence of actions) that will meet the objectives for as long as possible, avoiding the need to change pathways. To identify when a new action should be taken, signals and triggers are specified. These ensure that the plan is implemented over time (adaptively), by identifying signals that a new action is needed and by determining the triggers when actions must be taken, accounting for factors like lead time.

5 The adaptive plan is implemented along with a monitoring plan for the signals.

6 Monitoring the system is an ongoing activity. When signals are flagged, actions should be implemented, according to the adaptive plan. If conditions have changed so dramatically that the plan is no longer suitable, a reassessment can be made.

DAPP consists of six steps which can be carried out at different levels of detail and quantification. The steps guide decision makers and stakeholder groups through an adaptive planning process, which results in an adaptive plan. In other words, decision makers learn new ways to think about and implement planning and decision making, while developing their own plan. The Adaptation Catalyst is focused on supporting steps 1-4, while steps 5 and 6 are in line with planning and asset management practices. The Adaptation Catalyst is designed to be used by different types of stakeholders engaged in planning and decision making about infrastructure investments.

Several concepts are important to understanding and applying the DAPP approach. These are elaborated below.

2.2.2 Adaptation Tipping Points

An Adaptation Tipping Point (ATP) specifies the conditions under which the status quo, a particular action, or a portfolio of actions will fail. An ATP is reached when the magnitude of external change is such that the system can no longer meet its objectives, and new actions are needed to do so. The timing of this point (the sell-by year of actions) is scenario dependent (Haasnoot et al., 2013; Werners et al., 2013). For instance an accelerated sea level rise scenario will reach the acceptable flood risk level sooner than a low sea level rise scenario. With an adaptive plan, only the timing of the action needs to be adjusted, once signals indicate which future is unfolding. Figure 2 offers an ATP example.

From Werners et al., (2013) a useful way to define ATPs is to answer three questions:

1. What is the threshold for unacceptable change? This may differ by actor and system.
2. Under which climatic conditions is the threshold reached?
3. When is the threshold reached under different scenarios? The result is likely a range.

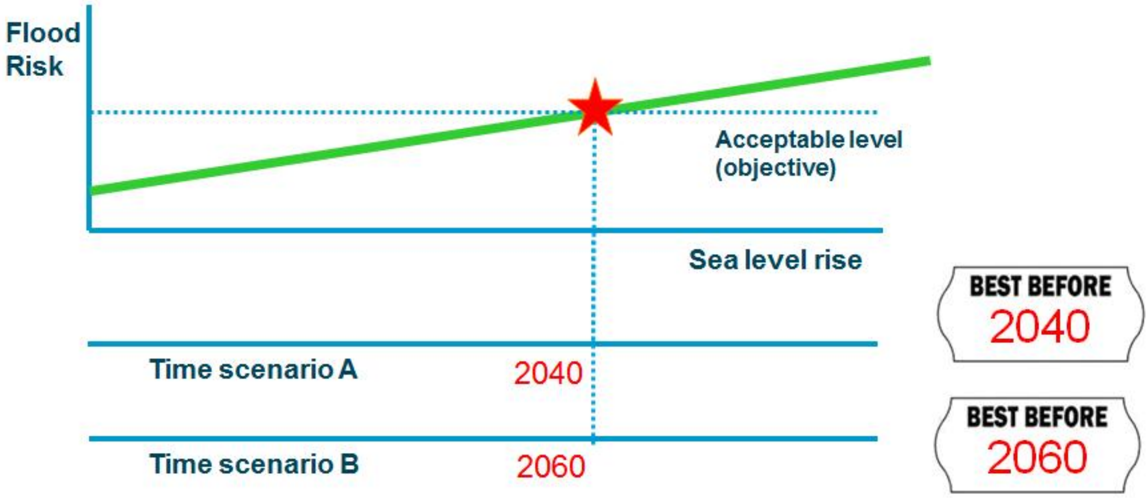


Figure 2 Example of an Adaptation Tipping Point (ATP). The ATP is reached when flood risk exceeds the acceptable level (objective). For Scenario A, the ATP is predicted to be reached in 2040, while in Scenario B, the ATP will be reached in 2060. An action will need to be taken before the ATP to ensure the objective continues to be met. The timing of the action will depend on whether the future is more like Scenario A or B.

ATPs reflect a vulnerability-based, bottom-up approach to adaptation planning. In more traditional top-down planning, the underlying question is: “What if climate changes or sea level rises according to a particular scenario?” This is followed by analysing the cause-effect chain from climate pressures (e.g. precipitation) to impacts (e.g. flooding). If the impact exceeds system capacity, adaptation measures are defined to overcome the problem. Then the chain is analysed again, answering the question: “What if *this* particular scenario becomes reality and we implement measure x, are the objectives achieved then?” By contrast, ATPs are driven by the questions “How much impact can we cope with? And when could that happen in different scenarios?” (Kwadijk et al., 2010; Werners et al., 2013). Figure 3 below summarises the difference between the two approaches.

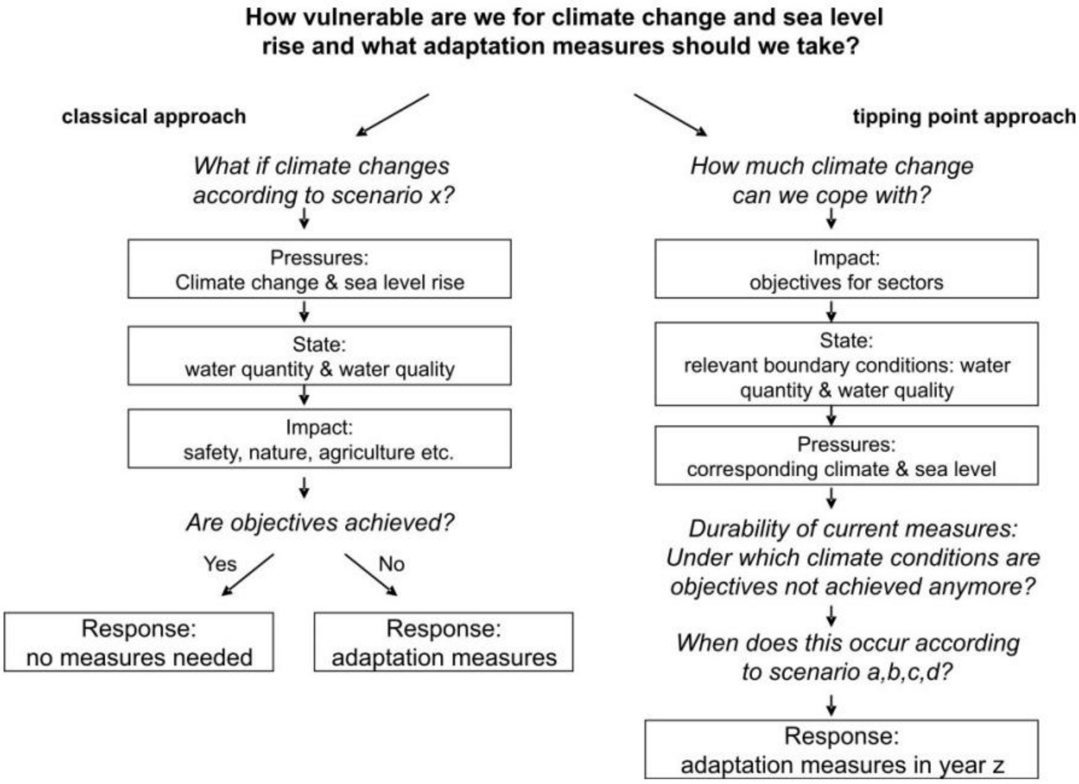


Figure 3 Comparison of the conventional approach to climate change adaptation, based on top-down analysis, and the adaptation tipping points approach, which emphasizes bottom-up, vulnerability analysis (Kwadijk et al., 2010)

> *The Adaptation Catalyst makes use of Adaptation Tipping Points (ATPs) to explore how the system will respond in different scenarios and to support scenario and performance-based planning and decision making under uncertainty.*

2.2.3 Adaptation Pathways

Adaptation pathways describe a sequence of policy actions or investments over time that will achieve an objective under a variety of future conditions. An adaptation pathways map shows different 'paths' into the future, by specifying options and the sequencing of actions over time, as well as by identifying potential lock-ins, and path dependencies (Haasnoot et al., 2013; Walker et al., 2013). A scorecard is used to compare the costs, benefits and co-benefits of different pathways, so that preferred pathways can be identified. Preferences can be based on robustness, flexibility, cost-effectiveness and other values and criteria (Haasnoot et al., 2013). For example, decision-makers may choose to invest in a long-term, robust solution upfront that is likely to perform in a number of future scenarios, or they may prefer to delay large investments until there is better information, by taking smaller, shorter-term actions that leave several future options open, avoiding lock-in. Based on the preferred pathways, an adaptive plan is developed that includes the short-term choices and long-term options. The plan can be further adapted as the future unfolds.

Figure 4 shows an example of an adaptation pathways map and a scorecard for each of the pathways. In the map, starting from the current situation, targets begin to be missed after four years; this is an adaptation tipping point. Following the grey line of the current plan, one can see that there are four options to achieve the desired level of service over time.

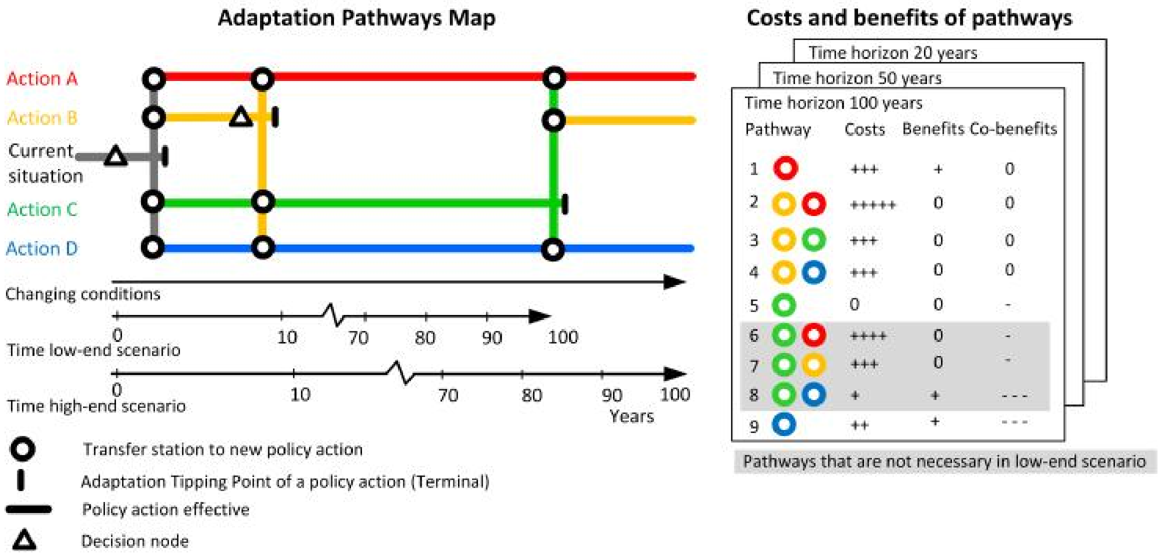


Figure 4 Example of an adaptation pathways map and scorecard

Actions A and D should be able to achieve the targets for the next 100 years in all scenarios. If Action B is chosen, a tipping point is reached within about five more years; a shift to one of the other three actions (A, C, or D) will then be needed. If Action C is chosen instead, a shift to Action A, B, or D will be needed after approximately 85 years in the high-end scenario (follow the solid green lines).

In all other scenarios, the targets will be achieved for the next 100 years. The colours in the scorecard refer to the actions: A (red), B (yellow), C (green), and D (blue). The point at which the paths start to diverge can be considered as a decision point (triangle icon). Taking into account a lead time e.g. for implementation of actions, this point lies before an adaptation tipping point.

For this pathways map, decision makers may choose to invest in a robust action, like A, or a less costly action, like C, which may require a later action, depending on how the future unfolds. If decision makers opt for Action B, they will have three options to choose from in the near future.

> *Pathways maps are a way to sequence actions over time. The Adaptation Catalyst makes use of pathways to explore 1) the timing of actions under different scenarios and 2) different possible actions and sequences of actions. Creating pathways is about learning to think and plan adaptively, as well as producing a map of options for the future.*

2.2.4 Scenarios

Scenarios are “consistent and coherent descriptions of alternative hypothetical futures that reflect different perspectives on past, present, and future developments, which can serve as a basis for action” (van Notten et al., 2005, p. 175). Scenarios are a useful way to explore a range of future conditions and uncertainty about external factors to the system (Kwakkel et al., 2016). External factors are those which cannot be influenced by the problem owner or decision maker but affect the system’s performance. Climate change impacts, such as changes in precipitation and sea level rise are examples of external factors. Another external factor could be local population, which can change rapidly due to migration for instance. Population changes in the pressure on a given system, such as sewers, but also changes the amount of damages if a system fails (i.e. the more people that are affected by a failure, the more impact or cost is likely associated with the failure).

Scenarios can help in anticipating the development of different factors and support exploring possible actions to mitigate or respond to risks and opportunities. Scenarios are not predictions with associated probabilities; instead they are instruments to guide strategic thinking (van Notten et al., 2005). The scope and variation of alternative futures is context-specific. For example, (Hugh G. et al., 2000) illustrates four levels of uncertainty, which categorizes the amount of futures and the degree of understanding on their potential development (see Figure 5 below).

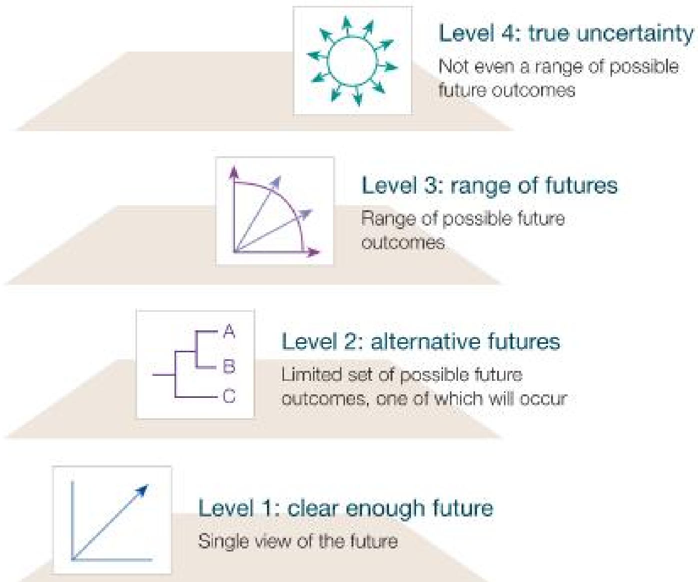


Figure 5 Four levels of uncertainty (Hugh G. et al., 2000)

Assessing how a particular plan or action performs under different scenarios gives insights into their robustness, e.g. a robust option is one that delivers the desired performance under all scenarios (Kwakkel et al., 2016). Different degrees of robustness can aid in prioritizing options. Moreover, scenarios can illustrate how the various options affect each other over time, which can be used to maximize complementarity of measures and to prevent potential lock-ins (Haasnoot et al., 2013).

The Adaptation Catalyst makes use of scenarios to identify different possible futures, to identify vulnerabilities and opportunities, to assess how the system would perform under different scenarios and to explore potential responses or actions. Scenarios can relate to climate change, socio-economic development or other factors, but they are all converted to 'System Pressure' in the Adaptation Catalyst. For instance, population growth and increased precipitation can both lead to increased pressure on the urban drainage system.

2.2.5 Level of analysis

DAPP can be applied at different levels of detail and quantification, depending on the data and resources that are available for the analysis. The three levels range from qualitative narrative-based analyses (Level I), through expert-based analyses (Level II), to fully quantitative model-based studies (Level III). Regardless of which level of analysis is applied, DAPP does not provide a "correct" decision, instead, it supports communication and a decision making *process* about which actions or investments to take now and the implications for future options. The result of a DAPP analysis is an adaptive plan, informed by assessing (qualitatively, quantitatively or in some combination) the path dependencies of decisions and the value of flexibility.

The three levels of analysis are valuable as independent processes, or can be used in a phased approach. A phased DAPP analysis could start with a qualitative narrative-based analysis, which could then be improved with an expert-based analysis, and finally, with a model-based analysis. A phased approach has the advantage of developing the direction of the analysis and familiarity with the approach, before investing significant time and resources. A narrative-based analysis can also be used to identify where additional analytical work is needed in the follow-up phases and what is already satisfactory. This helps to minimise the risk of over-investment in costly and potentially unnecessary modelling studies. A DAPP analysis can also comprise a combination of levels by making more detailed studies where needed and relying on narratives or expert-based pathways in other areas. All three levels serve the same purpose of facilitating informed multi-stakeholder communication to support decision making under deeply uncertain conditions.

The three levels of analysis are described below, starting with the most qualitative.

Level I: Pathways narratives
Narratives may be seen as storylines which aim to explore future scenarios and possible actions to mitigate the negative effects of changing conditions. Narratives are based on stakeholders' reflections on the system functioning. The main objectives of narratives are achieving an understanding of the context and learning about the system. The increased understanding can then be used to identify possible sources of vulnerability, a portfolio of actions that may be used to increase system robustness or performance, inter-connections between different actions and justification for stakeholders' preferences and choices.

The narratives start with the definition of scenarios for which strategies will be explored. For long-term planning, considering multiple possible futures is important. These scenarios can be based in full or in part on information from formal sources, such as climate, economic and population projections. However, a stakeholder might find it important to consider other sources of uncertainty that are not formally described, such as political changes, like popular support for climate change action, or conflict with neighbouring countries. When these additional sources of uncertainty are considered important, they can be used in the scenario description to explore the response of the system to that particular situation. This also brings additional flexibility to explore what-if scenarios and therefore a broader set of futures.

Choosing scenarios reflects the search for the most important variables in the future, as well as a wide range of potential values for these variables. Together with stakeholders, narratives are developed to describe a set of possible future scenarios and the potential actions and management options to respond to them. A first selection of narratives can be made by identifying challenging scenarios and strategies. Challenging scenarios may be scenarios that pose threats to the system that are difficult to handle, while interesting strategies to consider may be robust or especially flexible options.

This level of analysis can be based on qualitative and quantitative information, depending on what is available. For instance, the analysis described above can be carried out through dialogue in stakeholder workshops and supported by data or information, if it exists. Regardless of whether further levels of analysis are planned, the narrative level is valuable for shifting the way of thinking to more flexible and adaptive planning strategies. Narratives are also valuable for creating an image of the future that different stakeholders recognize. Core assumptions, common interests and conflicting views can be surfaced through narratives. The narratives can then be further explored in Levels II and III, if further analysis is planned.

Level II: expert-based pathways
The second level, expert-based pathways, aims to deepen the analysis by explicitly incorporating existing sources of information, such as strategic plans, previous assessment, existing models and previous studies. The design of the adaptation pathways continues to be carried out in close collaboration with stakeholders.

This level of analysis results in an evidence-informed assessment of actions, together with additional information on dependencies between actions. The identification of promising actions also raises the question of which indicators should be used to evaluate system performance. The choice of indicators is often not straightforward; different indicators may be chosen to illustrate different characteristics that are simultaneously relevant for the system.

Level III: model-based pathways
The third level of analysis aims to capture the main dynamics of the system and to evaluate the effectiveness of promising actions or combinations of actions on the system’s performance. This is the most quantitative and intensive level of analysis, as it requires the necessary data and models to be available or created. As stated previously, carrying out a narrative or expert-based analysis before a model-based one, can clarify which data are required.

The level of analysis is a factor of the information and resources available, the stage of planning and planning question, and who is involved. Any stakeholder can be involved in any level of analysis. In practice, however, as an analysis becomes more quantitative and detailed, it generally becomes less accessible to all stakeholders. Nevertheless, the results of any analysis should be communicable to a wide audience.

The Adaptation Catalyst is developed to support all three levels of analysis, since the values entered into the tool can be based on estimations or model results. This allows different types of stakeholders to explore pathways at different levels. For instance, a non-expert stakeholder may use the Adaptation Catalyst to explore different combinations of measures, using rough estimates, while an expert stakeholder can use the same tool to fine-tune the timing of investments for individual measures.

2.2.6 Types of adaptation actions

Adaptation actions can be characterized as three types, described below and illustrated with an example of river flooding.

Type I: increase coping capacity
Increasing the coping capacity of a system is the most common type of adaptation action. In the case of river flooding, an action that increases coping capacity would be raising the dikes or flood barriers, thereby increasing the water level the system can handle.

Type II: reduce sensitivity
Reducing sensitivity of a system is an important option in adaptation planning and building resilience. In the case of river flooding, an action that reduces sensitivity would be raising houses or otherwise “flood proofing” buildings, so that when the system fails and flooding occurs, the damages are limited.

Type III: decrease hazard
Decreasing hazards is an important adaptation option, when it is possible. In the case of river flooding, an action that decreases the hazard is dredging or otherwise making a larger cross-sectional area for the river, thereby reducing the water levels for equal flow.

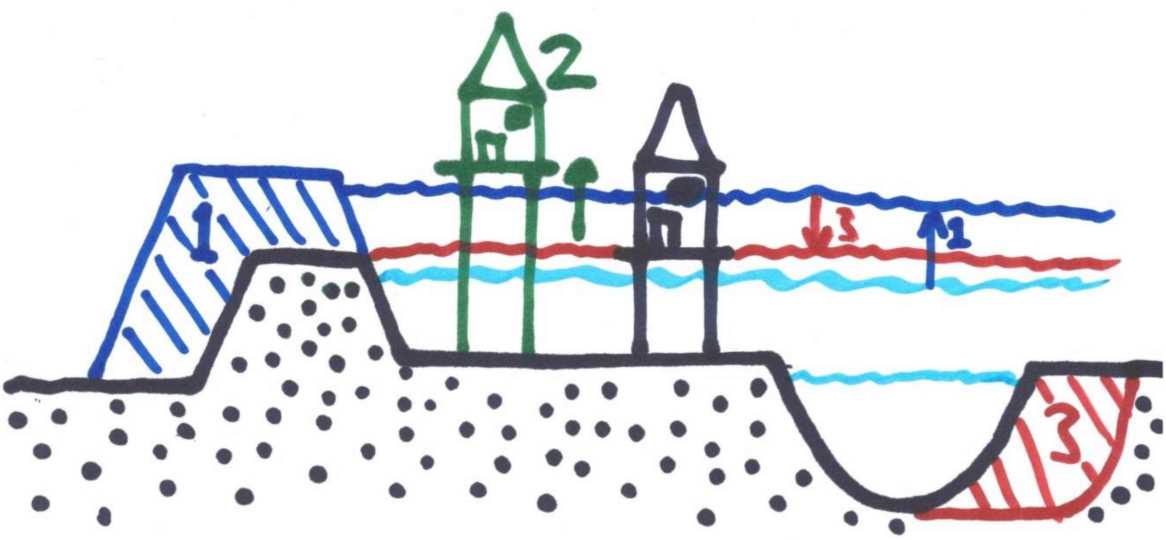


Figure 6 (to be improved) Schematic representation of three types of adaptation actions for a river flooding example. Type I increases capacity (raising dikes), Type II reduces sensitivity (raising houses, or “flood proofing”) and Type III decreases the hazard (dredging or making room for the river lowers the water level)

Annex A describes how the effect of these three types of measures is calculated in the AC.

The Adaptation Catalyst is developed to support all three types of adaptation actions. This allows different approaches to addressing risk. For instance, one pathway may be developed based on a Type I coping capacity approach, while another pathway may take a Type III hazard reduction approach.

2.3 Cost benefit analysis and the economic rationale for adaptation planning

The economic rationale for adaptation implies a net benefit from investing in climate change adaptation measures. Benefits of adaptation measures are based on avoided damages, due to risk mitigation, and any added value or co-benefits from implementing measures. Hence, an adaptation measure should reduce vulnerability to climate change and add value. However, traditional cost benefit analysis (CBA) and other economic assessments evaluate individual decisions, without accounting for sequences of decisions and potential path-dependencies. This undervalues flexibility (Haasnoot et al., 2019).

When determining the costs and benefits of pathways, the cost of "transferring" from one pathway or action to another should be included in the analysis. So called **transfer costs** represent the cost of flexibility, which has value when making decisions under uncertainty (Haasnoot et al., 2019). Based on the earlier example of sea level rise in the Netherlands, transfer costs would be the costs associated with removing the sand added previously in order to build the sea wall, once the adaptation tipping point of one meter of sea level rise was reached.

Another aspect to consider in carrying out CBA for adaptive planning is that the total expected **costs should be calculated over a pathway, as opposed to individual actions**. This includes the costs of each action in the pathway (both initial and recurrent costs) and the costs to transfer from one action to another. When combined with the total expected benefits over the entire pathway (both avoided damages and co-benefits), the net present value of each pathway can be calculated. Returning to the example of sea level rise again, the total costs of the sand-to-sea wall pathway would be the initial and recurrent costs of the sand action, plus the initial and recurrent costs for the sea wall action, plus the transfer costs (Figure 7).

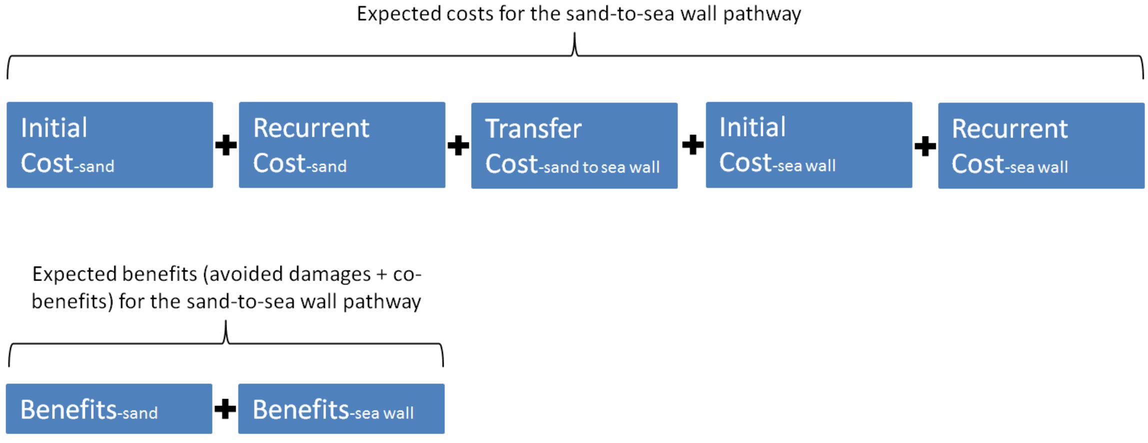


Figure 7 A simplified depiction of the expected costs and benefits for the sand-to-sea wall pathway for ensuring protection against sea level rise of two meters

When the transfer costs (or any other costs and benefits) are unknown, in a Level I analysis for instance, costs can also be represented qualitatively. For example, a scorecard can be used to indicate each pathway's transfer costs, or other transfer barriers (e.g. regulatory, technical, spatial, etc.), using the '+++ / - - -' symbols. For the quality of adaptive planning, it is most important that the concept of the transfer costs is included so that decisions are viewed as part of a sequence of decisions, as opposed to individual choices. This reduces the risk of inefficiencies and lock-in later on.

The Adaptation Catalyst promotes economic assessments of sequences of investments, as opposed to individual ones. Since timing of investments is important for the cost benefit analysis, the Adaptation Catalyst includes a sliding function to explore the timing of actions, while showing the impacts of different timings on the system's capacity to cope with pressure.

2.4 Asset management

Physical assets such as buildings, roads and coastal structures are exposed to short-, medium and long-term variability in environmental conditions. Cost-efficient asset management is based on predicting such variability and the expected environmental conditions over the asset's lifetime. This estimation serves as input to computations about the asset's performance (Rayner, 2010). Often assets have their own criteria or thresholds, which are used as "inputs to the design and construction of an asset, to the planning of operations and to gain an understanding of through-life maintenance requirements" (Rayner, 2010, p. 161). Such criteria can be employed based on a statistical analysis of past performance of assets, which provides a likelihood of exceedance of a certain threshold, e.g. precipitation levels in relation to the capacity of a sewer system.

Assets are designed according to their ability to cope with a certain degree of environmental conditions, e.g. port cranes have a maximum wind speed under which they can operate. This is indicated by an estimation of the most extreme event that is expected to happen for a certain return period (Rayner, 2010). However, predictions of the environmental conditions and asset performance are increasingly unreliable with climate change. Furthermore, the magnitude of changes in environmental conditions over the life-time of assets can be significant under some scenarios and are highly uncertain. Often the range of possible environmental parameters has a size that cannot be covered by additional safety margins, which is how regular analytical errors are accommodated. As such, asset management must be adapted to current conditions.

3 User guide for the Adaptation Catalyst

This chapter explains the basic functionality of the AC. In addition to this guide, chapter 4 describes the use of the AC in two example cases.

3.1 Terminology and information that serves as input for the AC

The Adaptation Catalyst (AC) tool supports local decision makers and planners in exploring system performance under changing conditions in uncertain futures. Where existing planning and asset management practices are based on optimizing systems for a static future scenario, the AC is a tool to explore changing pressures on systems and a variety of actions and timings.

The AC supports analyses that can be carried out by individuals or in groups, in a workshop setting. The analysis comprises four main steps, which are elaborated in the sections of this chapter. In each section, the variables and parameters are explained, along with guidance for using the tool.

The list underneath provides brief definitions for the terms that are used in the AC interface and in this guideline.

Pressure	The force that is put on the physical system caused by climate change. Examples of pressures are sea level rise and increase of frequency of intensive rainfall events.
Hazard	An occurrence or trend that could cause harm to people and damage to assets. In the AC, a hazard is expressed as the pressure that is put on the physical system
Impact	The harm to people or damages to assets that occur when the pressure on the system exceeds a threshold value (mostly the coping capacity of the system, or the sensitivity threshold of people or assets)
Excess pressure	The amount with which the pressure on the system exceeds the coping capacity
Alternative	A collection of measures that are put into action within a specific time span and work together to withstand with the pressure that is put on the system
Measure	Measures are constructions, systems, regulations etc. that deal with the pressure that climate changes puts on the system. Examples are a river dike, a sea wall and rainwater storage constructions.
Coping capacity	The capacity of a measure to withstand the pressure that is put onto the system and prevent any impact
Sensitivity	A measure for what happens to people or assets when they are exposed to a certain amount of pressure
Investment costs	The costs of creating, constructing the measure. These are allocated to the start year of the measure
Operational costs	The total costs of maintenance in one year
Yearly costs	The operational costs in a certain year, plus any investment costs that are spend in this year
Cumulative costs	The sum of the yearly operational costs, calculated in steps from the start year of a measure until the end year of the measure

Co-benefits — Co-benefits of measures are benefits that are not associated with counteracting the pressure, but arise as a bonus when a measure is created. Examples are the increase of liveability of cities and the increase of real estate values when green-blue measures are put into place to deal with increase of heavy rainfall.

A basic question that arises when using the AC is: what information should I have at hand to be able to use the AC? To answer this question, a summary of the variables that can be filled in in the AC, is provided in the list below. This list can be regarded as a 'shopping list' for a user. It can also be regarded as the ordered list of steps that a user makes when he/she is filling in values in the AC.

The values of these variables are often available through preliminary research that has been conducted to obtain insights into possible climate change effects and impacts. It's not necessary to have concrete values for all variables that are listed. It's possible to use the AC with some basic settings and chosen (expert judgement) values of variables and then experiment with different settings.

The input variables that the AC asks for and that a user preferably has information on from preliminary research are:

1) Hazard

- Development of pressure over time
  This variable expresses how a specific climate change effect develops over time. Annex B contains a list of various climate effects and how the pressures that are caused by these effects can be defined. An example is the yearly amount of sea level rise towards 2100. The development of the pressure is defined as a curve, which makes it possible to incorporate a nonlinear development of the pressure over time.

2) Timespan

- Start & end year of analyses period
  Usually the starting year is the present. The end year that is chosen depends on the time scale the user is interested in, or the timescale for which climate projections are available.

3) Potential impact

- % of people impacted at certain excess pressures
  If the climate change effect (the pressure) exceeds a certain threshold, people start to be affected. This threshold can be defined. Also the increase of the percentage of affected people, related to the increase of the pressure, can be defined as a function (curve). To be able to do this, information or insights must be available about the relation between the amount of affected people and the rise of the pressure.
- % of assets impacted at certain excess pressures
  In the same way as for the % of people impacted, the % of impacted assets can be defined with a function.

4) Alternatives

- Combinations of measures that are/can be active within timespan
  An alternative is a collection of different measures that together counteract the pressure caused by climate change. Usually different combination of these measures can be created. Each with its own cumulative costs and implementation plans (the start years

of the different measures). By defining separate alternatives in the AC, different combinations of measures can be defined and compared to each other. Ideas or proposals for alternatives are usually available from preliminary research. These can then be used to compile the alternatives accordingly in the AC.

5) Measures

- Coping capacity / reduction of sensitivity / decrease of pressure
  To deal with the increase of pressure, of the climate change effect, measures are defined in the AC. The adaptive capacity of these measures can work in three ways. This is explained in Annex A. Key is to define the adaptive capacity in the same unit that is used to define the pressure. So, if the pressure is sea level rise, with the unit meters, the adaptive capacity of a measure that deals with sea level rise also has to be expressed in meters. Information about the adaptive capacity of measures is usually available from preliminary research on adaption options.
- Start & end year of measure activity
  The start year is the year in which a measure is in place and active. The end year is the end of the lifespan of a measure, of the construction.
- Investment costs
  The investment costs is the amount of money that is spend to create a measure. In the AC this amount is connected to the start year of the measures activity and becomes visible as a spike in the cost graph.
- Operational costs
  The operational costs is the amount of money that has to be spend every year to keep the measure functioning. These are usually the costs related to maintenance.
- +/- co-benefits
  Co-benefits are extra benefits that a measure brings. These are awarded in the AC in a relative way, as an integer. A high number means lots of co-benefits. A low or even negative number depicts no co-benefits or even drawbacks.

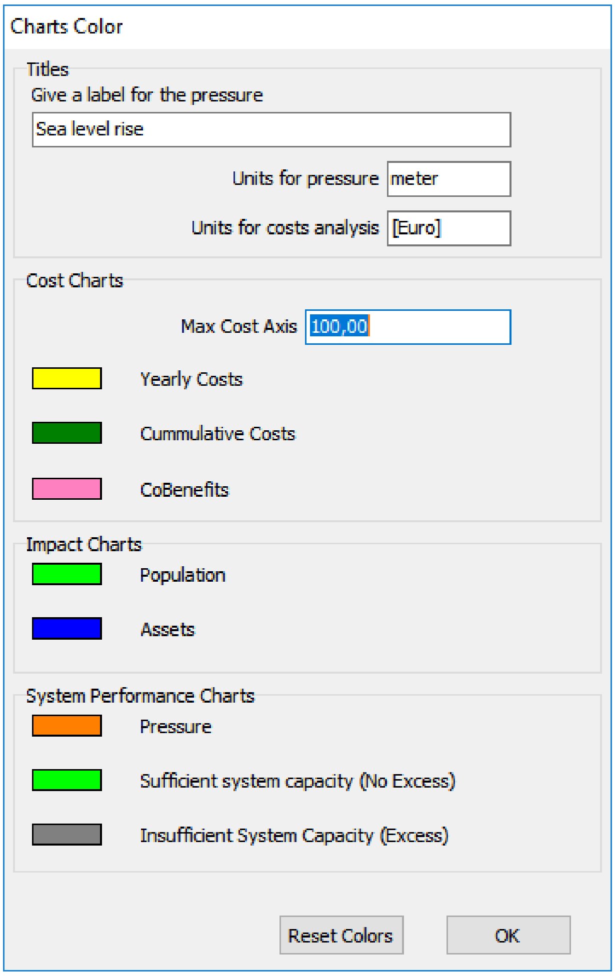
The following paragraphs provide more detailed information about how to fill in these variables in the interface of the AC, and how to analyse the results.

3.2 Define current situation and climate pressure

3.2.1 Starting the AC

The AC is contained in 1 executable file and needs no installation. Double clicking the AdaptationCatyalyst.exe file starts the AC. The .exe file can be started from a harddrive, networkdrive or usb stick.

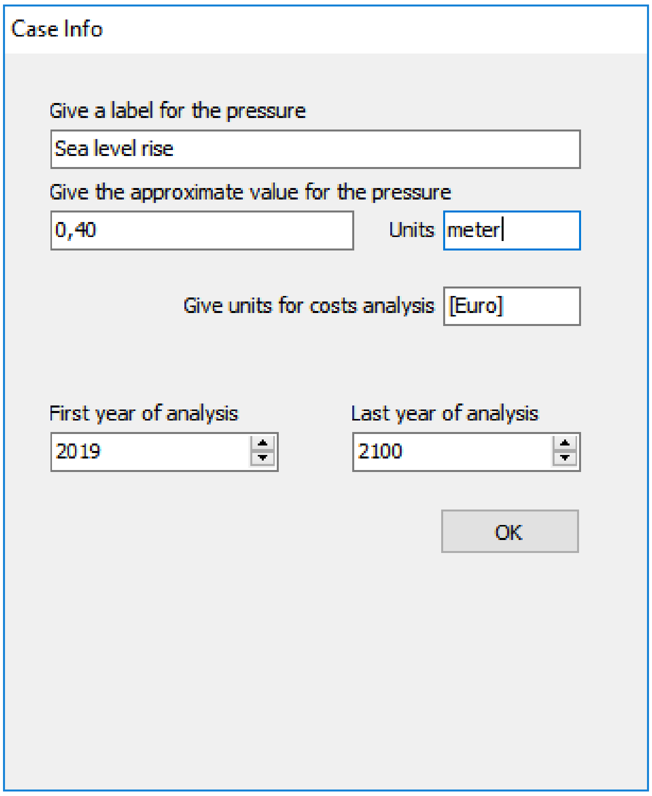
The titles and basic colours that are used in the graphs of the AC can be changed by pressing the Chart settings button. This produces the following window.



3.2.2 Setting up a case

Establishing the basic information of the case is the first step in using the AC. A Case Info box initiates the process. The case is established by defining:

- A pressure on the system
- An approximate value for the pressure
- Units for the pressure
- A starting year for the analysis: often the present year
- An ending year for the analysis: this represents the planning horizon. The default is 2100.



Pressure refers to the pressure or demand on the system in question. For instance, sea level (rise) could be the pressure on a coastal town, temperature the pressure representing heat stress in an urban area, and flow the pressure on a drainage system. Sometimes pressure can be defined in different ways. For instance, heat stress could be defined by the mean temperature, or by the number of days on which temperatures surpass a certain threshold, so called “hot days”. Annex B gives a number of examples of what kind of pressure fits with which type of climate change effect.

The units of pressure must be the same as the ***system capacity***, the amount of pressure it can accommodate while still performing satisfactorily. This can help in defining pressure correctly. For example, rainfall intensity [mm/hr] does not match the capacity of a drainage system [m^3/s], therefore, rainfall intensity is not the correct way to represent the pressure on the drainage system and should be converted to runoff discharge [m^3/s].

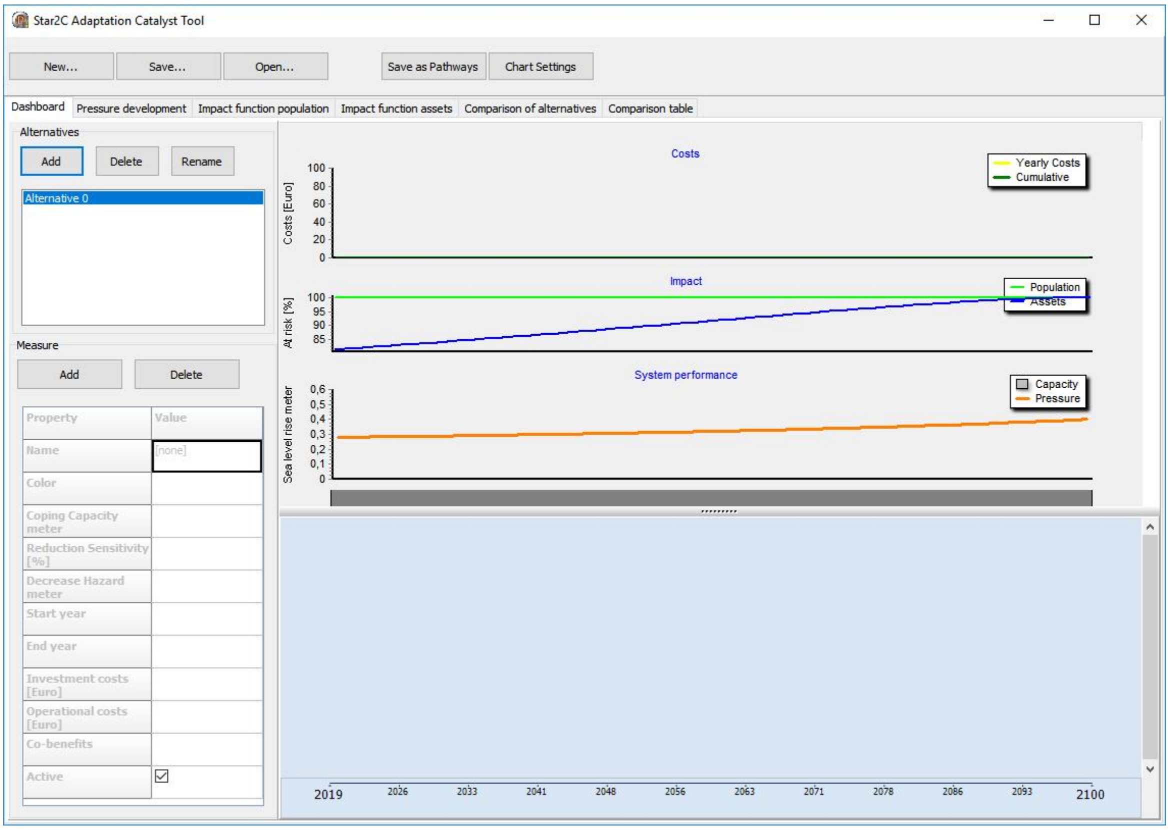
When setting up a case, the pressure can represent the current conditions, or a future scenario. Pressure can also be expressed relatively. For instance, the current sea level can be considered 0 and 1m of sea level rise may be interesting to explore. The value entered for pressure can be the result of detailed analyses and models, an estimate, or a way of exploring “what if” scenarios.

Pressure often changes over time. This will be addressed in Pressure Development.

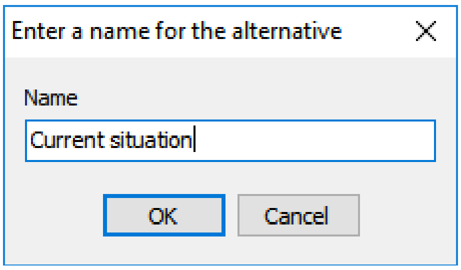
Planning occurs over different ***time horizons***. When setting up a case in the AC, the time horizon is defined by the first and last year of analysis. This time horizon becomes the horizontal axis of most graphs. An 80 year time horizon could start in 2020 and end in 2100.

3.2.3 Defining the current - reference - situation

Once the basic case information has been established, the AC dashboard opens with default settings for the different variables.



It is useful to start with defining the current situation as a separate alternative. This can be used for reference. The reference alternative shows how long the current situation, a situation without extra climate adaptation, will cope with developing pressure. The current situation can be established by modifying the name of the default Alternative 0 to Current Situation.

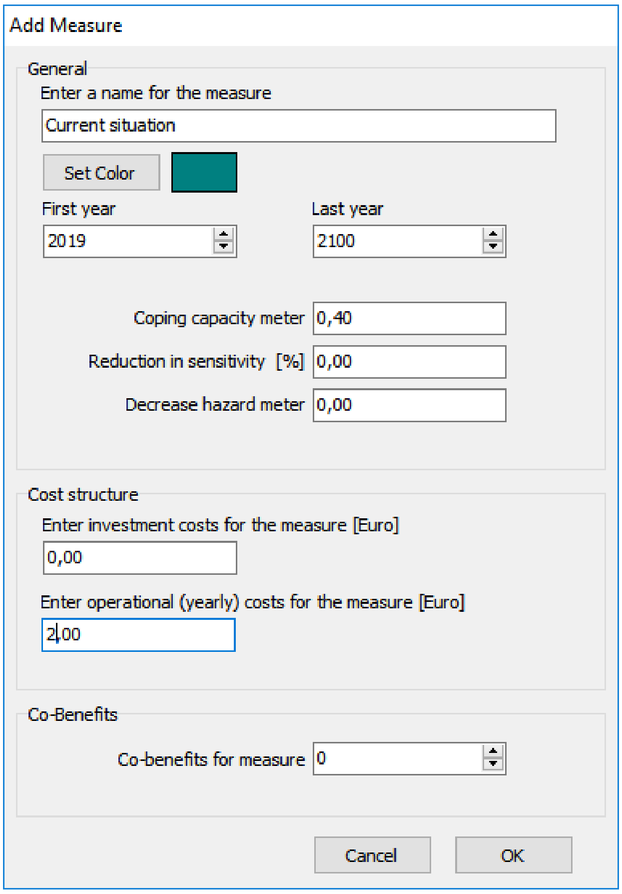


Subsequently, a 'measure' must be added to this alternative that reflects that coping capacity, reduction of sensitivity or hazard decrease in the current situation.

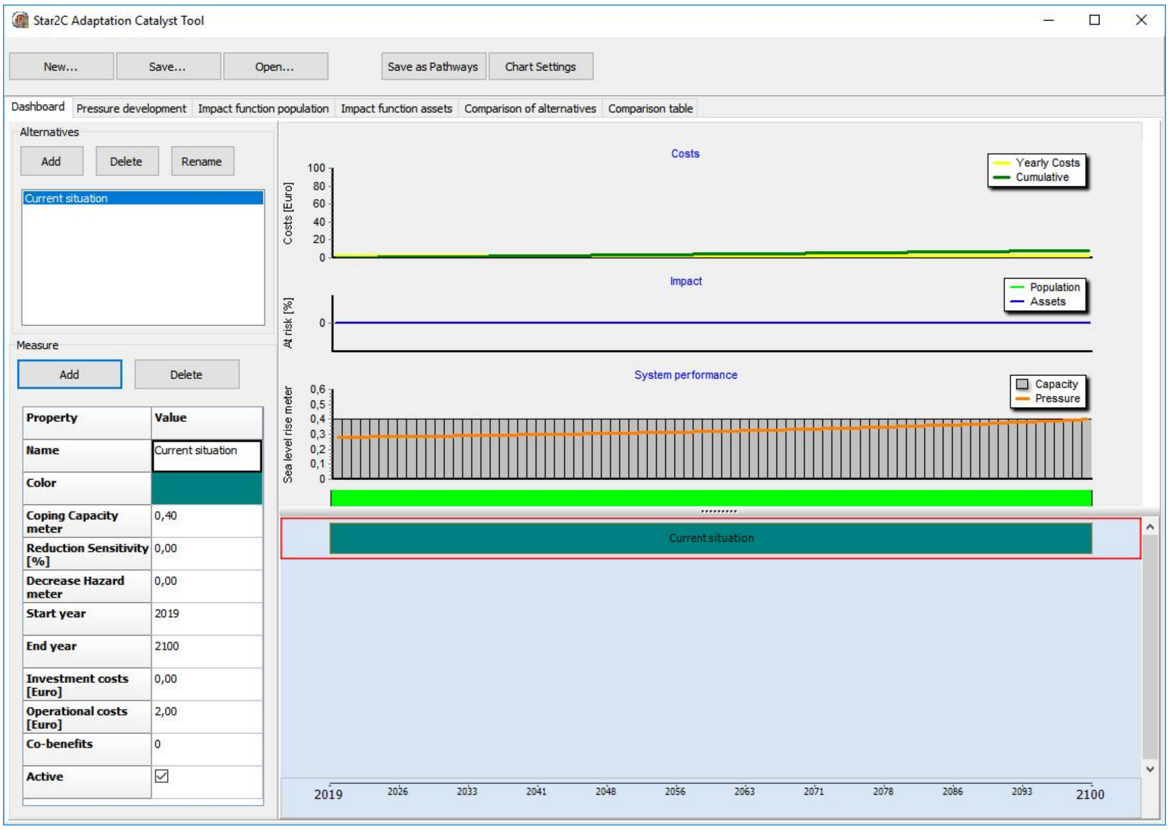
In our example the current situation is established by defining:

- Measure name: Current Situation
- Coping capacity: performance under current conditions, e.g. system can handle 0,2 meter sea level rise.

- Reduction sensitivity: 0
- Decrease hazard: 0
- Start year: now = 2019
- End year: … end year that the current condition is expected to be valid. This can be the duration of the planning horizon or shorter, if an asset will deteriorate, etc. We chose 2100.
- Investment costs: 0, the current situation is already present
- Operational costs: set to 2 Meuro in our example
- Co-benefits: this is defined as a integer value, varying from -5 to 5, that represents the relative amount of co-benefits. The current situation has no co-benefits, so this variable is set to 0.



After this, the dashboard looks like this:

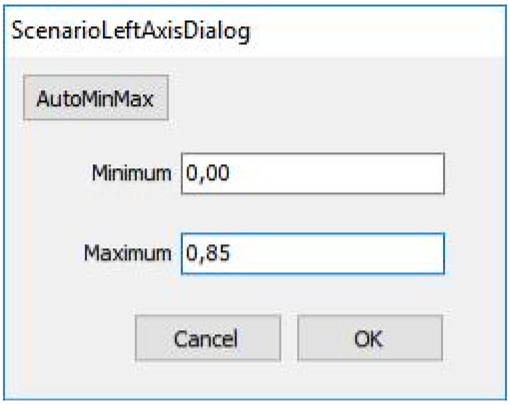


3.2.4 Defining climate change - pressure development

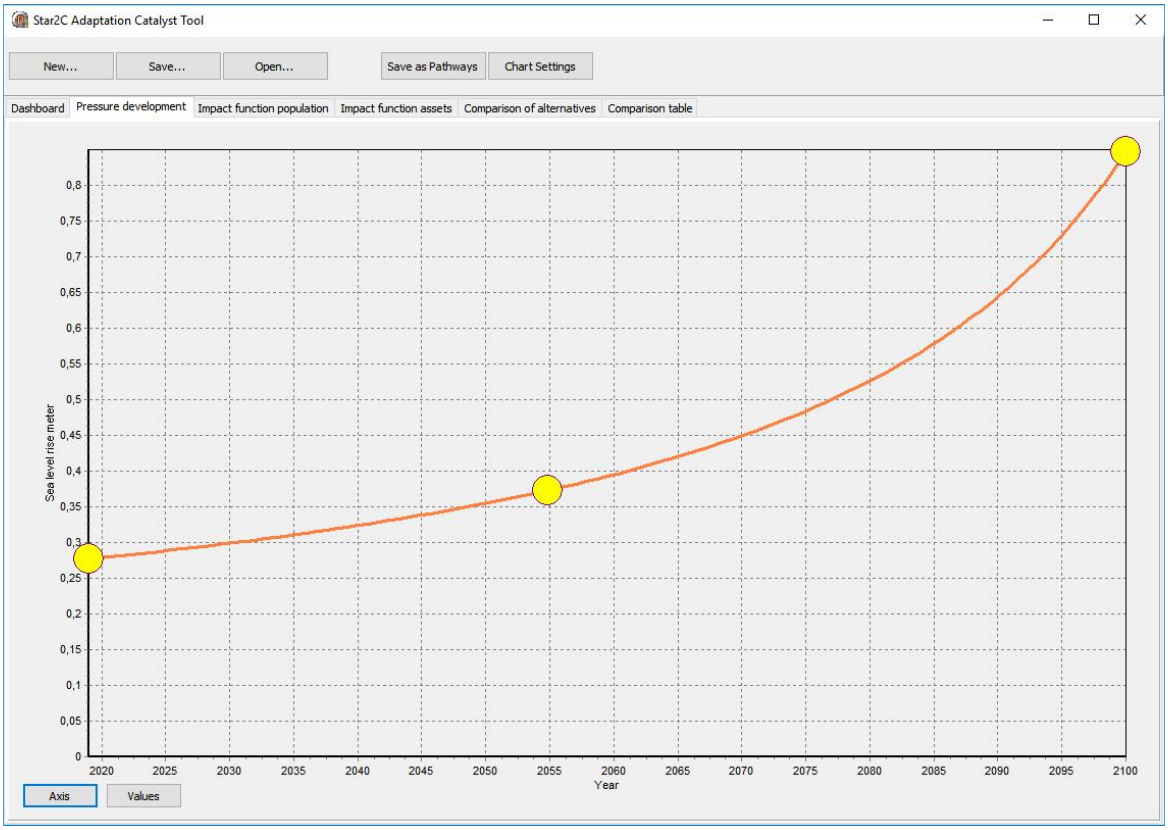
Pressure can remain static, or change over time. It is typically a function of multiple factors and it is often unclear how or when pressure may change. For instance, the pressure on pumping capacity is a function of changing rainfall and changing land use. If high-intensity rain events become more extreme or more frequent, this creates higher demand on pumps. If population growth leads to a greater built area, runoff will increase without additional precipitations, creating higher demand on pumps. If both precipitation and population increase, the effects are cumulative. In addition to changing over time, pressure can develop in different ways. For instance, sea level rise could increase rapidly after a slow rate of change, or it could progress linearly.

In the AC, pressure is defined on Pressure Development tab. A pressure curve is used to specify the magnitude and form of pressure over the planning horizon. The value of pressure can be changed (from the value entered in the Case Information) and the shape of the pressure curve can be modified by sliding the round toggles. The pressure development curve can be based on models and analysis, as well as on expert opinion. However, the curve is also useful for exploring how the system performs under different pressure curves (scenarios). This will be explained in Exploring Different Scenarios.

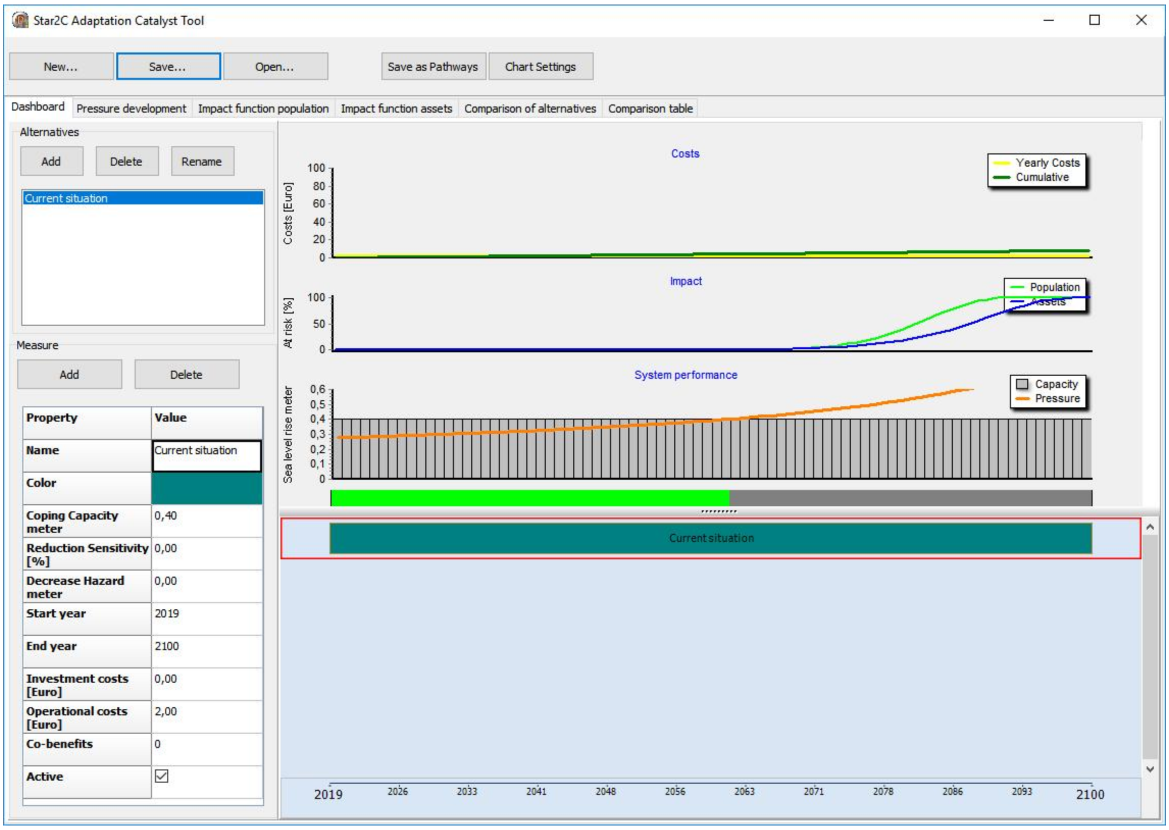
In our example the pressure curve represents the rise of sea level from now until 0,85m in 2100. First, the y-axis of the Pressure development curve is changes by clicking on the Axis button and filling in a new minimum and maximum value for the axis.



Now the curve can be set by moving the yellow points to the appropriate values. The curve that is used in this example reflects an accelerated rise of sea level toward 2100.



Where pressure exceeds capacity, the system has failed, or no longer meets its level of service or objective. This is a ‘tipping point’ of the existing system, under the given pressure and is represented in the dashboard by point at which the green beneath the pressure curve bar turns grey, around the year 2063. This is when sea level, the pressure, exceeds the coping capacity. It is important to realize here that tipping points can represent different levels of failure. For instance, if the pressure on a storm drain is slightly above the capacity, this could be considered acceptable, while if storm surge breaches a sea wall, the failure is catastrophic. Considering the acceptability of a given system’s failure is important.

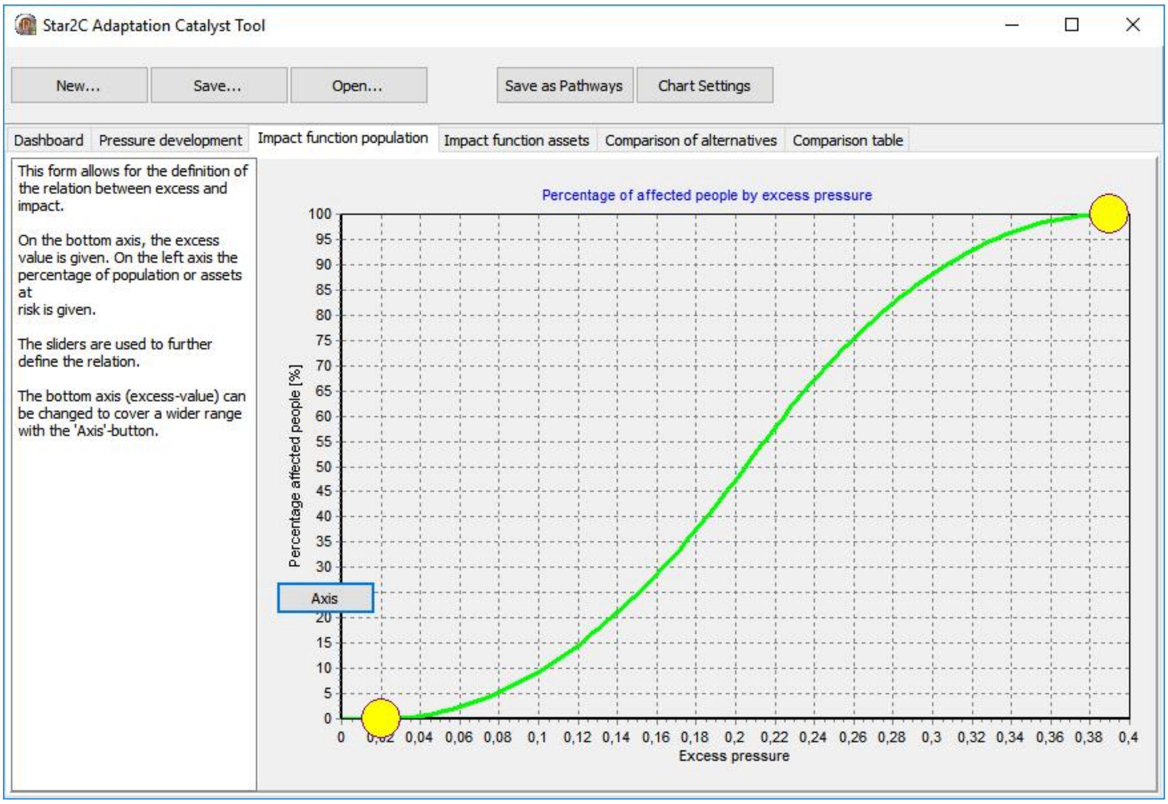


3.2.5 Impact function population

The impact of a system failure is of critical interest for planners in deciding the acceptability thresholds of failure. The failure of a sea wall that would inundate an urban area is catastrophic, compared to a storm water drain that may overflow.

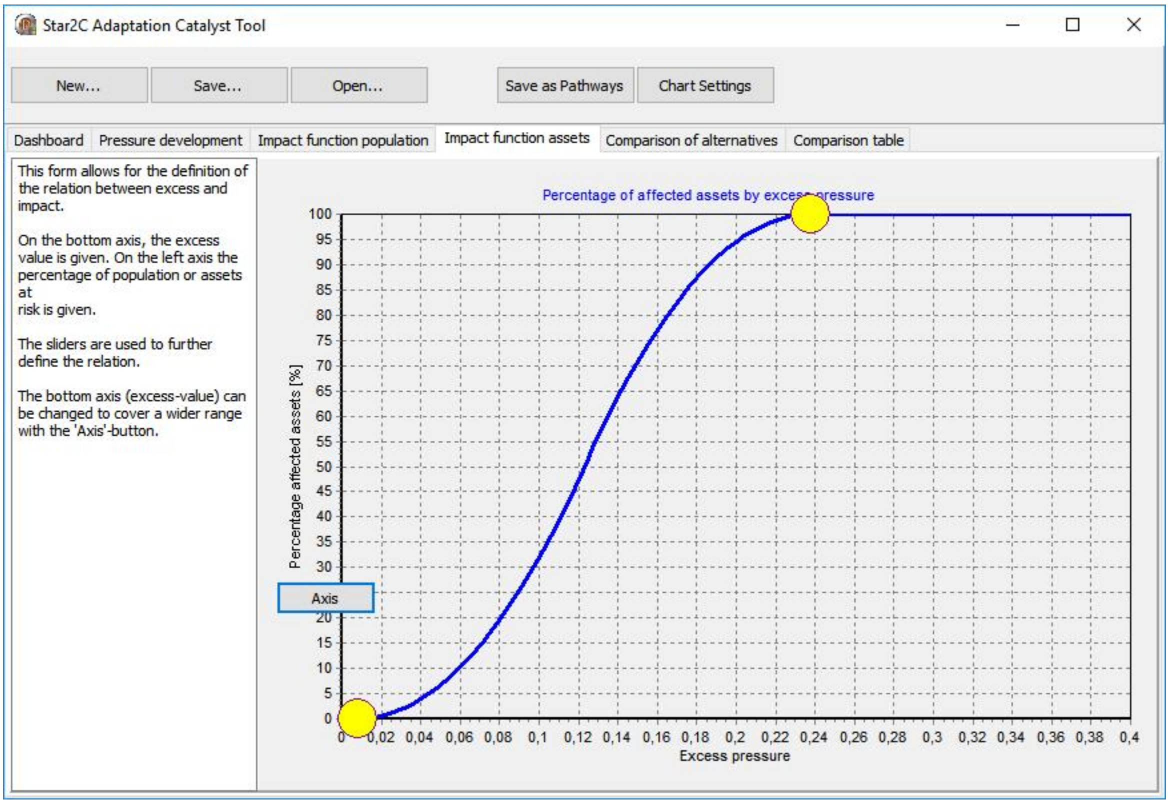
An impact curve is used to describe the relation between ***excess pressure*** (a system failure, when pressure exceeds capacity) and impact on the ***population***. The population impact curve displays excess pressure (=pressure-capacity) on the horizontal axis. The unit (in our example: meters) is the same as that of the pressure and capacity. The percentage of population at risk, or impacted by a system failure, is displayed on the vertical axis. The relation between excess pressure and the impacted population can be modified by dragging the round yellow toggle points. The range of excess pressure can be changed with the 'Axis'-button.

There is rarely a known impact curve; therefore the shape is likely to be based on expert opinion or estimation. It is also useful to explore different failure impacts, such as catastrophic (a sudden large % of impacted people and assets once a specific amount of pressure is exceeded) versus incremental impact, by 'playing' with the impact curve. A catastrophic impact, like a sea wall failure in an urban area, would show a nearly vertical line at the level of excess pressure resulting in the failure. By contrast, the impact curve of pluvial flooding will show an increasingly greater percentage of population at risk with an increasing level of flooding.



3.2.6 Impact function assets

In addition to the impact of a system's failure on the population, the impact of failure on assets (e.g. buildings, infrastructure, utilities) is also important to consider. A second impact curve is used to describe the relation between ***excess pressure*** (a system failure, when pressure exceeds capacity) and impact on ***assets***. The asset impact curve functions in the same way as the population impact curve, except that the vertical axis represents the percentage of assets at risk, or impacted.



3.3 Define adaptation measures and compile alternatives

3.3.1 Add adaptation alternatives and measures

An ***adaptation measure*** is an individual action, such as adding a sea wall, which may address pressure on the system wholly or partially. An ***alternative*** is a strategy or pathway that addresses the pressure wholly and can be compared to other alternatives. Alternatives can be comprised of one or multiple measures.

Adding a new alternative (after the Current Situation) can be achieved by clicking the Add button in the Alternative box and assigning a name. It can be useful to create alternatives with specific themes, such as a Capacity alternative, or a Hazard Reduction alternative. Other differentiations could be Robust versus Flexible alternatives, types of measure, like Hard Infrastructure versus Nature Based Solutions, or by strategy, such as Advance, Protect, Accommodate, Retreat responses to sea level rise.

Adding an adaptation measure within an alternative is achieved by clicking the Add button in the Measure section of the dashboard.

Adaptation measures are used to modify ***system capacity***. Adding measures to the existing system before a tipping point is reached, can avoid failure. For instance, if an existing system can accommodate 0,4m of rise in sea level from the current level, adding a sea wall of 1,5m increases the capacity from 0,4m to 1,5m (or 1,9m if the adaptive effects of measures are cumulative). Capacity can change over time, as measures are added or removed, or as assets deteriorate. Capacity – of the existing system or of proposed measures – can be based on information from detailed analyses, from expert opinion or from rough estimations, depending on the level of analysis and the available information.

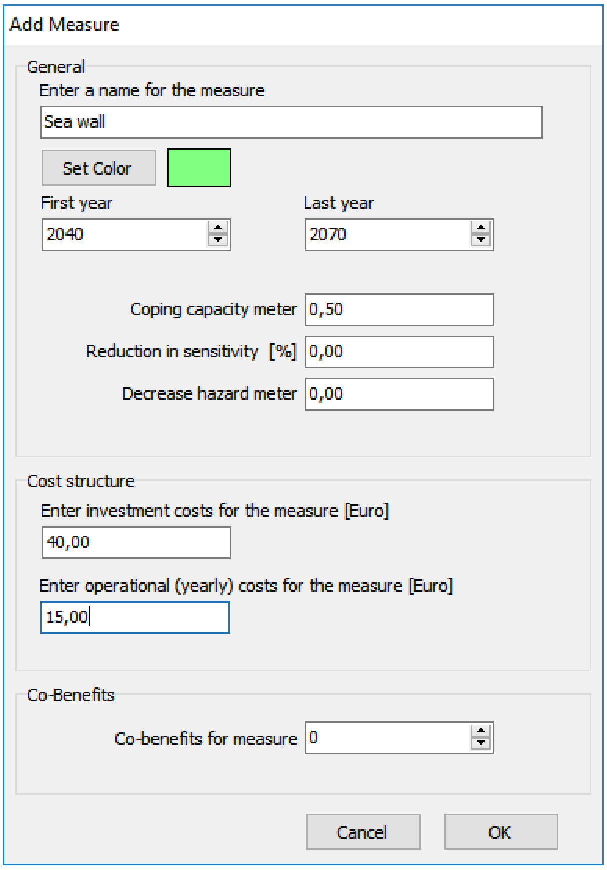
In addition to changing the system's capacity, adaptation measures can also reduce sensitivity to a pressure, or decrease the hazard itself (Figure 6). When a measure is added in the AC, its effect can be entered as coping capacity [pressure units], by sensitivity reduction [%], or by decrease in hazard [pressure units].

Two types of cost are defined for each measure: investment and operational costs. These are entered when a new measure is added and can also be adjusted later in the measure section of the dashboard, by selecting a measure and changing the cost values in the properties table. Costs can be based on detailed analysis, expert opinion, rough estimation, or expressed relatively using scores (e.g. 1-5). If costs are not included, the default is 0.

1. **Investment costs** are the costs associated with implementing a measure, or the initial costs.
2. **Operational costs** are the annual costs associated with operating and maintaining the measure, or the recurrent costs.

In this example we add the following measure:

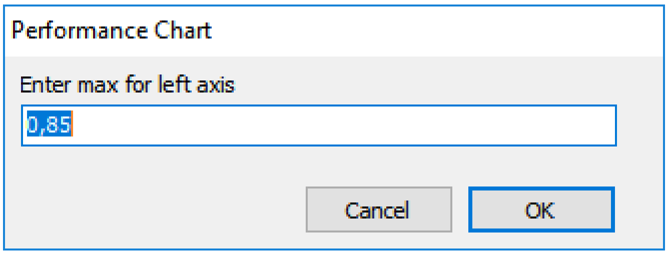
- Measure name: Sea wall
- Start year: 2040
- End year: … end year that the measure is expected to be valid. This can be the duration of the planning horizon or shorter, if an asset will deteriorate, be removed, etc. We set it to 2070
- Coping capacity: amount of sea level that the sea wall can cope with, 0,5 meter
- Reduction sensitivity: 0 in our example (see explanation Figure 6)
- Decrease hazard: 0 in our example (see explanation Figure 6)
- Investment costs: can be included in real terms, based on estimates, or using relative values (i.e. 1-5). 40 Meuro in our example
- Operational costs: can be included in real terms, based on estimates, or using relative values (i.e. 1-5). 15 Meuro in our example
- Co-benefits. Set to 0 in our example, which means: no benefits and no deficits. The situation for the factors that are expressed in co-benefits stays the same.

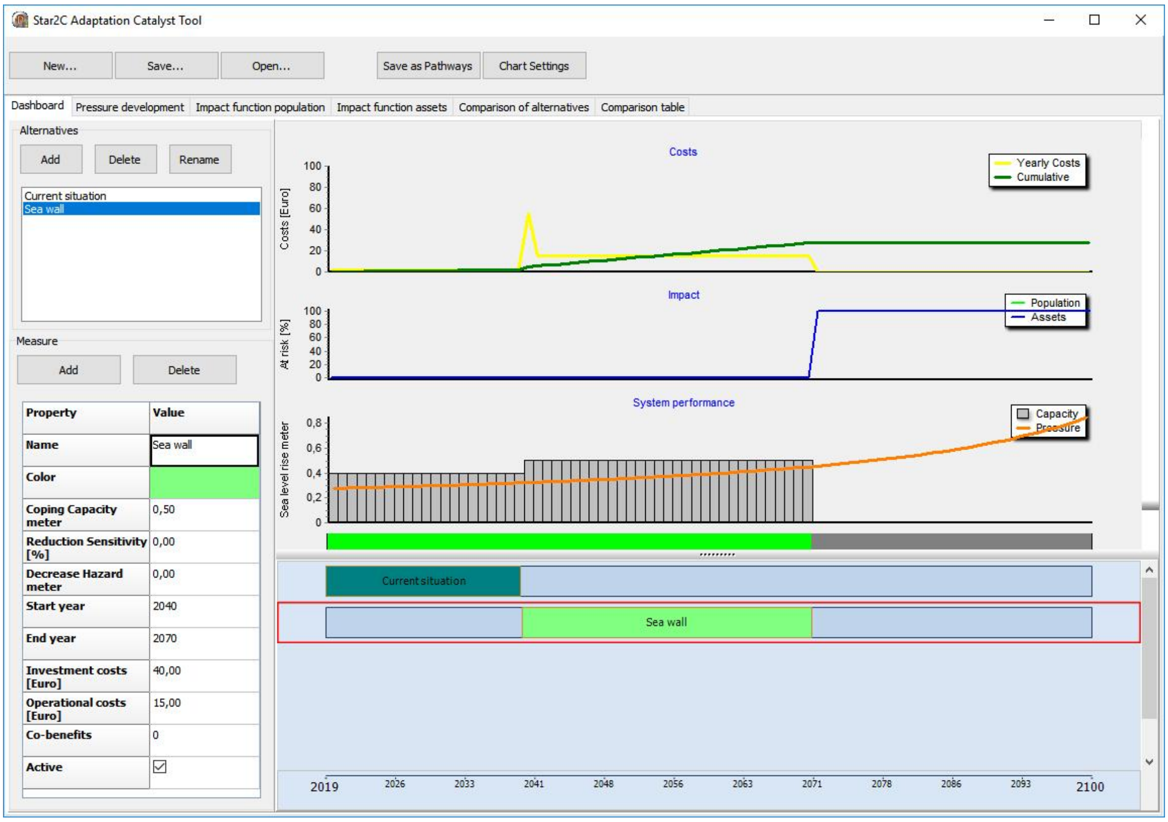


When forming different alternatives, the Current Situation is often included as the first 'measure' in all alternatives, unless it will not remain after the start of the analysis.

After adding the sea wall measure, the dashboard shows the resulting costs, the impacts and the capacity of the measure to deal with the increasing pressure.

The scaling of the y-axis of the graphs in the dashboard can be modified by clicking on the y-axis. This produces a popup screen in which the maximum value of the y-axis can be set.



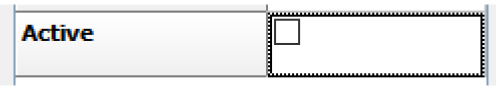


3.3.2 Compare measures and alternatives

Alternatives can be compared to one another, and within alternatives different measures can be compared. When comparing measures and alternatives, they can be assessed by:

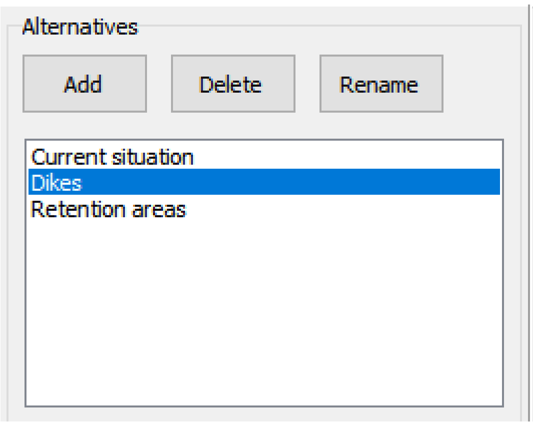
- Performance
- Costs
- Impacts
- Co-benefits

Within an alternative, the additional adaptive effect of measures can be evaluated quickly by deactivating and activating them with the radio button in the Measure section of the dashboard.



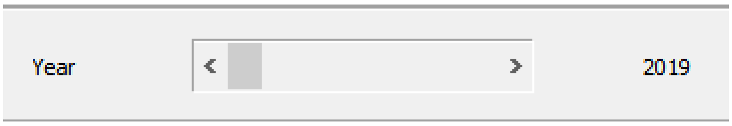
The graphs then immediately show the results with or without the measure.

Alternatives can be compared in the dashboard by toggling between them in the Alternatives section.

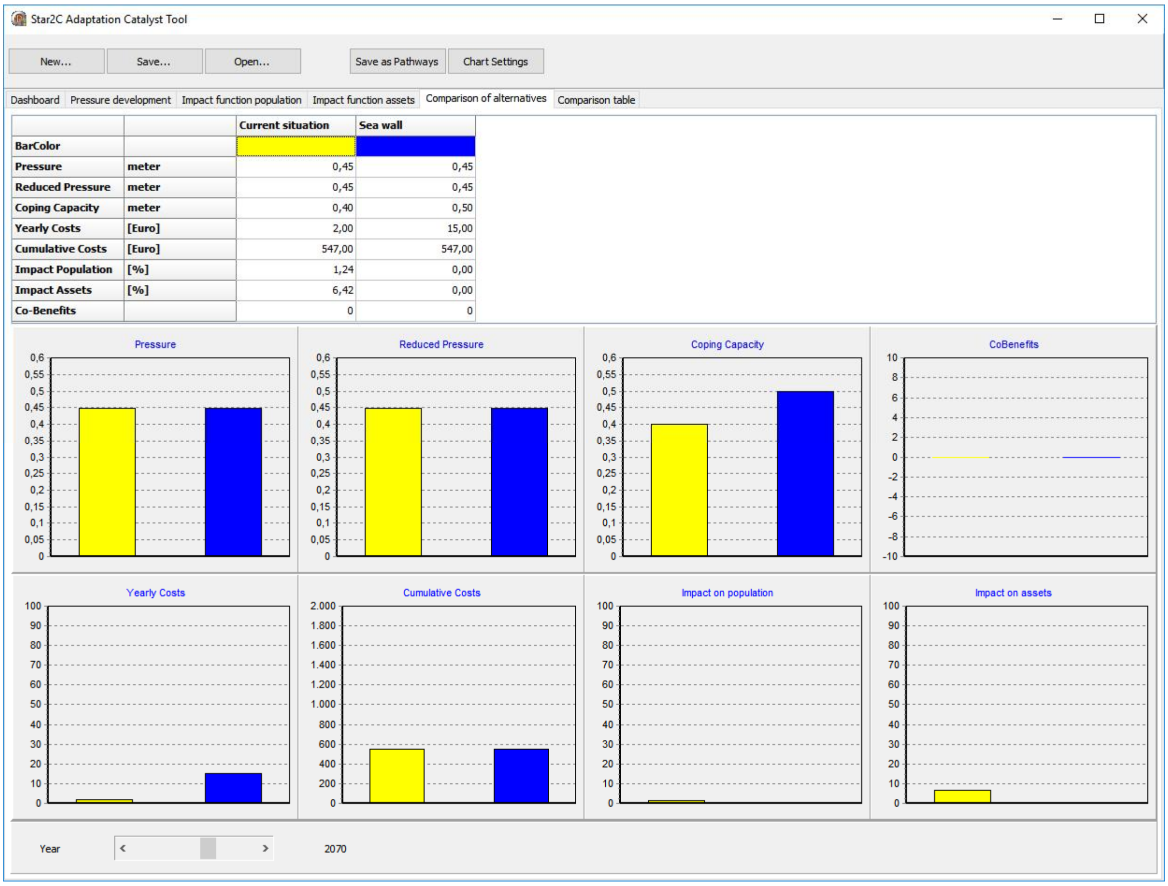


A more comprehensive overview of the alternatives is given in the Comparison of alternatives and Comparison table tabs.

The Comparison of alternatives tab gives an overview of the performance of the alternatives in certain years. Years can be set by adjusting the slider.

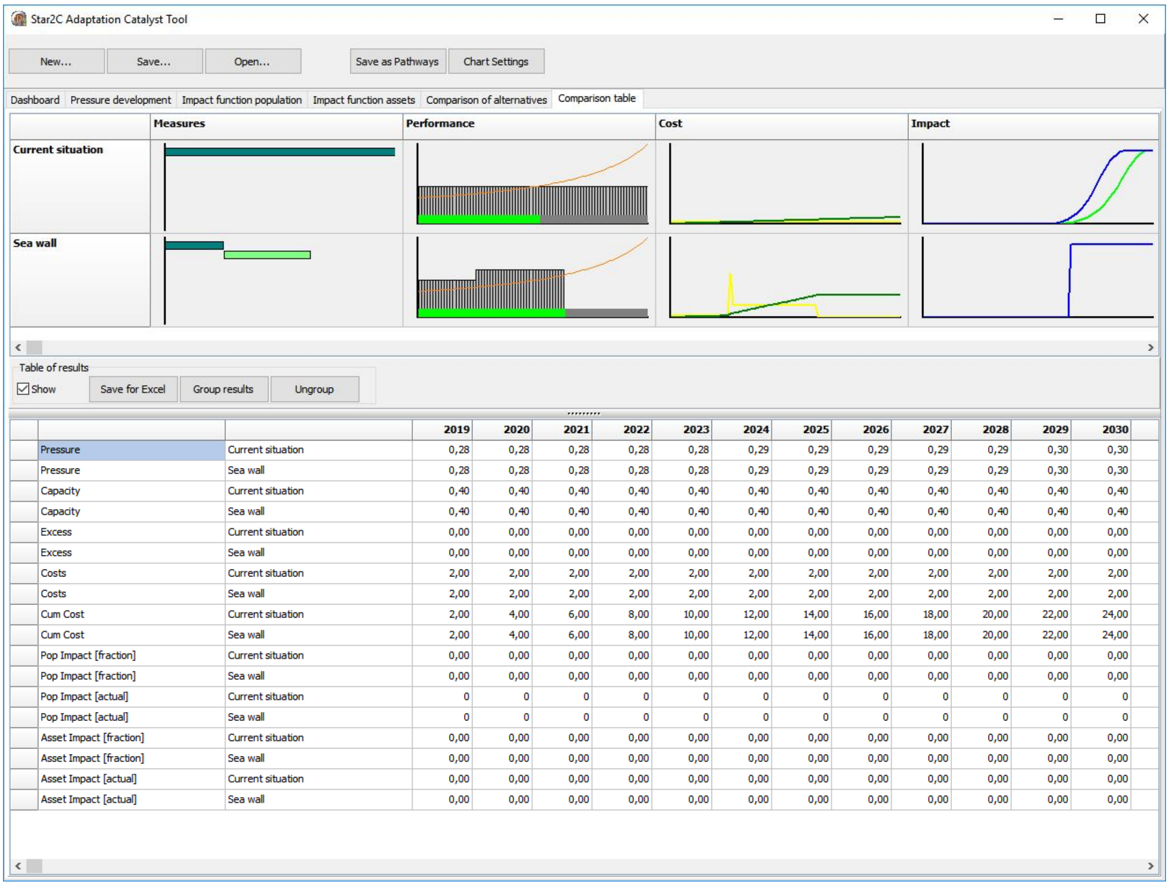


As the slider is moved, the bar charts change according to the values of the parameters in the year that is chosen.



		Current situation	Sea wall
BarColor			
Pressure	meter	0,45	0,45
Reduced Pressure	meter	0,45	0,45
Coping Capacity	meter	0,40	0,50
Yearly Costs	[Euro]	2,00	15,00
Cumulative Costs	[Euro]	547,00	547,00
Impact Population	[%]	1,24	0,00
Impact Assets	[%]	6,42	0,00
Co-Benefits		0	0

The Comparison of alternatives tab shows a summary of the measures and the performance, cost and impact graphs for each alternative. Additionally, the numerical results are included in a table, which can be downloaded to Excel.



		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Pressure	Current situation	0,28	0,28	0,28	0,28	0,28	0,29	0,29	0,29	0,29	0,29	0,30	0,30
Pressure	Sea wall	0,28	0,28	0,28	0,28	0,28	0,29	0,29	0,29	0,29	0,29	0,30	0,30
Capacity	Current situation	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40
Capacity	Sea wall	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40
Excess	Current situation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Excess	Sea wall	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Costs	Current situation	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Costs	Sea wall	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Cum Cost	Current situation	2,00	4,00	6,00	8,00	10,00	12,00	14,00	16,00	18,00	20,00	22,00	24,00
Cum Cost	Sea wall	2,00	4,00	6,00	8,00	10,00	12,00	14,00	16,00	18,00	20,00	22,00	24,00
Pop Impact [fraction]	Current situation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pop Impact [fraction]	Sea wall	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pop Impact [actual]	Current situation	0	0	0	0	0	0	0	0	0	0	0	0
Pop Impact [actual]	Sea wall	0	0	0	0	0	0	0	0	0	0	0	0
Asset Impact [fraction]	Current situation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Asset Impact [fraction]	Sea wall	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Asset Impact [actual]	Current situation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Asset Impact [actual]	Sea wall	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

When comparing different measures and alternatives, the level of confidence is related to the level of analysis and the basis of the inputs. For instance, if most of the input values have been based on simple estimations, the comparisons of measures and alternatives will be less detailed and reliable than if values have been based on model results and analyses.

3.3.3 Optimize alternatives and measures

Measure variables can be modified and adjusted for optimal alternative pathways. For instance, a measure may be better implemented earlier or later than originally planned, or more detailed cost information may become available and be entered for the measures. The values can be changed in the Measure Properties box on the left side of the dashboard. The timing of measures can also be adjusted sliding the round toggles on the measures bar

3.4 Explore different scenarios

Once the alternatives and measures have been optimized, it is useful to explore how they perform under different scenarios. In the AC, scenarios can be represented by:

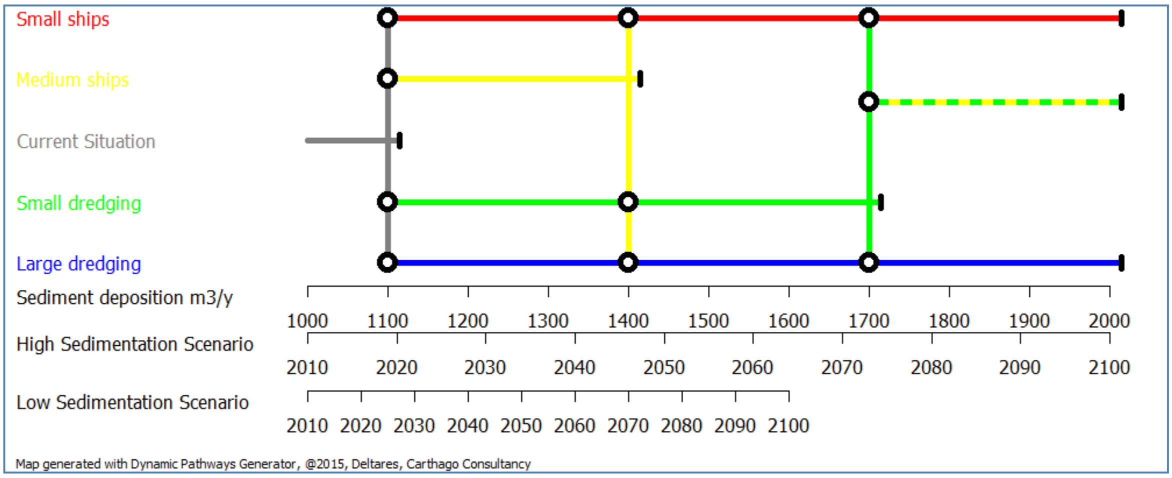
- Changing the pressure development curve, to a different magnitude or rate of change, or to a different shape (e.g. linear versus exponential sea level rise)
- Changing the impact curves for population and assets, for instance to a greater impact for a given excess in pressure, or changing the shape of the curve (e.g. catastrophic versus incremental)
- Changing the costs to represent different operational or economic scenarios, such as higher annual costs.

While pressure changes can be the result of climate and socio-economic factors, they can be translated to total pressure on the system. For instance, climate change may lead to lower precipitation, while migration may lead to a lower local population, both of which would lower the pressure on the local urban drainage system. In the AC, the pressure curves can be used to explore extreme scenarios, or well-established ones.

3.5 Export to pathways generator

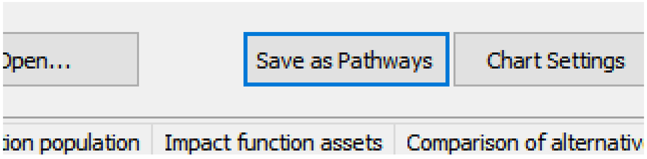
The Pathways generator is a software tool that allows users to draw and explore policy pathways in an interactive way. More information and the software itself can be found here:

https://publicwiki.deltares.nl/display/AP/Pathways+Generator

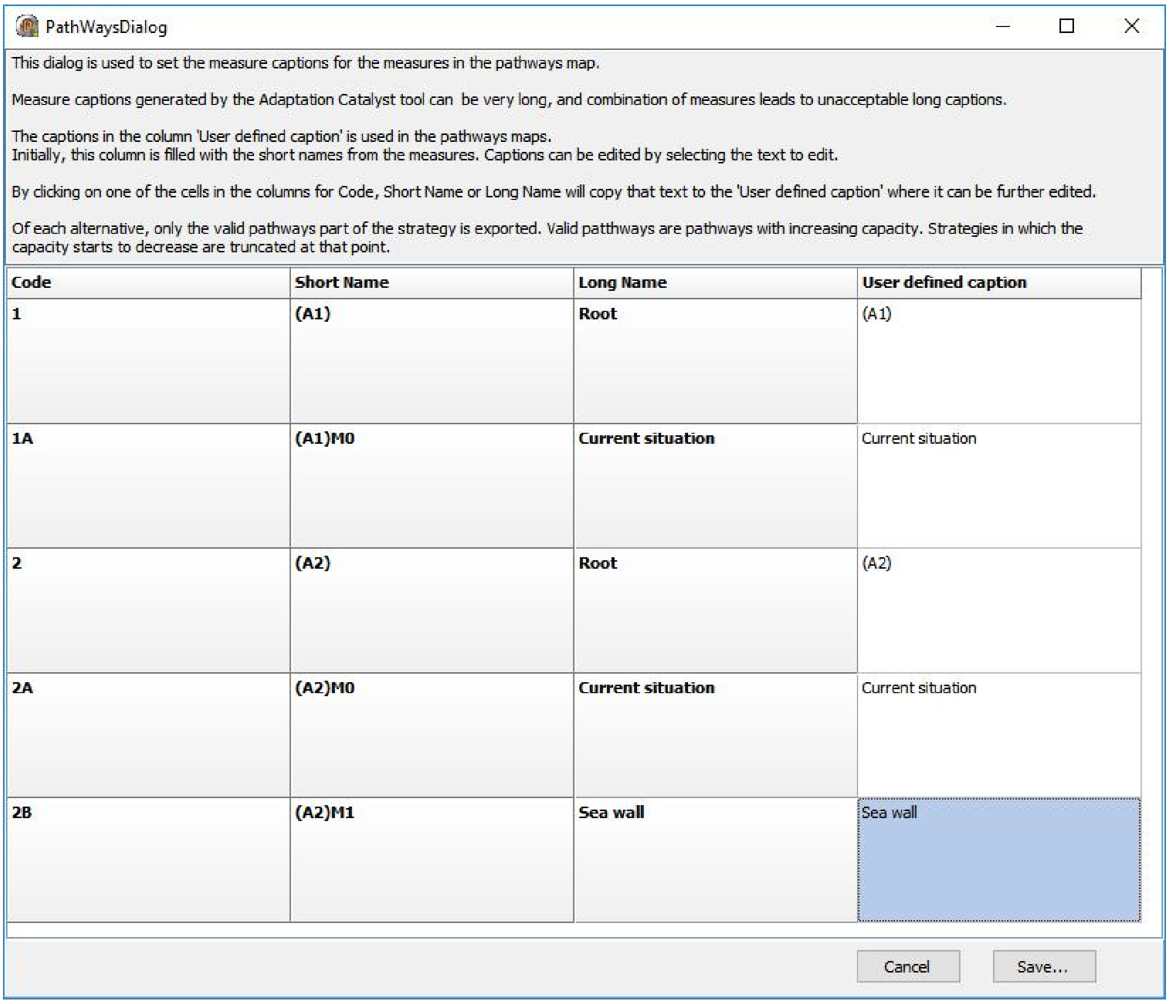


The figure above shows an example of an adaptation pathways schematic. In the scheme, five different measures are shown. The circles indicate points in time when a switch could be made from one measure to another measure. Vertical black lines indicate the moments at which measures are not effective anymore. For more explanation about the pathways systems, go to https://publicwiki.deltares.nl/display/AP/Adaptation+Pathways

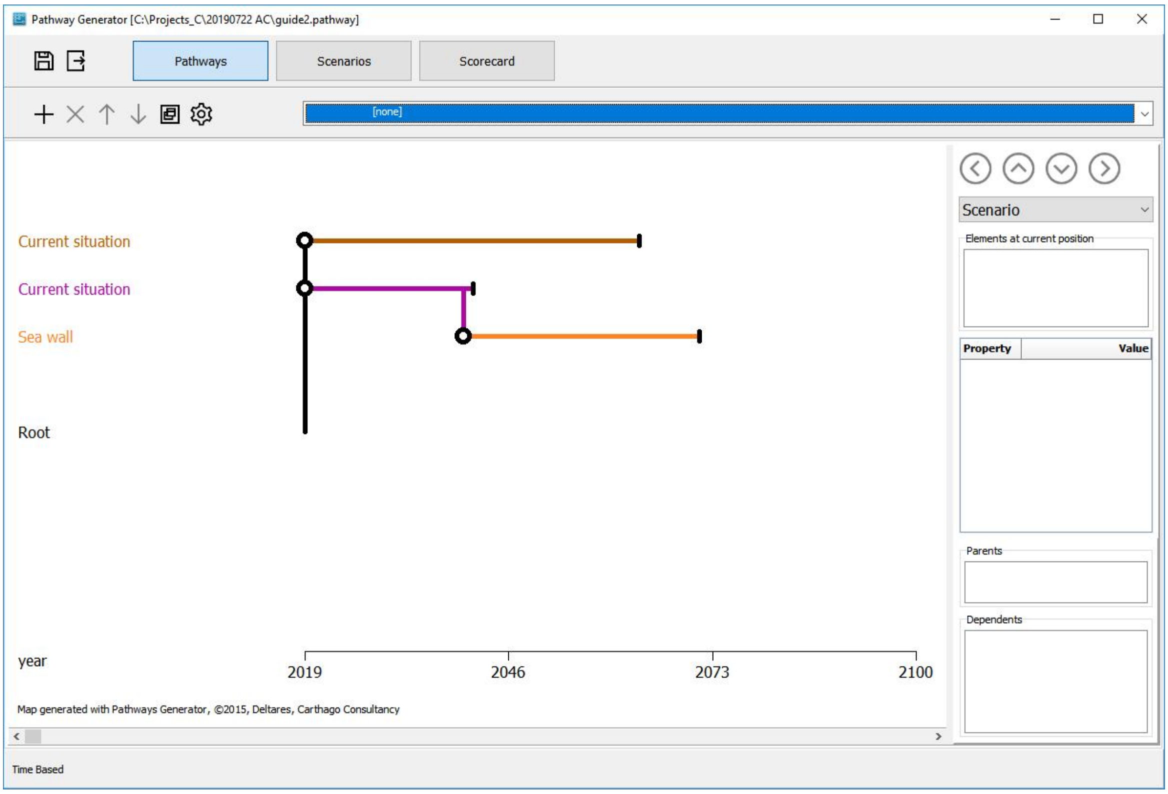
As the result of using the AC is a collection of alternatives that consist of various measures that are projected on a timeline, this result can function as the foundation for adaptation pathways. The AC therefor offers the option to export the results in a file format that can be loaded into the pathways generator for further processing.



The window that opens after clicking the Save as Pathways button is used to define the names of the measures in the column ‘user defined caption’. These are the names that are that are exported to the pathways generator.



The next figure shows how the results is shown in the pathways generator.



Shown in brown is the Current situtation alternative. The purple and orange lines represent the Sea wall alternative, in which around the year 2040 the switch is made from the current situation to a sea wall. Within the Pathways generator, this simple schematics forms the starting point for further work.

Alternatively, it is also possible to first start using the Pathways generator to construct and explore various optional pathways. After this phase, preferend pathways can be recreated in the AC to evaluate there adaptive capacity in a (more) quantitative manner. The Pathways generator does not contain an export option to transfer pathways to the AC.

4 Application of the AC in example cases

In this chapter the functionality and practical use of the AC is explained step-by-step, using two example cases. These cases deal with different types of climate effects: increase of subsidence caused by increase of drought and the increase of flooding caused by rising river discharges, which are caused by an increase of rainfall. Annex B contains a list of other climate effects and example settings that can be used in the AC to explore impacts and adaptation options.

It is important to note that all the values that are mentioned in the cases are examples that have been chose to illustrate the functionality of the AC. They are not necessarily the values and outcomes that reflect the reality of these cases.

4.1 Adaptation to subsidence caused by drought

4.1.1 Description of the case

The STAR2Cs pilot “WaterWeg” in the municipality Capelle aan de IJssel (The Netherlands), is a scale-up of experimental setups where innovative methods and materials are used. Aim is to solve risks associated with water issues like drought, heavy rainfall, high groundwater and soil subsidence. The pilot investigates the long-term costs of the innovative adaptive solutions. A primary question in the case is if the initial higher costs will be compensated by a longer lifespan and lower maintenance overall.

The scale of the case, the scale on which damages caused by climate effects appear and adaptation measures are planned, is on a neighbourhood and street level.

The main focus is on adaptation to subsidence, as this leads to other problems like water nuisance caused by the collection of rainwater in low lying areas. In this case area, the subsidence is partly caused by longer and more extreme periods of drought. This leads to low groundwater levels during the summer months and subsequently to the drying out of the clay and peat soils. Without adaptation, the negative effect of climate changes will manifest itself as an increase of damages to buildings, foundations, roads and other infrastructure, and an increase of maintenance costs.

The following aspects of the case are the essentials, and are therefore relevant in the setup of the AC:

- The climate effect that puts pressure on the system is the increase of the severity and frequency of drought periods (extreme precipitation deficit), which in turn leads to a secondary climate effect: increase of the amount of subsidence.
- The increasing subsidence causes an increasing amount of maintenance and the need to replace constructions more often. This increase of costs is regarded as damage of climate change.
- Solutions, adaptation measures, consist of using other types of construction techniques that decrease the vulnerability to drought and limit the amount of subsidence.

4.1.2 Define current situation and climate pressure

Basic case information

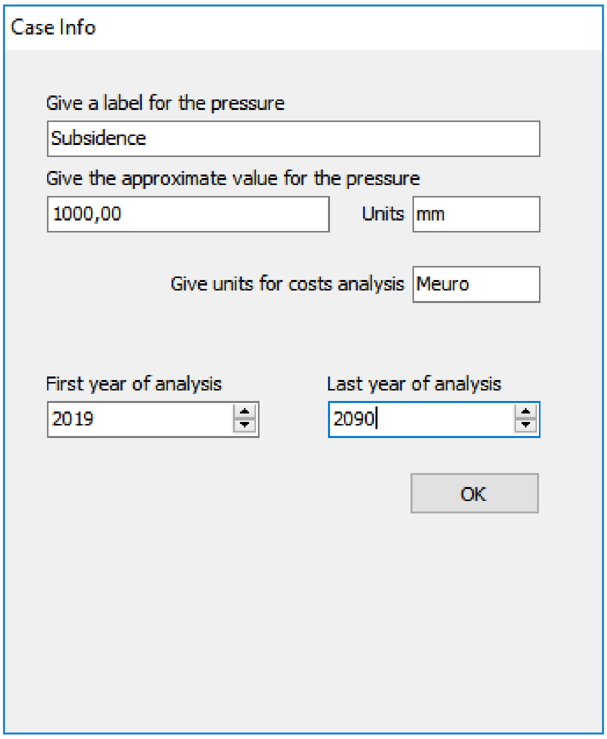
Pressure
In the AC, the effectivity of adaptation measures is evaluated against the pressure that climate change puts on a system. The easiest and clearest way to do this is to express the pressure and the adaptive capacity of measures in the same unit. Or, if this is not possible, to express climate change as the pressure factor that the measures affect the most direct. In this case, this is subsidence, which is a secondary climate effect. The primary climate effect that causes the increase of subsidence is drought (extreme precipitation deficit).

Approximate pressure value
Subsidence is measured and projected in an amount of subsidence per year, usually but not necessarily in millimetre. As the amount of subsidence increases over the year, the pressure on the system, on assets like roads and buildings, increases. At a certain amount of cumulative subsidence, maintenance of replacement of assets is needed.

As a start, a cumulative amount of 1000 mm of subsidence is chosen for the entire analyses period. This can be fine-tuned and changed later in the graph of the Pressure development tab. The subsidence rate in the case areas is about 10 mm/year.

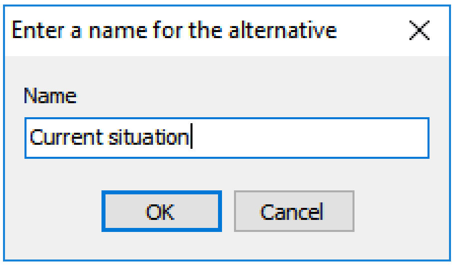
Units for costs analysis
To express the costs, millions of euros [Meuro] is chosen as unit.

Start and end year of timeline
The length of the timeline could be tuned to the rate of subsidence in a specific area or to the lifespan of assets. An important asset that is affected by subsidence, is the sewer system. This system has a shorter lifespan in areas with a lot of subsidence, which causes breakages. In stable non subsiding areas, the sewer system can have a lifespan of around 70 years. Using this lifespan as a reference, and to offer the possibility to express the differences between a subsiding area with this reference, the analyses period could be extended to 2090. Another way to determine a usable timeline would be to use the timeline of the regular cost/benefit calculations as a reference. In Capelle a/d IJssel this is 50 years. To combine both, we choose 2090 as the last year of analysis.

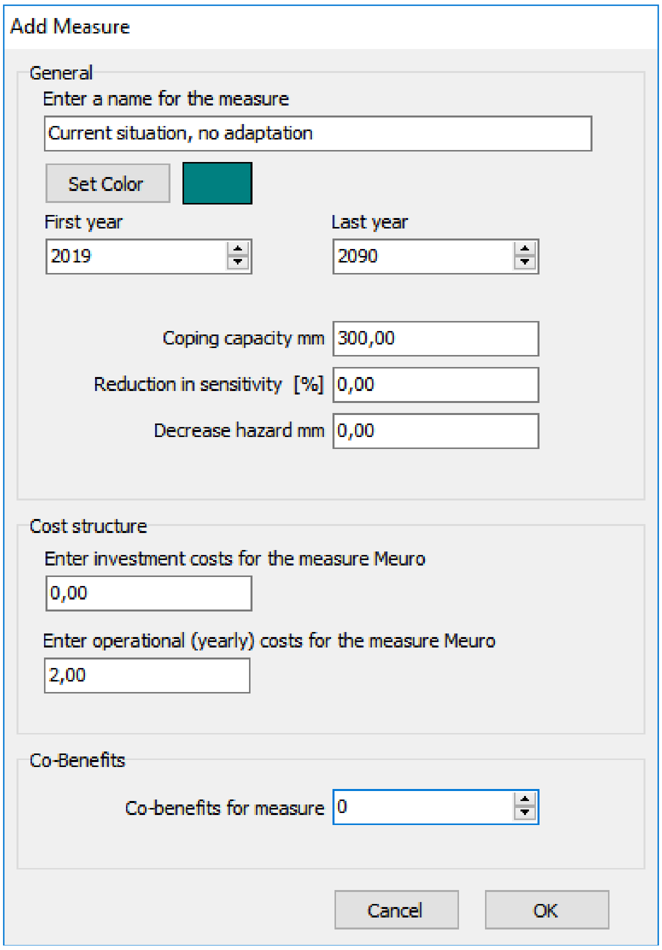


Current situation

Defining the capacity to deal with the pressure, with subsidence, in the current situation offers a reference for judging when adaptation measures are needed. This is done by adding an alternative in the Dashboard tab with just one ‘measure’ that reflects the current coping capacity.

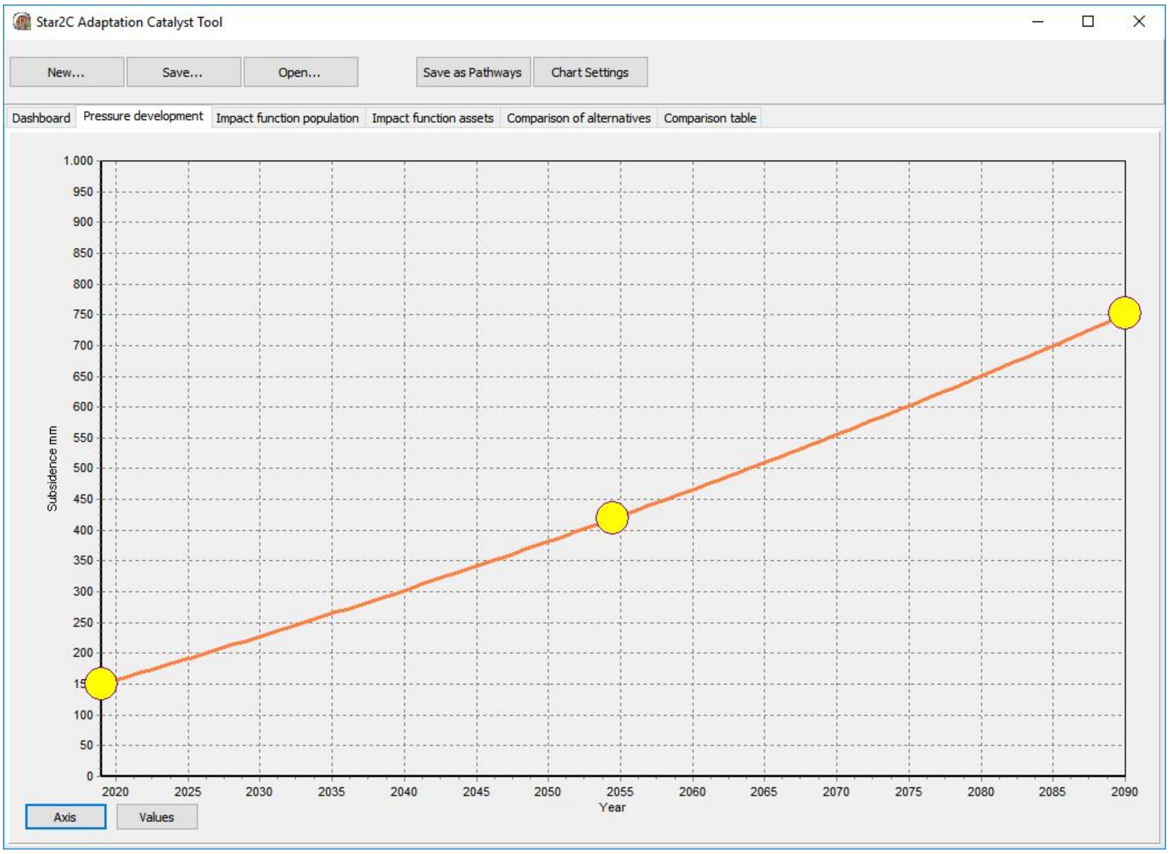


In the case situation, when the cumulative subsidence reaches 300 millimetres, it is absolutely necessary to renew infrastructure and perform serious maintenance. So 300 mm is the current coping capacity. In the current situation, there is no reduction of sensitivity or a decrease of the hazard. The investment costs are 0, as the situation is already in place. The yearly operational costs for regular maintenance are 2 million Euros. To start the analyses, the end year is the same as the end year of the analyses period. This can be changed later. The current situation has no co-benefits, so this value is set to 0.

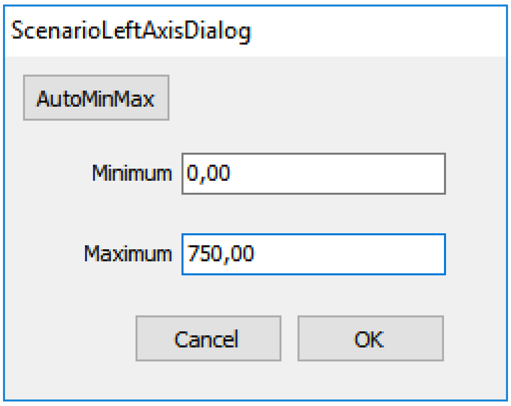


Pressure development

By changing the graph in the Pressure development tab, the expected future increase of subsidence is defined. The last big maintenance round of the area was 15 years ago. Since then, 150 mm of subsidence occurred (10 mm/year). The range of the pressure will be between 150 mm (start situation) and around 710 mm in 2090 (71 years times 10 mm/year). Using the slider function, the pressure curve is defined.

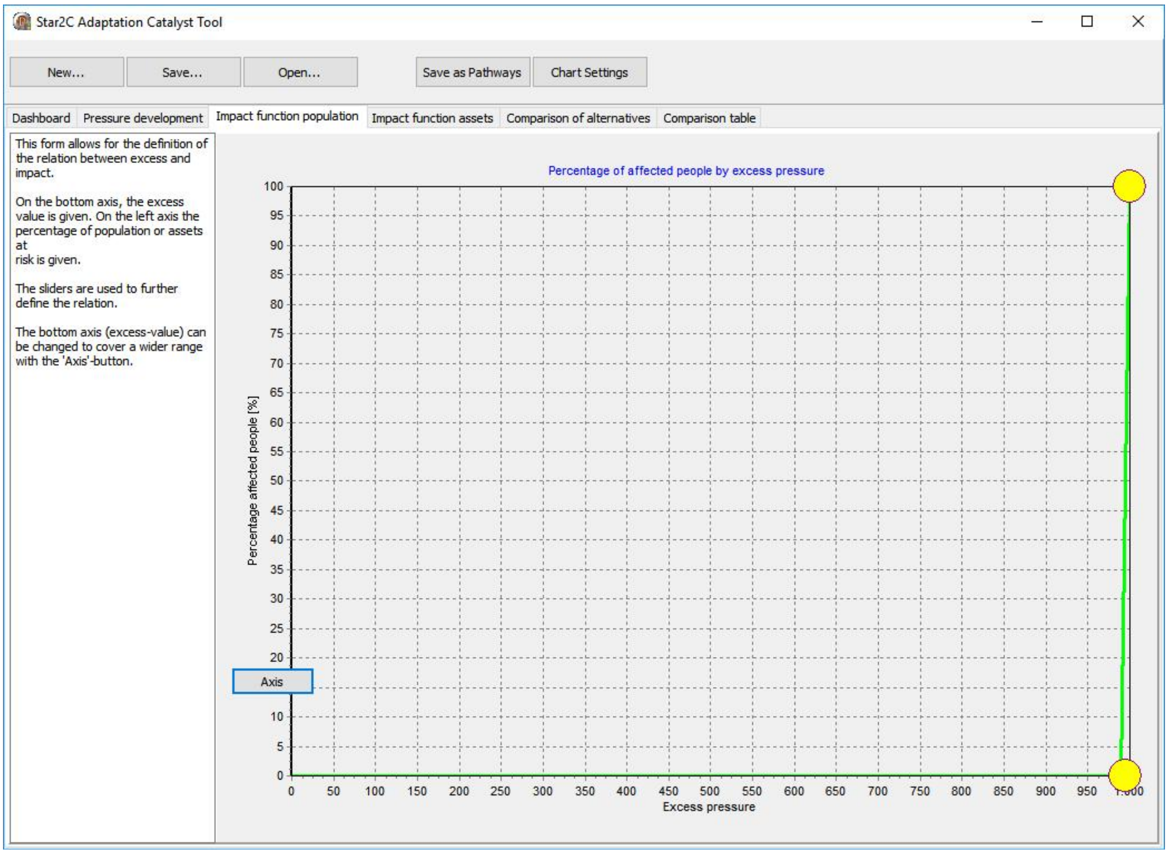


By clicking on the Axis button, it is possible to fine tune the extend of the y-axis, e.g. to a maximum of 750,00 mm.



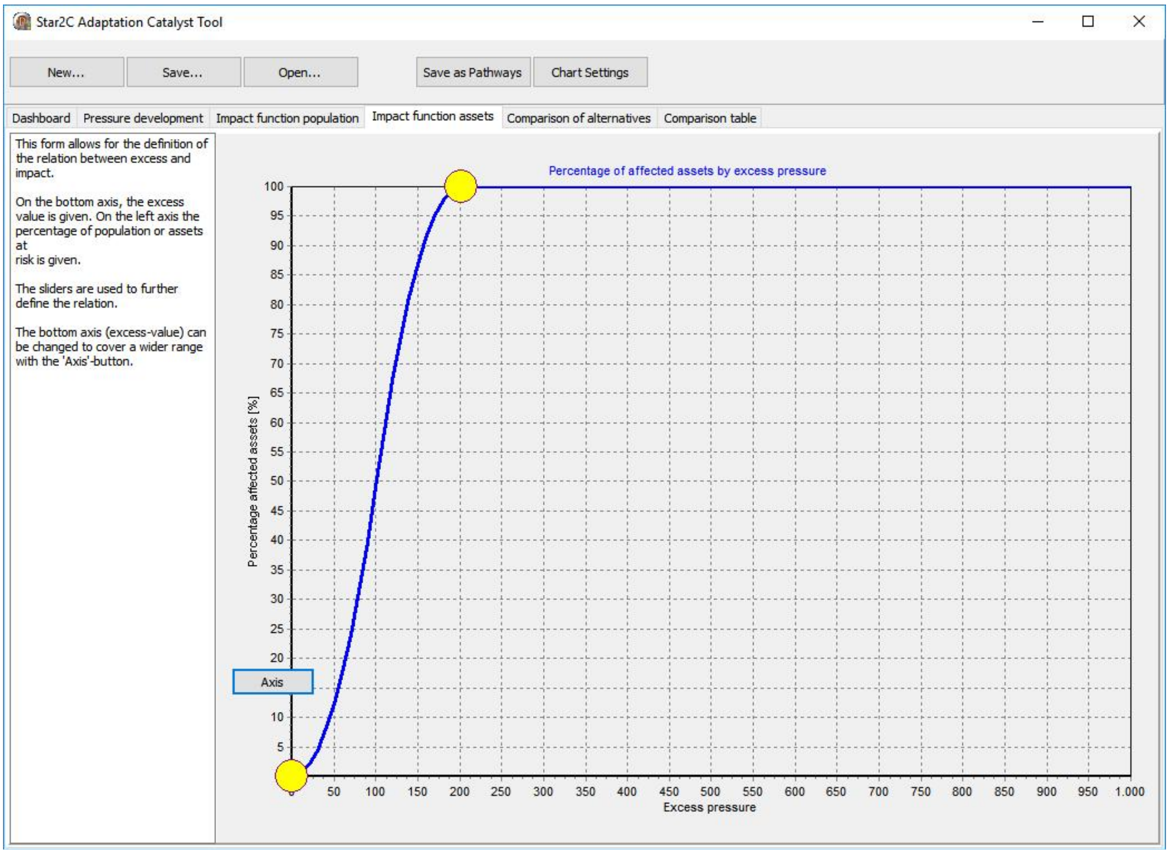
Impact function population

In this case the pressure, subsidence, does not pose threats to the population (casualties). In the 'Impact function population' tab, the percentage of people that is affected by excess pressure is defined as 0 for the entire pressure range by sliding the left yellow of the curve completely to the right. It is not possible to slide the right yellow dot of the curve to 0.

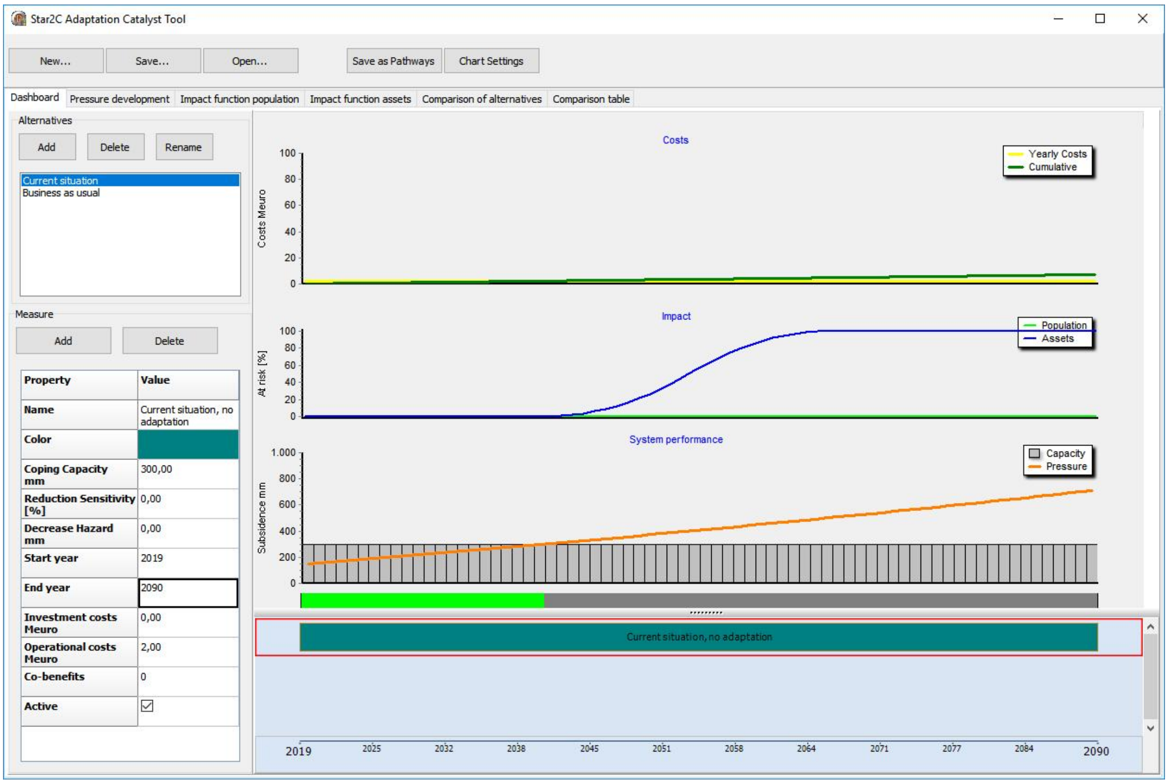


Impact function assets

Assets, like roads and buildings, are affected (damaged) when the pressure exceeds the coping capacity of the current situation and the adaptive effect of additional measures. In the case, impact starts to occur and rise immediately when the amount of subsidence exceeds the coping and adaptive capacity. At an excess pressure of 200 mm, all (100%) assets are impacted. So in the current situation, which has a coping capacity of 300 mm, the point of 100% impact is reached when the total subsidence reaches 500 mm.



After completion of these steps, the Dashboard shows the following overview of the current situation and impact of climate change (subsidence).

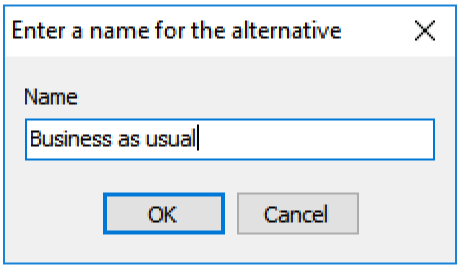


The most prominent thing to notice is the moment where the pressure exceeds the current coping capacity, which is around the year 2041. This point of failure is indicated by the green bar turning grey in this year. At this moment, the percentage of assets that is affected begins to rise and reaches 100% in about 2066, when subsidence reaches 500 mm.

4.1.3 Define adaptation measures and compile alternatives

Add alternatives and adaptation measures
To react to the increase of pressure and to prevent impact, different alternatives with packages of different types of measures are added.

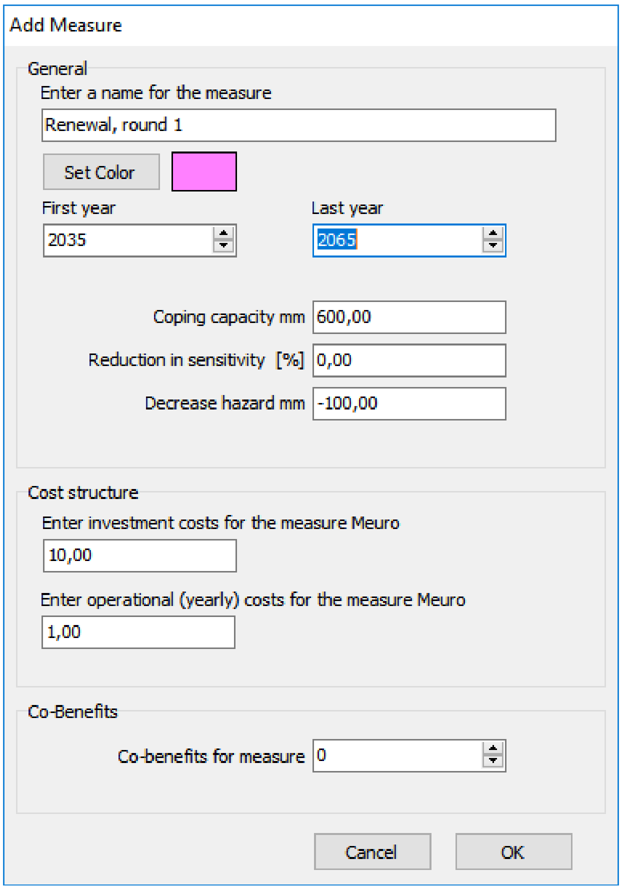
The first alternative to add is ‘Business as usual’.



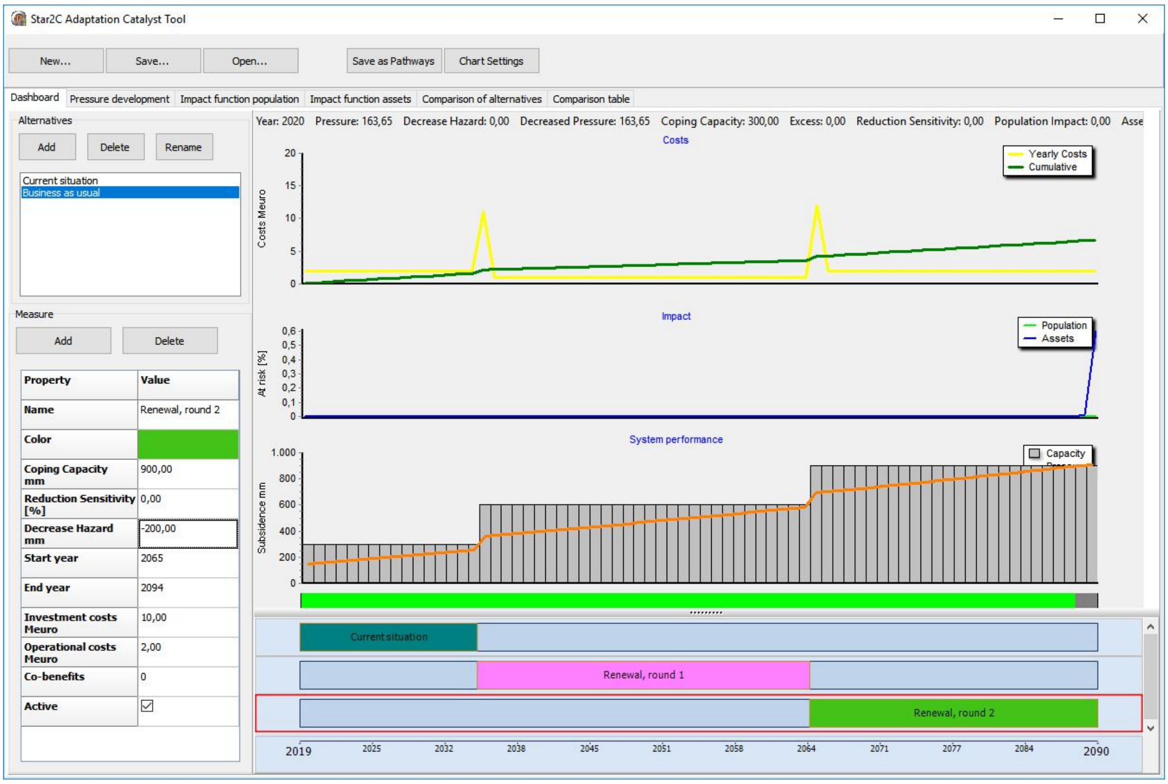
In this alternative the current practice of renewal and extensive maintenance just before reaching an extra 300 mm of subsidence is expressed. During the analyses timeline this results in two consecutive measures: two moments of renewal, at the latest around 2035 and 2065. At each renewal the coping capacity is increased with 300 mm to counter the increase of pressure that will take place in the next 30 years. This is done by adding a new layer of sand on top of the old one. In the year of renewal, the investment costs are expressed as a peak in the curve of the yearly costs. These costs are higher in the second round than in the first round, as it becomes more and more difficult to deal with the increasing amount of subsidence. Also the yearly operational costs become higher.

We build up the alternative by first defining the current situation as a base line measure, like in the 'Current situation' alternative. We then add the two consecutive measures 'Renewal, round 1' and 'Renewal, round 2'. Each round of sewerage renewal has a life span of 30 years.

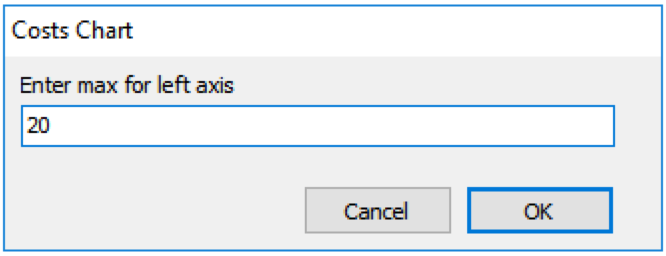
A disadvantage of using sand to compensate for subsidence is that the weight of this sand compresses the soil even more. This effect comes on top of the subsidence that is caused by extreme drought. In the AC this can be defined by using a negative value for the Decrease Hazard parameter. So this measure has both a coping capacity but also increases the pressure to a certain amount. In the case, a value of -100 mm is used. For round 2 the value for Decrease of hazard is set to -200 mm. This value is the 100 mm of extra subsidence caused by round 1, and the extra subsidence caused by round 2 (which is an additional 100 mm).



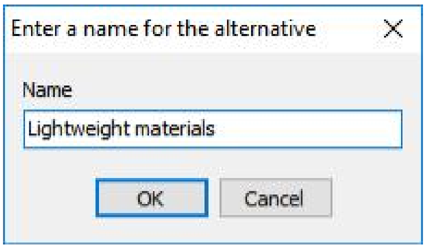
The Dashboard shows that because of the added weight of the sand, there is sudden rise in subsidence of an extra 100 mm in the first year of the renewal. This extra subsidence shortens the period in which impact is prevented. In the year before the next renewal, assets almost suffer impact. At the end of the second round of renewal, the pressure exceeds the coping capacity. At this point, around 2089, the green bar turns grey and the impact on assets curve starts to rise.



The scale of the y-axis of the costs graph is set to 100 by default, but it can be changed by clicking on this axis in the dashboard. This produces the following menu to popup which can be used to redefine the maximum value. It is set to 20 in our example.

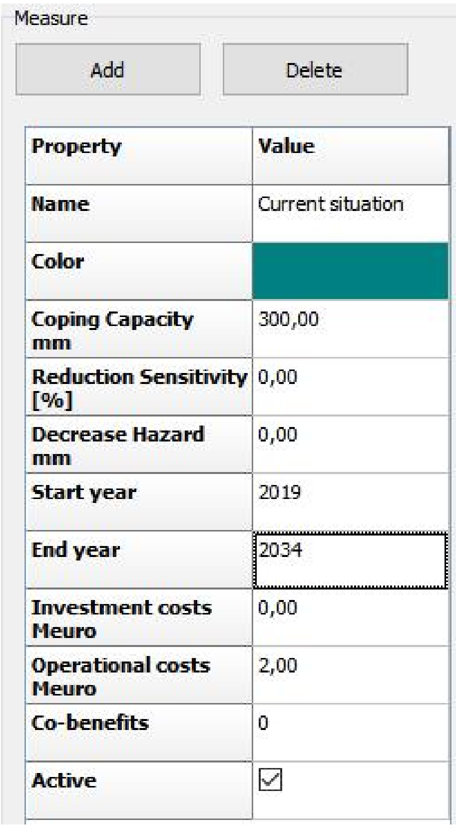


The next alternative consists of using innovative lightweight materials in the renewal of foundations and for the restoration of the surface height.

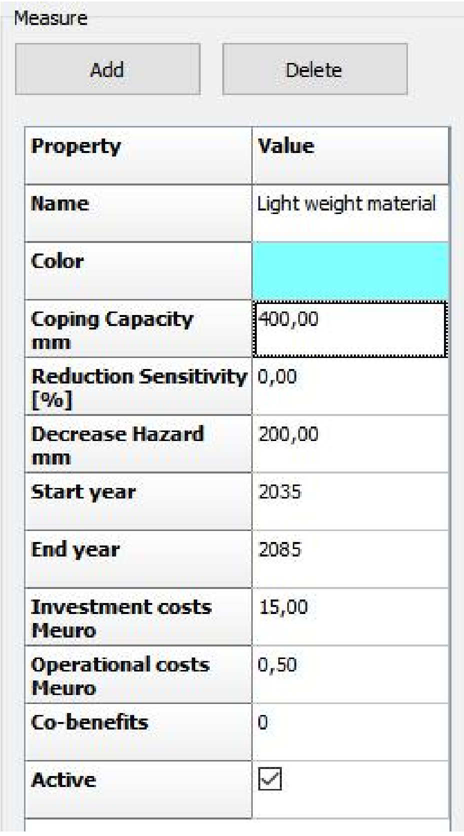


In this alternative the old layer of foundation sand is partly removed and replaced by the lightweight material. The investment costs for removing the old sand and the new materials are higher (15 million Euro) than the business as usual alternative (just adding a new layer of sand). But the lifespan is longer and the yearly maintenance costs are lower (0,5 million/year). The bonus of lightweight materials is that it not only delivers additional coping capacity (400 mm) but also reduces the amount of subsidence because of its lower weight. It is expected that it will decreases the pressure with 200 mm over its lifespan. The expected technical lifespan of the material is at least 50 years.

The first measure to add is, like in the business as usual alternative, the current situation.

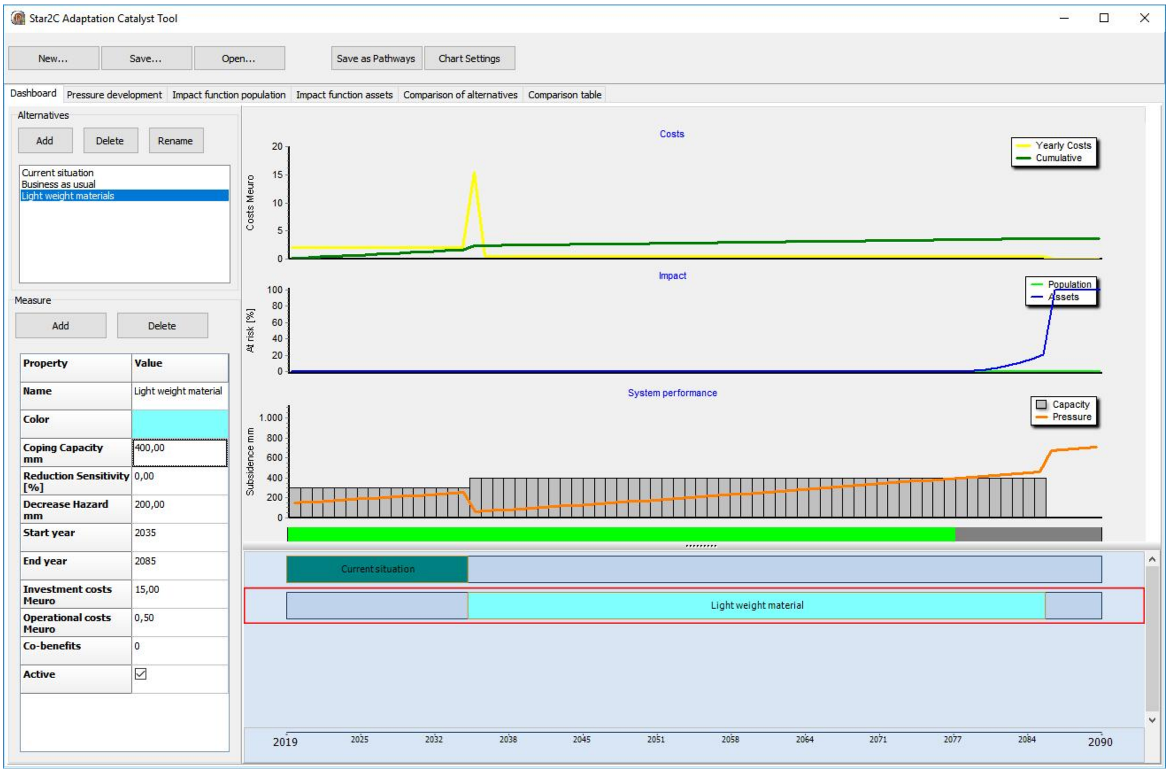


Next, light weight materials are added as a measure, starting in the year 2035.



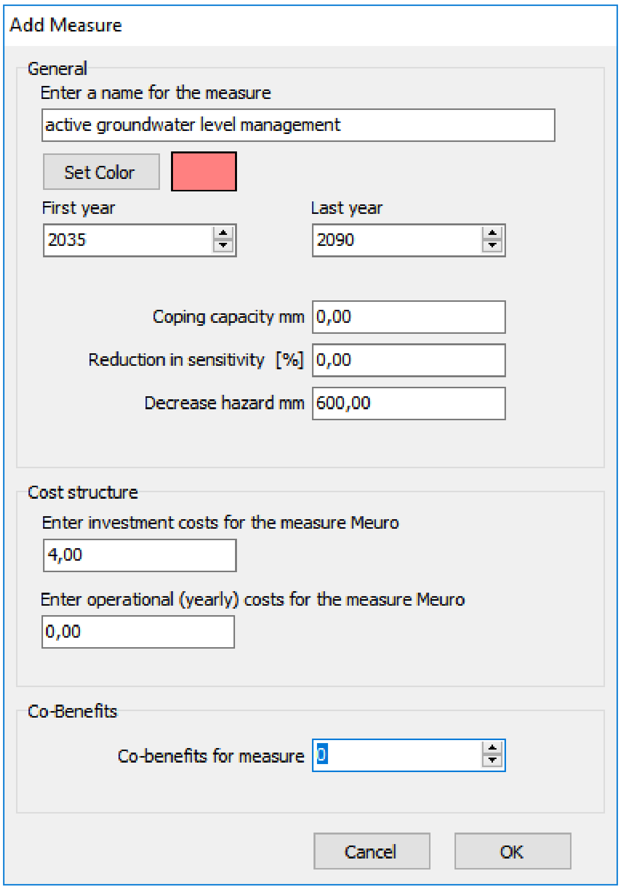
Property	Value
Name	Light weight material
Color	
Coping Capacity mm	400,00
Reduction Sensitivity [%]	0,00
Decrease Hazard mm	200,00
Start year	2035
End year	2085
Investment costs Meuro	15,00
Operational costs Meuro	0,50
Co-benefits	0
Active	☑

The result that is showed in the Dashboard indicates that this measure counters the pressure longer, with lesser costs. But before the end of the technical lifespan of the material, the subsidence passes the adaptive capacity of the measure, around the year 2077. At that moment an additional or new measure is needed.

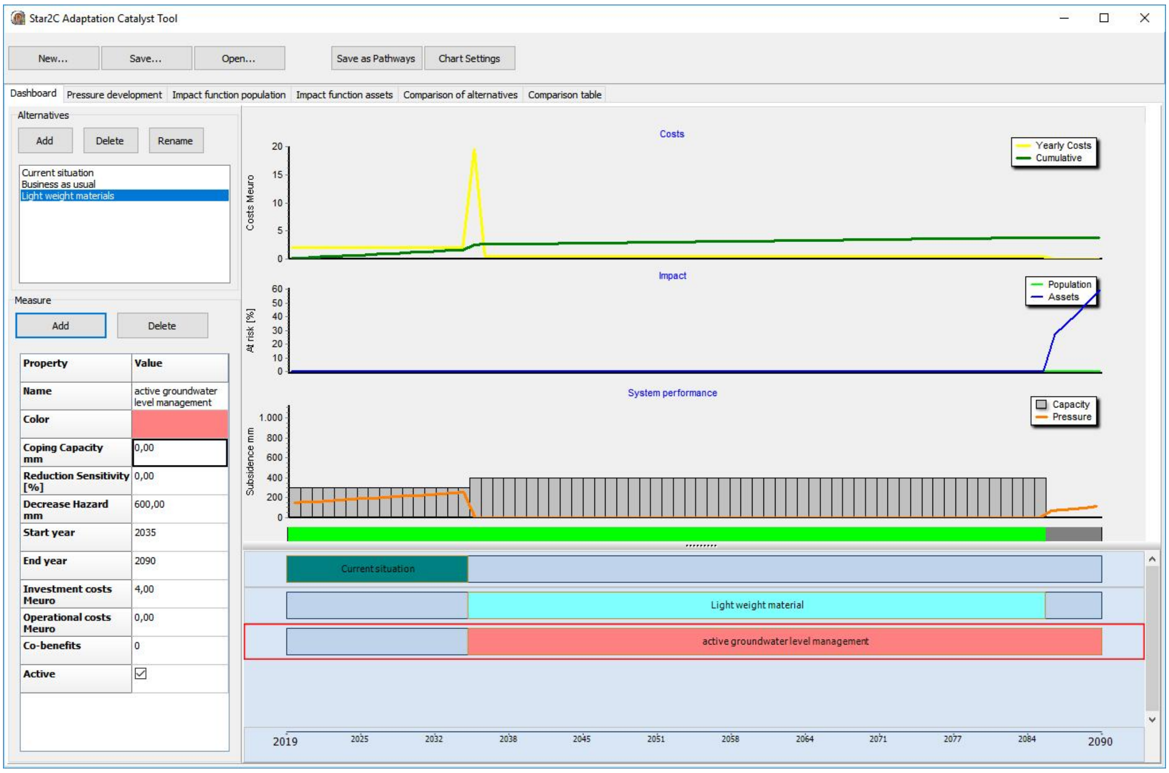


Optimize alternatives and measures

To reduce the amount of subsidence even further, active groundwater level management is added as a measure. This consist of infiltrating additional water in the soil during periods of drought, using horizontal infiltration/transport pipes. Keeping the soil moist reduces the amount of subsidence. To reduce costs (4 million Euros), the pipes are added at the same moment as the lightweight ‘bufferblocks’. There are no maintenance costs. The measure has no coping capacity (it does not compensate for subsidence that occurs), but it decreases the amount of subsidence very effectively (600 mm).

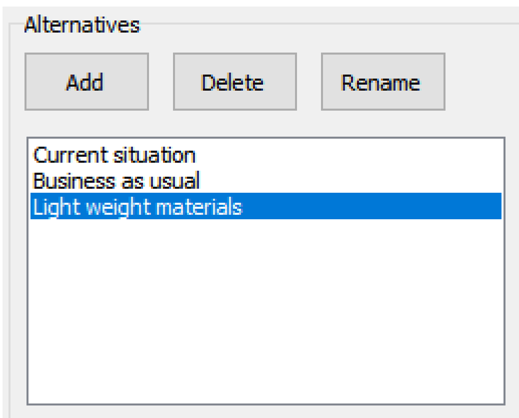

Add Measure
General
Enter a name for the measure
active groundwater level management
Set Color
First year
2035
Last year
2090
Coping capacity mm
0,00
Reduction in sensitivity [%]
0,00
Decrease hazard mm
600,00
Cost structure
Enter investment costs for the measure Meuro
4,00
Enter operational (yearly) costs for the measure Meuro
0,00
Co-Benefits
Co-benefits for measure
0
Cancel
OK

The Dashboard shows that adding this measure delivers more than enough adaptive capacity during the entire technical lifespan of the lightweight material. At the end of this lifespan (2085), renewal of this measure is needed or another type of measure must be put in place to prevent impacts.



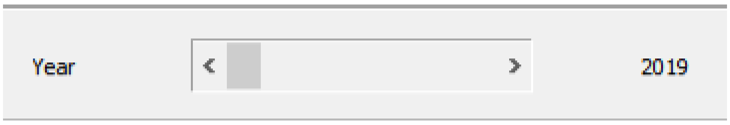
Compare alternatives and measures

Alternatives and measures can be compared by switching between the alternatives in the Dashboard.

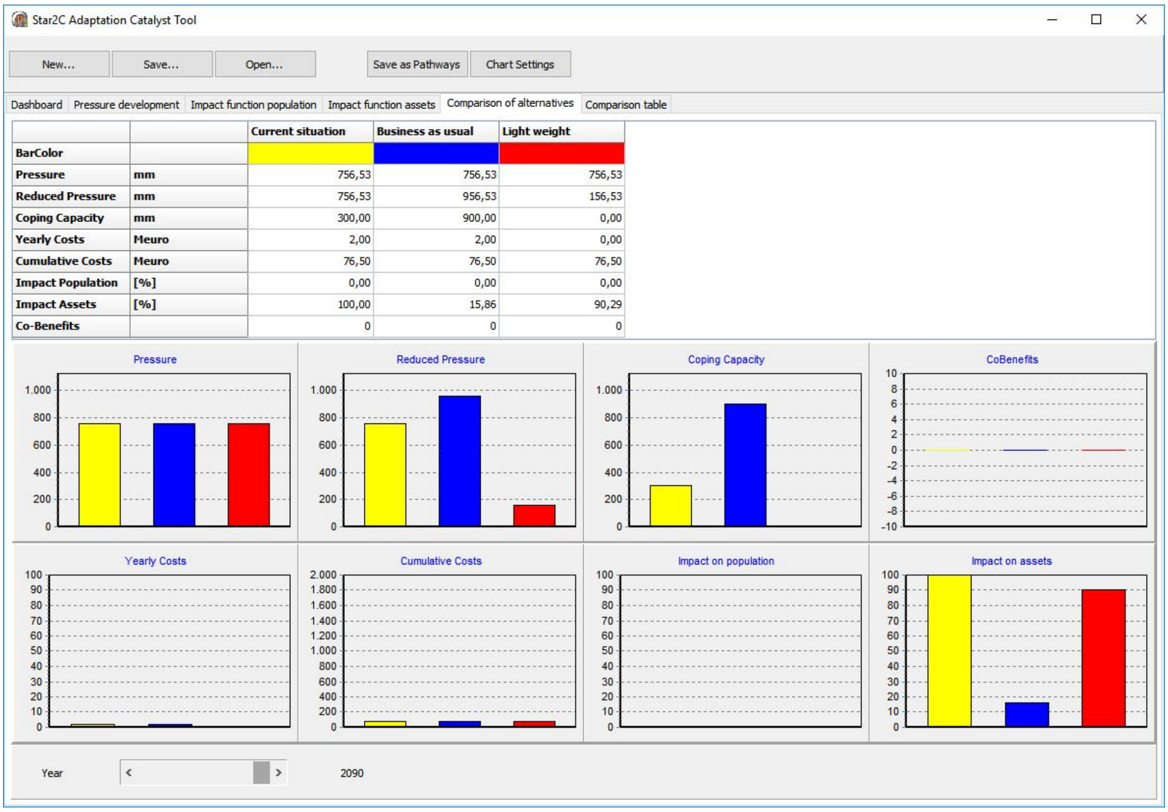


Or by using the 'Comparison of alternatives' and 'Comparison table' tabs. Both tabs provide the possibility to show the outcome of the alternatives in a compact manner, which is of use in discussions about the pros and cons of alternatives. Alternatives can be compared based on performance (how effective are the measures in adapting to the pressure), on costs (what are the differences in cumulative costs over a certain period) and the expected impact on people and assets.

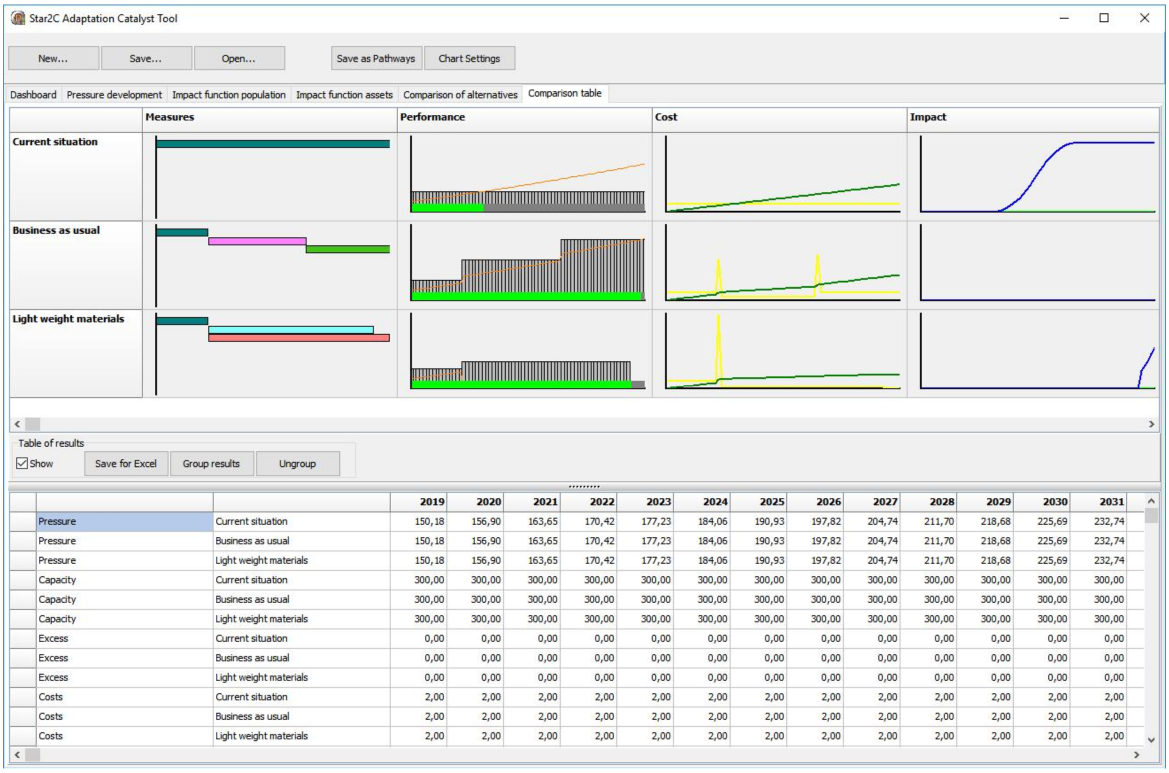
The Comparison of alternatives tab gives an overview of the performance of the alternatives in certain years. Years can be set by adjusting the slider.



As the slider is moved, the bar charts change according to the values of the parameters in the year that is chosen.



The Comparison table tab provides an indicative overview of all graphs and a complete table of results that contains the values that are visualized in the graphs. This table can be exported to Excel for further calculations (e.g. combining the results with more detailed cost data) or the construction of custom graphs.



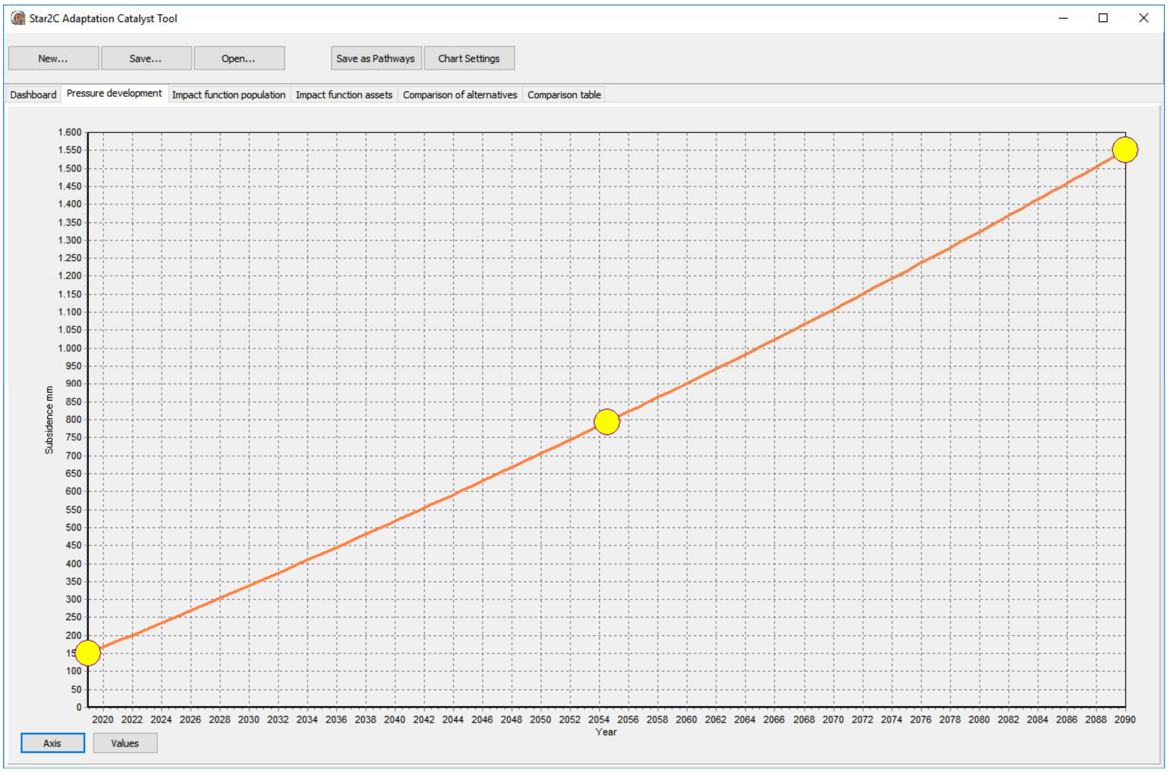
		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Pressure	Current situation	150,18	156,90	163,65	170,42	177,23	184,06	190,93	197,82	204,74	211,70	218,68	225,69	232,74
Pressure	Business as usual	150,18	156,90	163,65	170,42	177,23	184,06	190,93	197,82	204,74	211,70	218,68	225,69	232,74
Pressure	Light weight materials	150,18	156,90	163,65	170,42	177,23	184,06	190,93	197,82	204,74	211,70	218,68	225,69	232,74
Capacity	Current situation	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00
Capacity	Business as usual	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00
Capacity	Light weight materials	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00	300,00
Excess	Current situation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Excess	Business as usual	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Excess	Light weight materials	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Costs	Current situation	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Costs	Business as usual	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Costs	Light weight materials	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00

In this case, the tabs show that impact occurs soon if nothing is done (current situation alternative). The business as usual alternative is just enough to cope. But the Lightweight materials alternative has a much bigger adaptive capacity and is less expensive in the long run because of the lower maintenance costs and longer lifespan (cumulative costs in 2085 of business as usual alternative are 124 million Euro, and of the light weight material alternative 76,5 million Euro).

4.1.4 Explore different scenarios

Explore performance under different pressures and/or different impact functions
Changing the curves that represent how the pressure develops over the years and what percentage of people or assets is affected by excess pressure, have impact on the outcomes. It is useful to explore some scenarios to gain insight in the sensitivity of alternatives or measures to other circumstances. These scenarios can reflect the circumstances in different areas (neighbourhoods).

Pressure
In the case area, different neighbourhoods are characterised by different rates of subsidence. In a new scenario, the rate of subsidence is doubled to 20 mm/year.

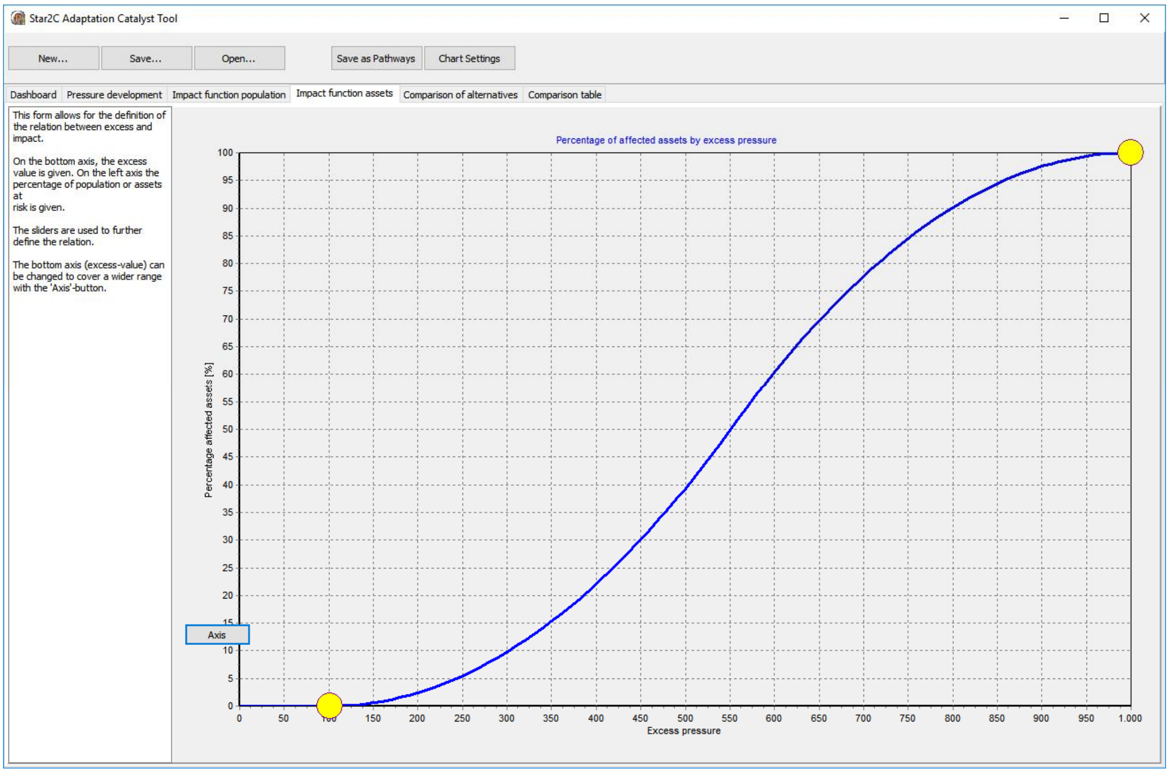


Impact function population

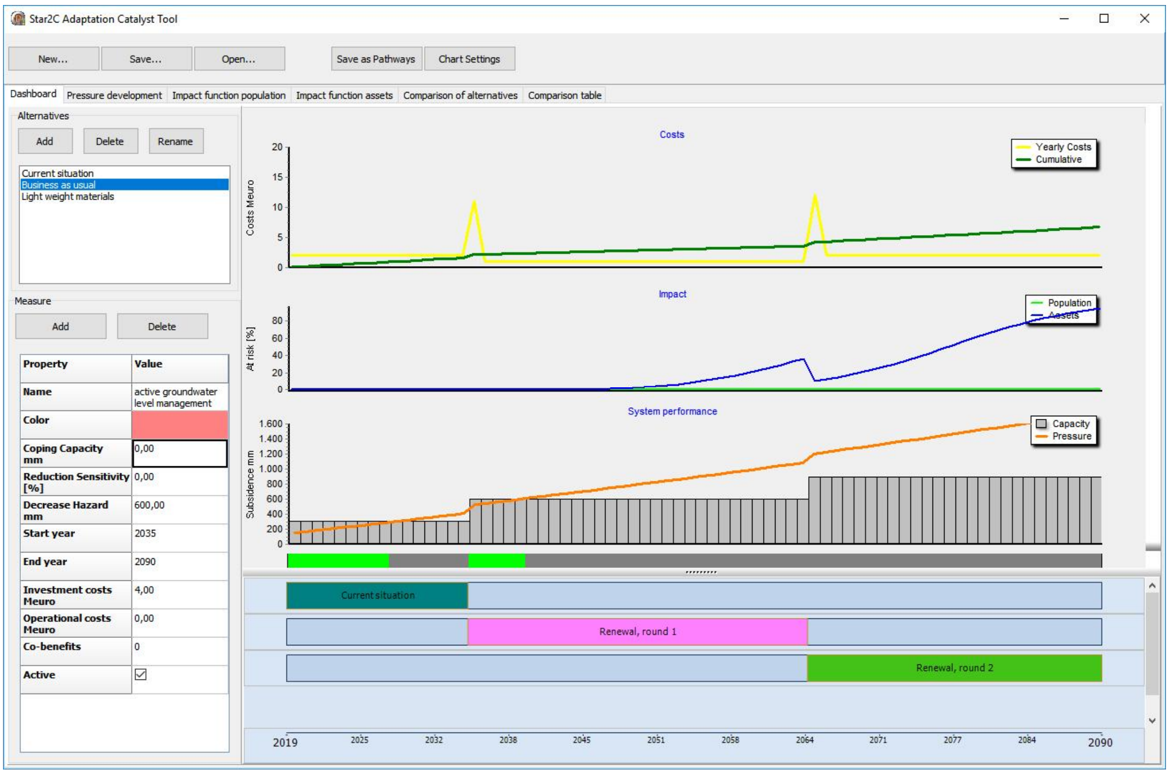
The function of the impact on population is not changed because there will be no risk of loss of life at any rate of subsidence.

Impact function assets

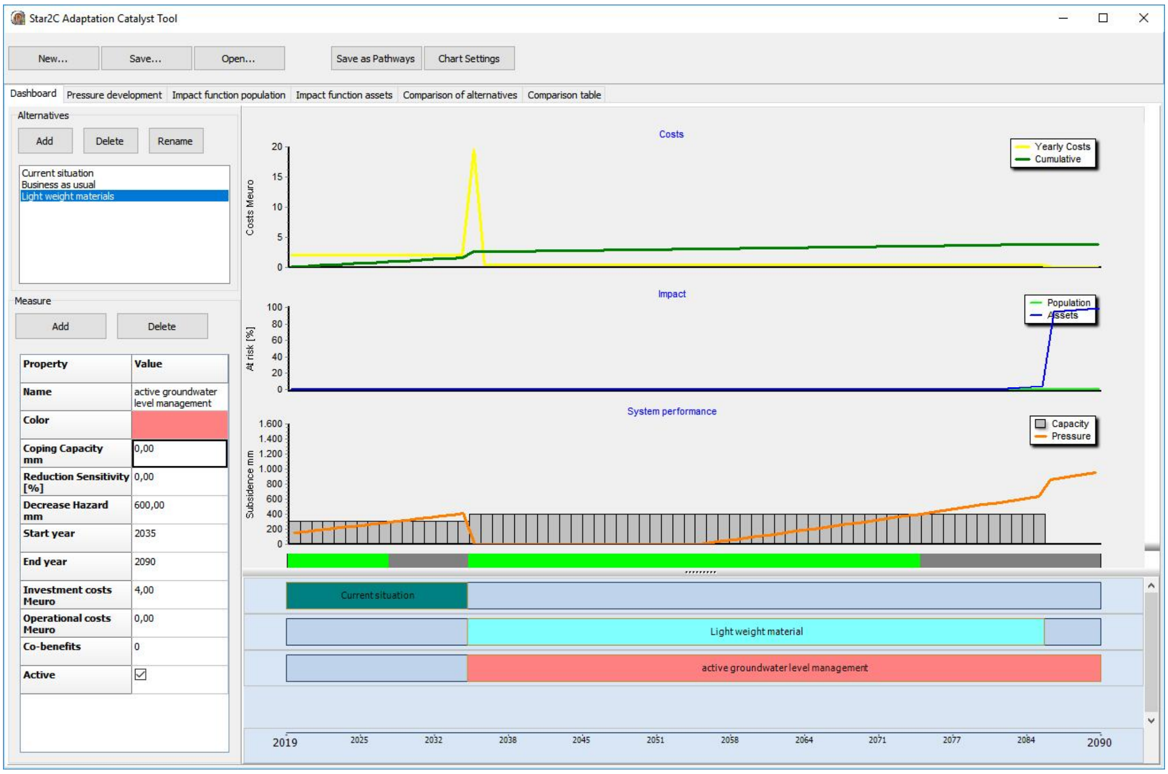
The function of the impact on assets that was used before is already steep: 100% of the assets is impacted at only 200 mm excess subsidence. Now a more moderate scenario is used in which the impact starts at 100 mm excess pressure and rises to 100% at 1.000 mm excess pressure.



The resulting Dashboards of the two alternatives with measures show that the Business as usual alternative must be adjusted to a large extend to deal with the increased pressure. In a Business as usual setting this would result in increasing the renewal frequency.

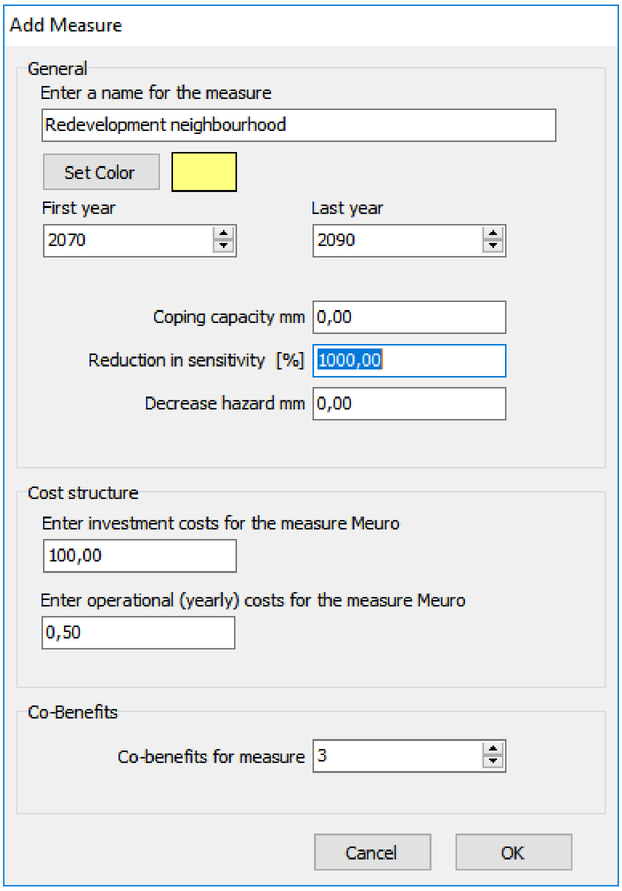


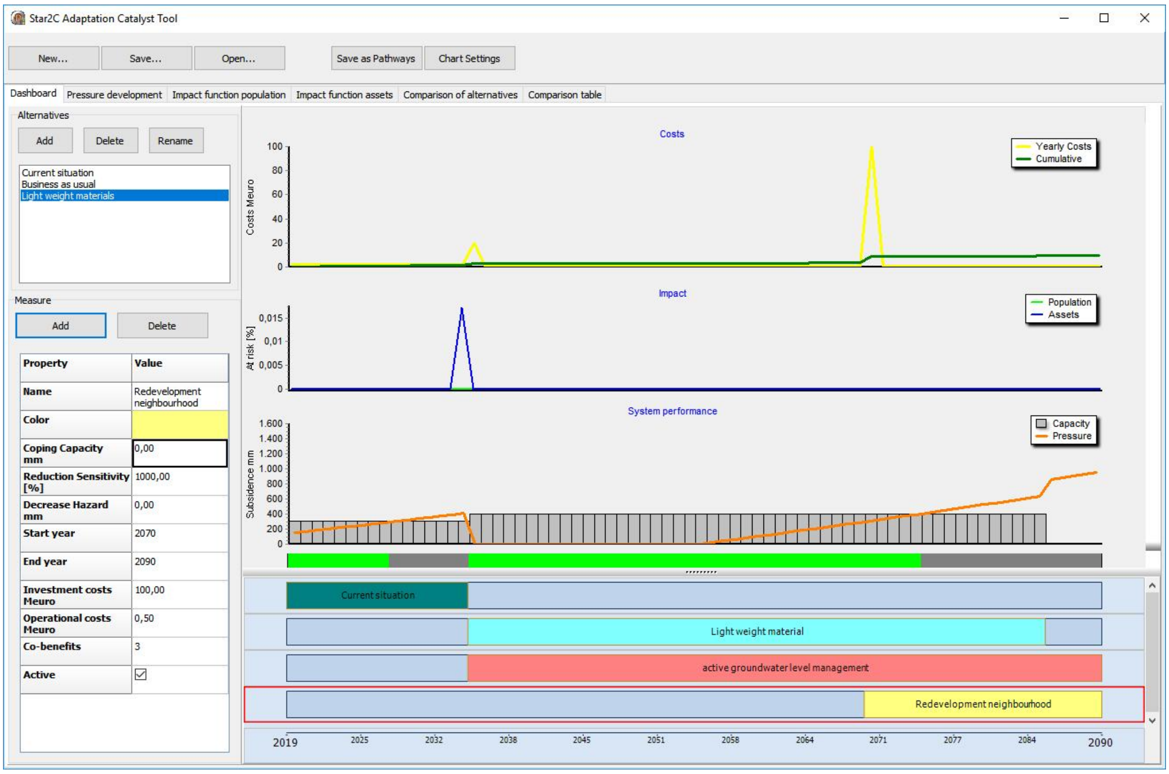
The Lightweight material alternative performs much better, but not enough to deal with the pressure during the entire technical lifespan of the lightweight bufferblocks. Extra measures are needed around the year 2080. This is the moment where impact on assets starts to occur.



Optimize alternatives and measures

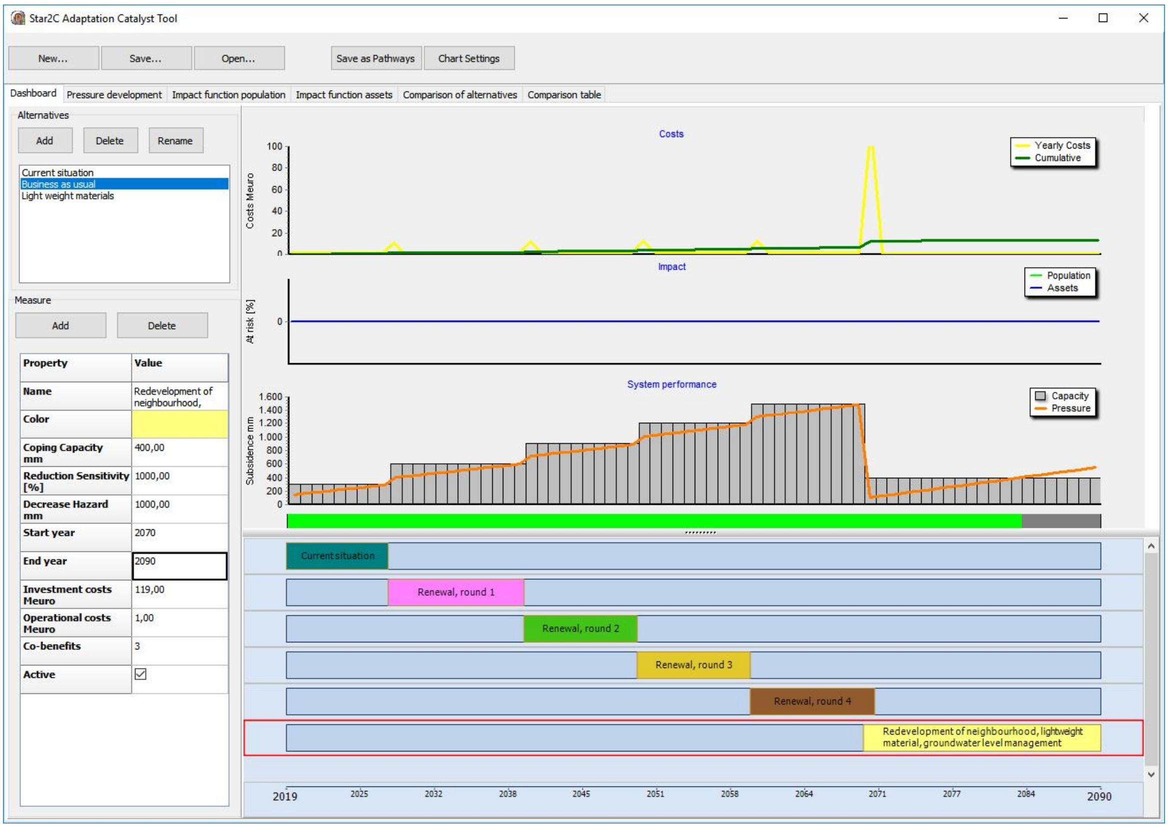
To deal with this more extreme situation, the best performing alternative (Lightweight materials) is chosen and a possible additional measure is added to prevent impact in the far future: the complete redevelopment of the neighbourhood. In this rigorous measure, all buildings and infrastructure is renewed around 2070, which is around the end of lifespan of the current housing. Again, lightweight bufferblocks and active groundwater management are used, and added to this the sensitivity of the houses to subsidence is reduced by using light weight building materials. The investment costs for renewal are big, but the long term savings on maintenance are significant.


Add Measure
General
Enter a name for the measure
Redevelopment neighbourhood
Set Color
First year
2070
Last year
2090
Coping capacity mm
0,00
Reduction in sensitivity [%]
1000,00
Decrease hazard mm
0,00
Cost structure
Enter investment costs for the measure Meuro
100,00
Enter operational (yearly) costs for the measure Meuro
0,50
Co-Benefits
Co-benefits for measure
3
Cancel
OK


Star2C Adaptation Catalyst Tool
New...
Save...
Open...
Save as Pathways
Chart Settings
Dashboard
Pressure development
Impact function population
Impact function assets
Comparison of alternatives
Comparison table
Alternatives
Add
Delete
Rename
Current situation
Business as usual
Light weight materials
Measure
Add
Delete
Property
Value
Name
Redevelopment neighbourhood
Color
Coping Capacity mm
0,00
Reduction Sensitivity [%]
1000,00
Decrease Hazard mm
0,00
Start year
2070
End year
2090
Investment costs Meuro
100,00
Operational costs Meuro
0,50
Co-benefits
3
Active
Costs
Costs Meuro
Yearly Costs
Cumulative
Impact
At risk [%]
Population
Assets
System performance
Subsidence mm
Capacity
Pressure
Current situation
Light weight material
active groundwater level management
Redevelopment neighbourhood
2019
2025
2032
2038
2045
2051
2058
2064
2071
2077
2084
2090

Important to notice in the resulting dashboard is that although the pressure of subsidence exceeds the coping capacity of the new development (the green bar turns grey at around 2075), the added reduction of the sensitivity ensures that the impact remains 0.

Dealing with this more extreme situation in the Business as usual manner requires four renewal rounds before a redevelopment of the neighbourhood (using the same technique as in the previous alternative + use of lightweight materials + groundwater level management) around 2070.



Compare alternatives and measures

In the comparison of the two alternatives, the most prominent factor is the higher cumulative cost of renewals in the Business as usual way, between now and the moment of complete redevelopment of the neighbourhood. That moment is about the same in both alternatives (2070). An important co-benefit of the Lightweight materials alternative is the lesser degree of nuisance for inhabitants caused by renewal and maintenance. Other co-benefits are the added value of ‘bufferblocks’ to rain water storage, and the better total performance of this alternative in reducing risks.

4.2 Adaptation to river flooding

4.2.1 Description of the case

The location of the case is the Zwalm Valley in East-Flanders, Belgium. For this valley an adaptive vision was created and delineated in a so-called 'river contract'. The Province of East-Flanders and the Flemish Environment Agency cooperated with a wide spectrum of stakeholders to develop this contract. It stipulates a pathway of measures to be implemented by different actors in order to reduce the frequency and the impact of flooding in the context of climate change. By simultaneously taking into account other spatial challenges in the valley (concerning nature, agriculture, heritage, recreation, working and living) these measures will also contribute to the spatial development of the valley as a whole.

For this case, an extensive amount of background research was already available. Actually, the case had evolved beyond the phase in which the Adaptation Catalyst would be of most value: exploring possible future scenarios and adaptation measures. This paragraph therefore describes how the Adaptation Catalyst could have been used, using example data from the Zwalm case and information from the national climate information portal (https://klimaat.vmm.be). Types of data that are usually available in the exploratory phase of a river flooding climate adaptation study.

The following aspects of the case are relevant in the setup of the AC:

- The landscape in the case consists of hilly terrain. River flooding is caused by excessive rainfall in the catchment
- The water depth (river flood level – surface height) is an important variable that is used in this case to derive possible damages and risks.
- Damages to residential buildings arise from 0,25m water depth. Beyond 1m water depth, extensive protective measures to houses are advised.
- The time horizon of the case end in the year 2100. Beyond 2050, the analysis relies more and more on assumptions. The possible situation in 2050 is an important target for optimization of flood protection measures.
- There is a variety of possible measures that work in different ways: protection against flood levels (e.g. dikes), prevention of flooding (e.g. retention areas, constructions that improve discharge, increasing river), reduction of sensitivity (e.g. waterproofing buildings, areas with building prohibition) and preparedness (e.g. flood forecasting).

4.2.2 Define current situation and climate pressure

Basic case information

Pressure
Climate change puts pressure on the system in the form of an increase of excessive rainfall: more often heave rainfall events and more rain during these events. The rainfall leads to flooding situations, which causes damages. An important parameter that is used to express the severity of the flooding situation is water depth [meter] at different flooding events (different recurrent intervals) and at different points along the river bed. It is not possible to distinguish different situations at different spots with the Adaptation Catalyst. So the setup and analyses must be generic, representing an average situation along the river. Alternatively it's possible to choose a certain spot or river stretch and perform the analyses with the Adaptation Catalyst for that specific spot or stretch, exploring which measures perform best under the conditions that

prevail there. Another parameter that expresses the severity of flooding, the possible impact, is the area [hectares] that floods.

For the setup of the AC in this case, we chose to use the increase in mean water depth in a part of the river basin as the pressure, because:

- There is background information available about how water depth determines the amount of damages (impact).
- The performance of measures is expressed in how they decrease water depth of how they cope with a certain water depth
- Measures have to fit within the situation of a certain area, a part of the river basin. Not for just one point along the river or the entire river catchment.

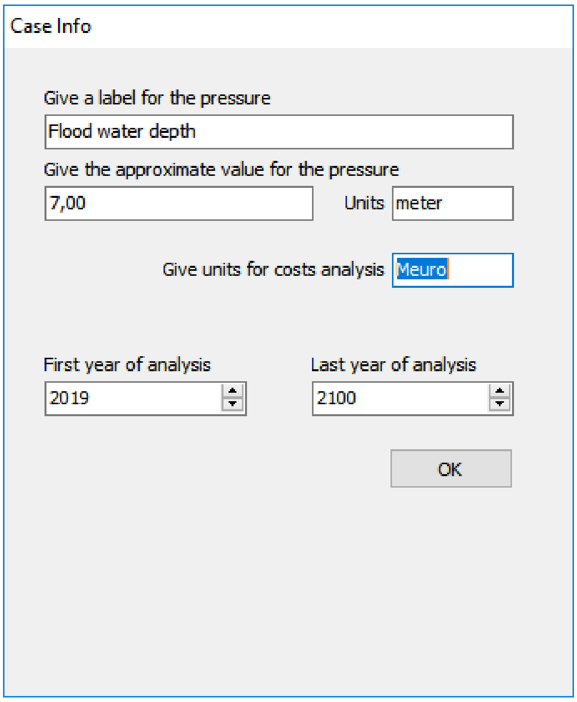
In the available background information, Climate change is expressed by the increase of water depth at different reoccurrence frequencies. Because we chose to express the increase of the pressure as an increase of mean water depth, it is necessary to do that for one certain reoccurrence interval, preferable a normative interval. In this case, this is a 1:1.000 year event.

Note: Alternatively, it would be possible to fix the water depth and express the increase of the pressure as in increase of the reoccurrence interval of that water depth. Choosing one or the other depends largely on information availability and how impact and the performance of adaptation measures are quantified in a particular setting.

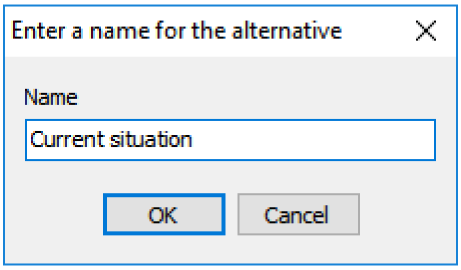
Approximate pressure value
The mean maximum mean water depth that is considered possible in the case area is about 0,77 meters. The maximum possible water depth (not the mean) is about 7 meters. This value is chosen to set up the AC.

Units for cost analysis
The unit for the expression of costs is set to millions of euros.

Start and end year of timeline
Default, the starting year for the analysis is the present: 2019. The last year of analysis is 2100, which is according to the time horizon of the case. An important moment in the timeline of the case is the situation around the year 2050.



Current situation
Defining the capacity to deal with the pressure, with flood water depth, in the current situation offers a reference for judging when adaptation measures are needed. This is done by adding an alternative with just one 'measure' that reflects the current coping capacity.



In the case situation, the current mean maximum water depth in the Zwalm area is 0,46 meter during a 1:1.000 rain event.

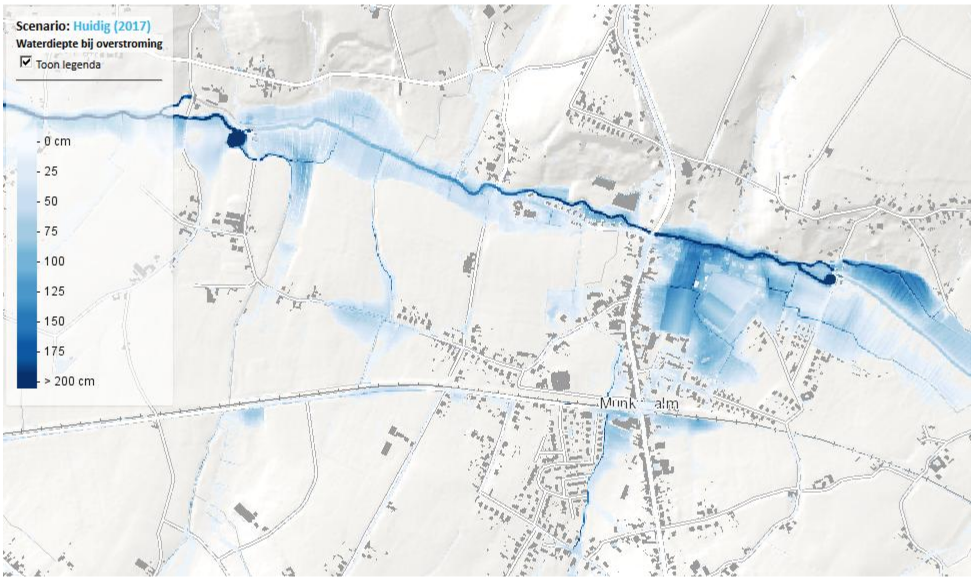
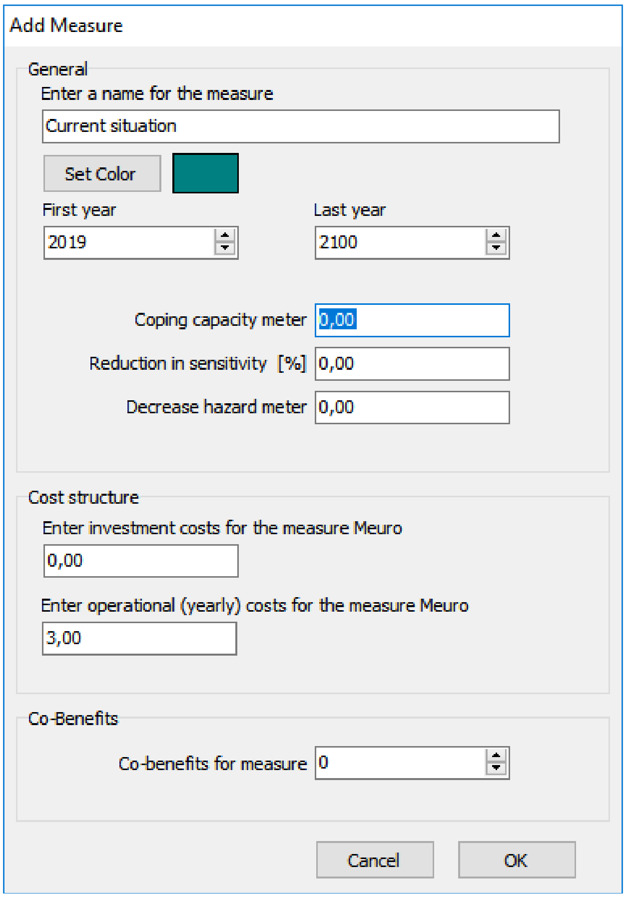


Figure 4.1 Current flood water depth around the Munkzwalm municipality during an 1:1.000 event. Source *https://klimaat.vmm.be/nl/kaartapplicatie-thema-2*

In the current situation, there is no reduction of sensitivity or a decrease of the hazard. The investment costs are 0, as the situation is already in place. The yearly operational costs for regular maintenance are 3 million Euros. There are no co-benefits. To start the analyses, the end year is the same as the end year of the analyses period. This can be changed later on.



Pressure development
Outcomes of flood models and studies show that the mean maximum water depth could increase to 0,77 meter in 2100.

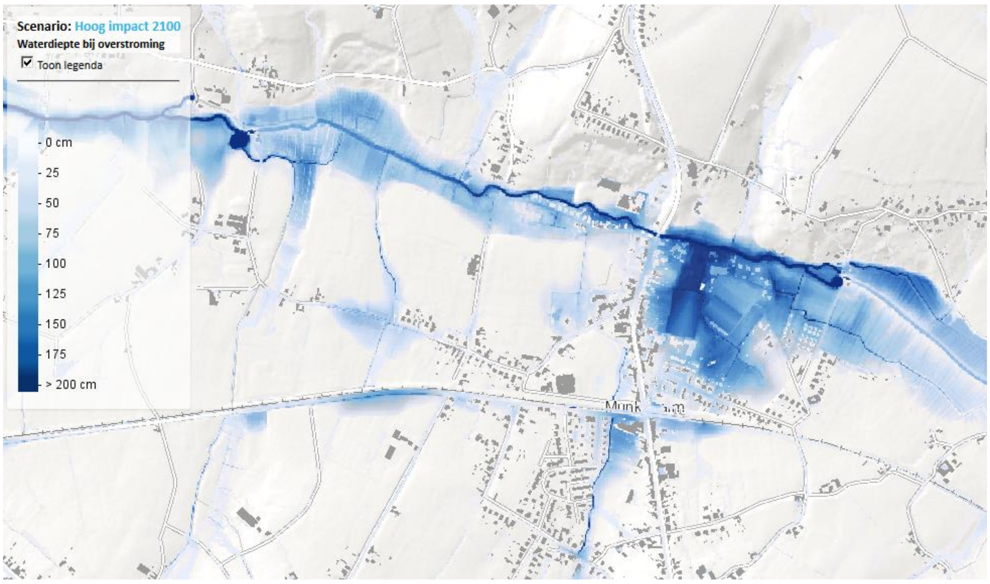
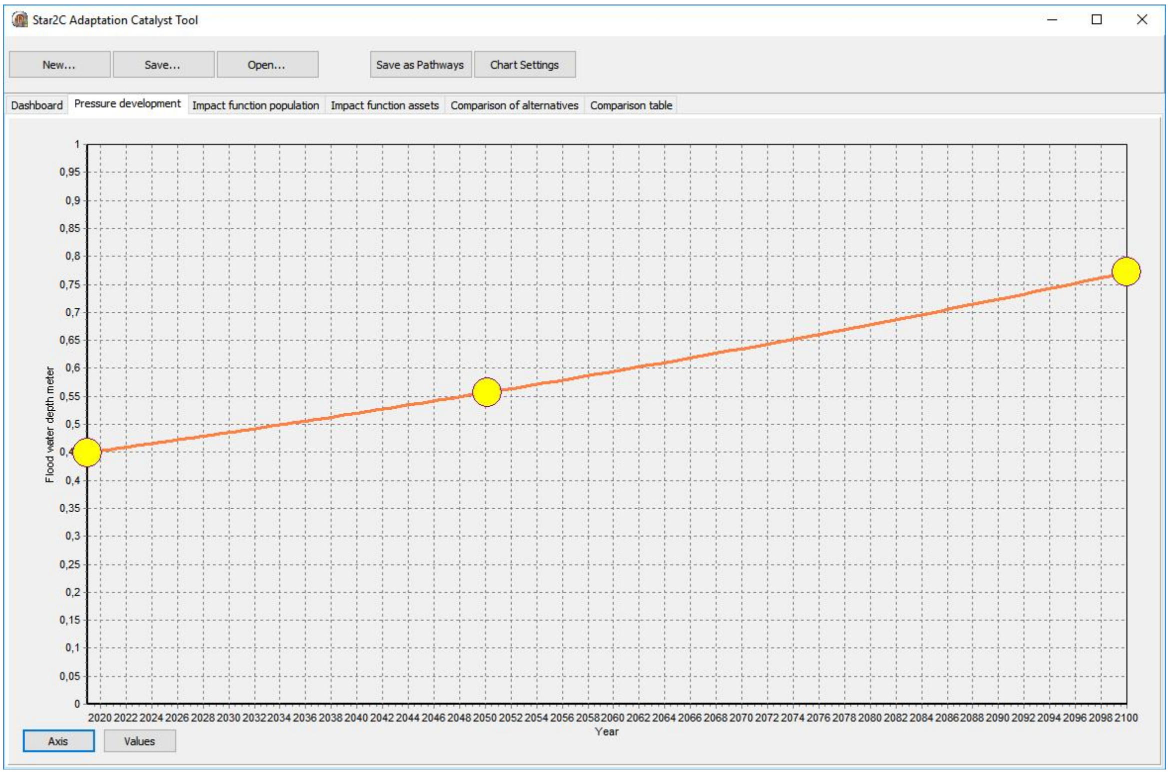


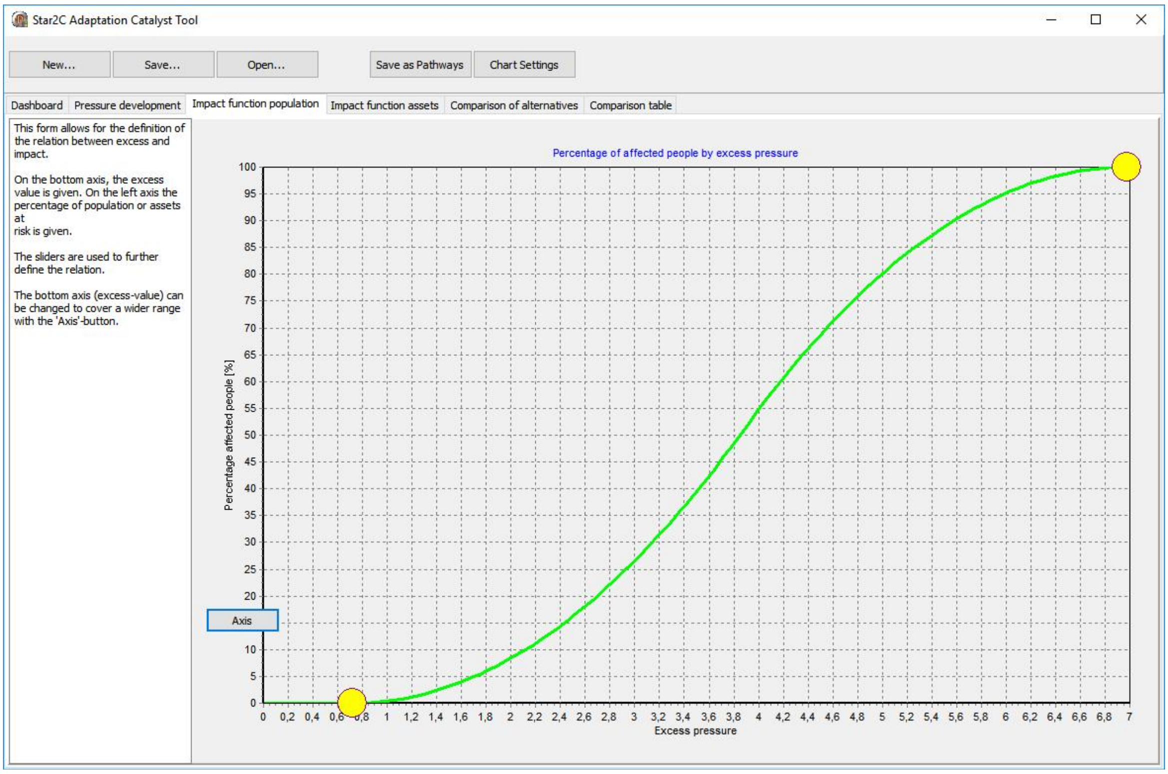
Figure 4.2 Flood water depth around the Munkzwalm municipality during an 1:1.000 event in 2100. Source https://klimaat.vmm.be/nl/kaartapplicatie-thema-2

The pressure development curve is changed accordingly, using a linear increase over years. The scale of the y-axis is adjusted to 0 – 1 to enable more accurate settings of the curve.



Impact function population

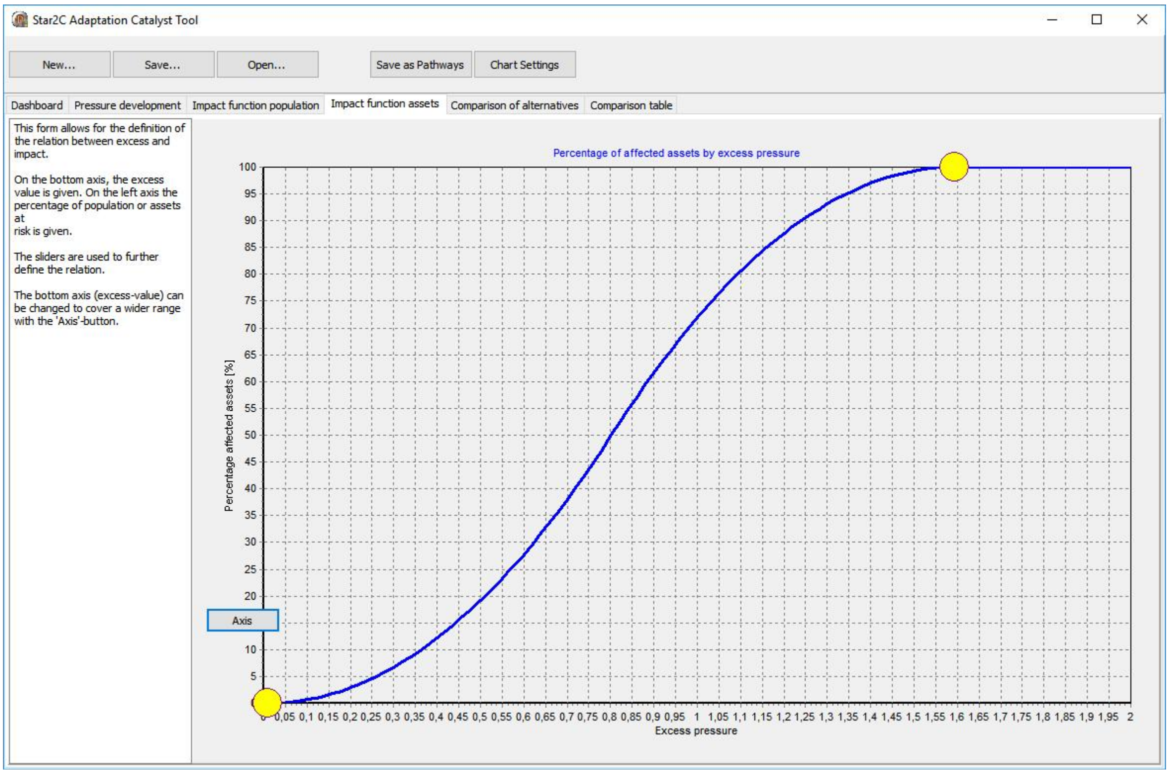
At a water depth of 0,7 meter or more, a situation of significant risks starts to occur for (main) buildings and their functions. The case offers no background information about the impact on the population. Using expert judgement, the assumption is made that the impact on the population starts at a mean 0,7 meter water depth and reaches its maximum of 100% at a depth of 7 meters (the maximum possible water depth in the area, not a mean).



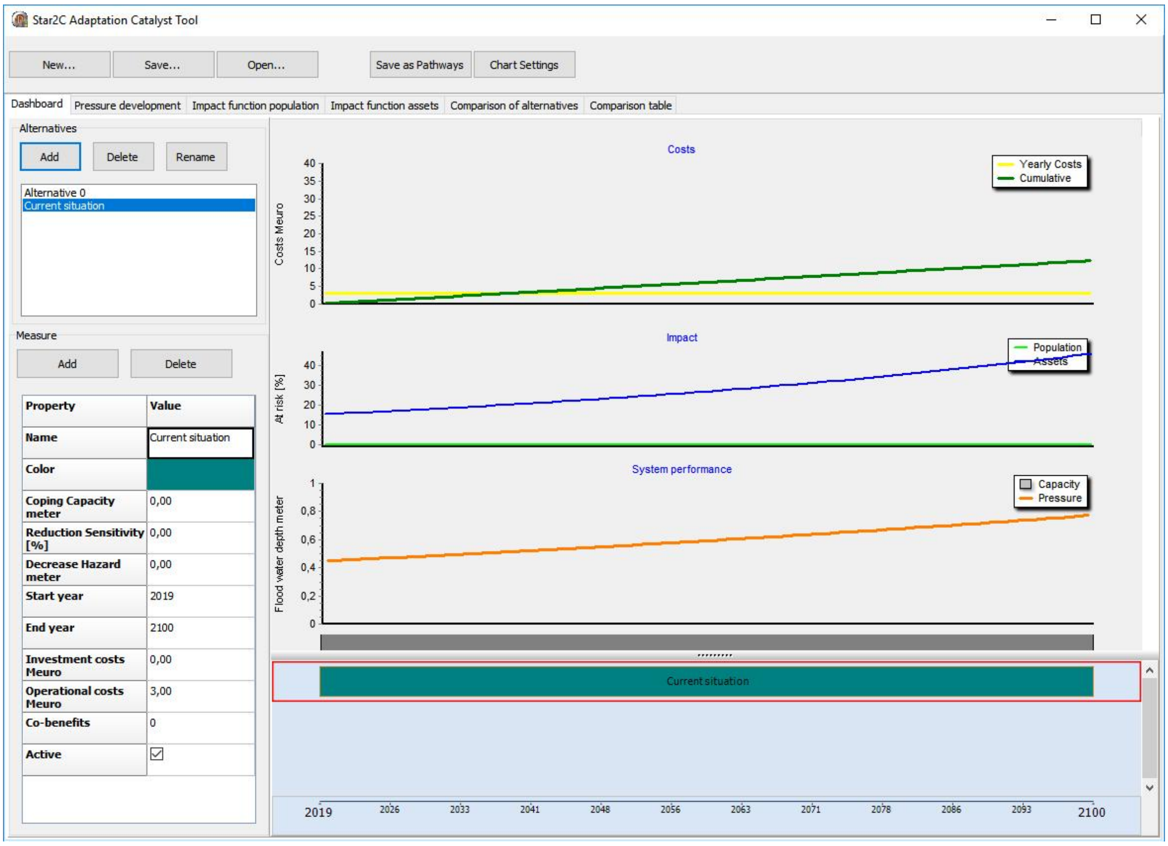
Impact function assets

Significant risks for buildings start to occur at a water depth of 0,7 meters. But to some extent, lesser water depths already cause damages and nuisances like traffic obstructions. The available background information shows that at present, about 19% of the vital buildings are affected at a mean maximum water depth of 0,46 meter. In 2100 this has increased to about 38% because of the increase of water depth to 0,77 meter. As mentioned earlier, this is the maximum mean water level that is deemed possible in the case, so the percentage of affected assets is not expected to transcend 38%, although the curve that we set allows for this.

Using these figures as landmarks and by changing the scale of the x-axis with the 'Axis' button, the 'Impact function assets' curve is set to approximate these values as much as possible. This is done by extending the range of the Excess pressure axis to 2 meters and using the sliders to fit the curve near the landmark figures.



After completion of these steps, the Dashboard shows the following overview of the current situation and impact of climate change.



The dashboard reflects how the impact of an 1:1.000 event rises into the future. Because the current adaptive capacity is set to zero, the impact on assets curve starts at 19% and rises steadily towards 2100. The mean water depth is not big enough to lead to impact on the population: the curve is level at 0%.

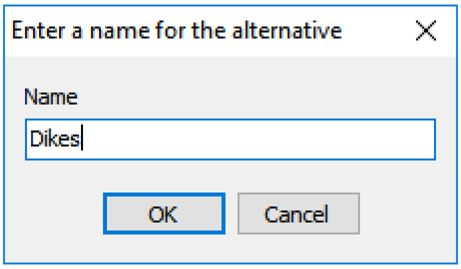
4.2.3 Define adaptation measures and compile alternatives

Add alternatives and adaptation measures

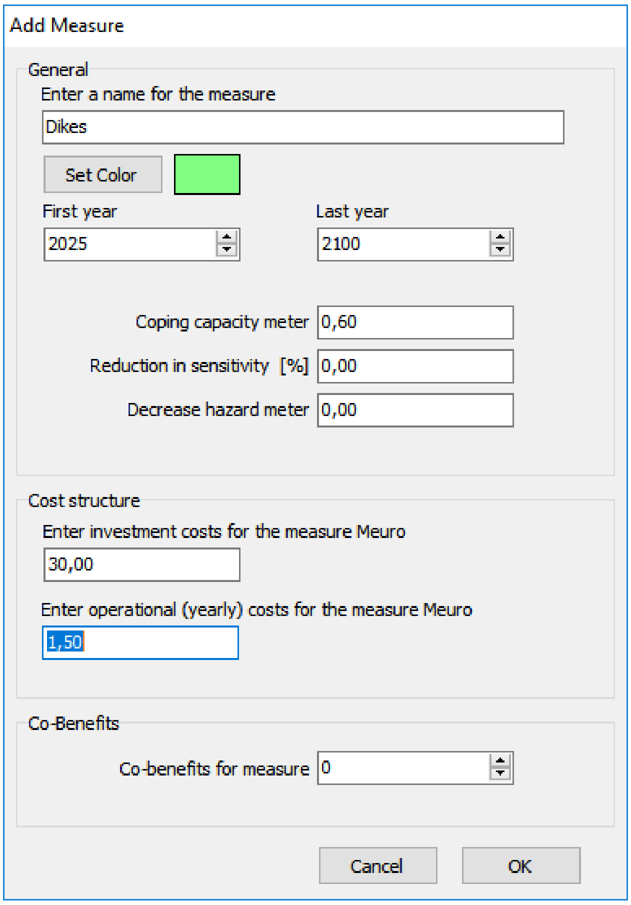
To react to the increase of pressure and to prevent impact, different alternatives with packages of different types of measures are added. In the case, three types of measures are considered:

1. Increase of coping capacity = dikes (artificial embankment)
2. Reduce the sensitivity = waterproofing buildings; flood early warning system
3. Decrease the hazard = retention areas; remove obstacles to improve discharge; increasing storage volume of river bed

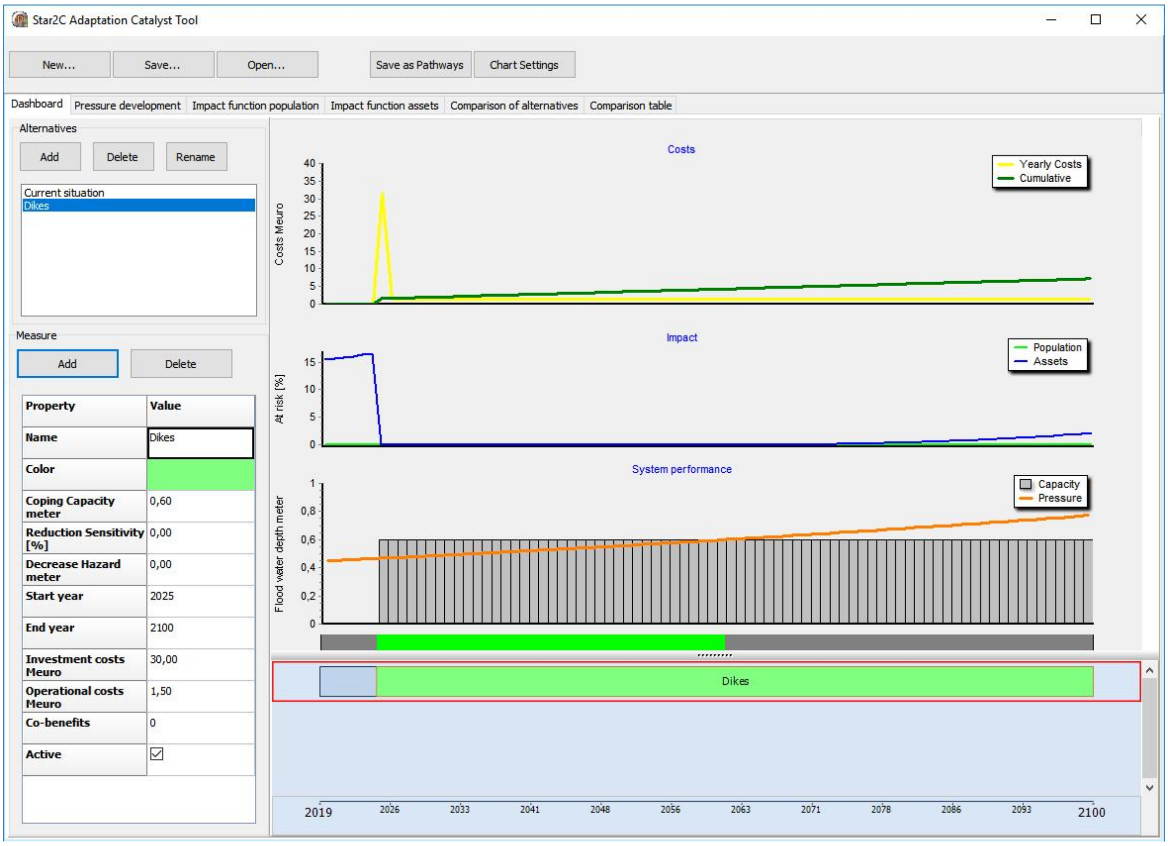
The first alternative uses dikes as the main measure. Dikes are relatively expensive constructions but do not take up a lot of space.



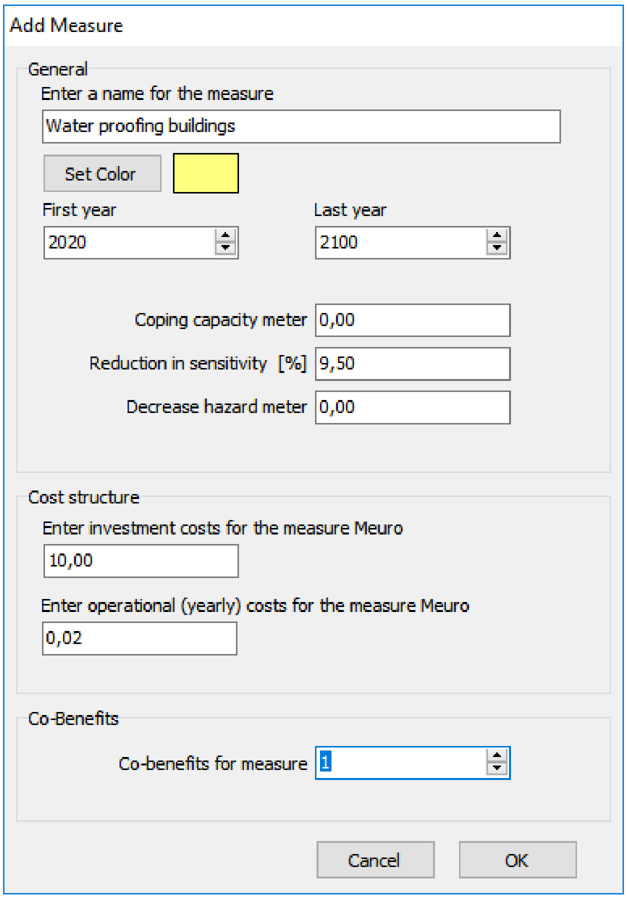
Planning and building dikes takes about 5 years. They are in place in the year 2025. The coping capacity of the dikes in expressed in the mean maximum water depth they can retain. This is set at 0,6 meter. Investment costs are high, 30 million Euro. Yearly maintenance costs are 1,5 million Euro. There are no co-benefits.



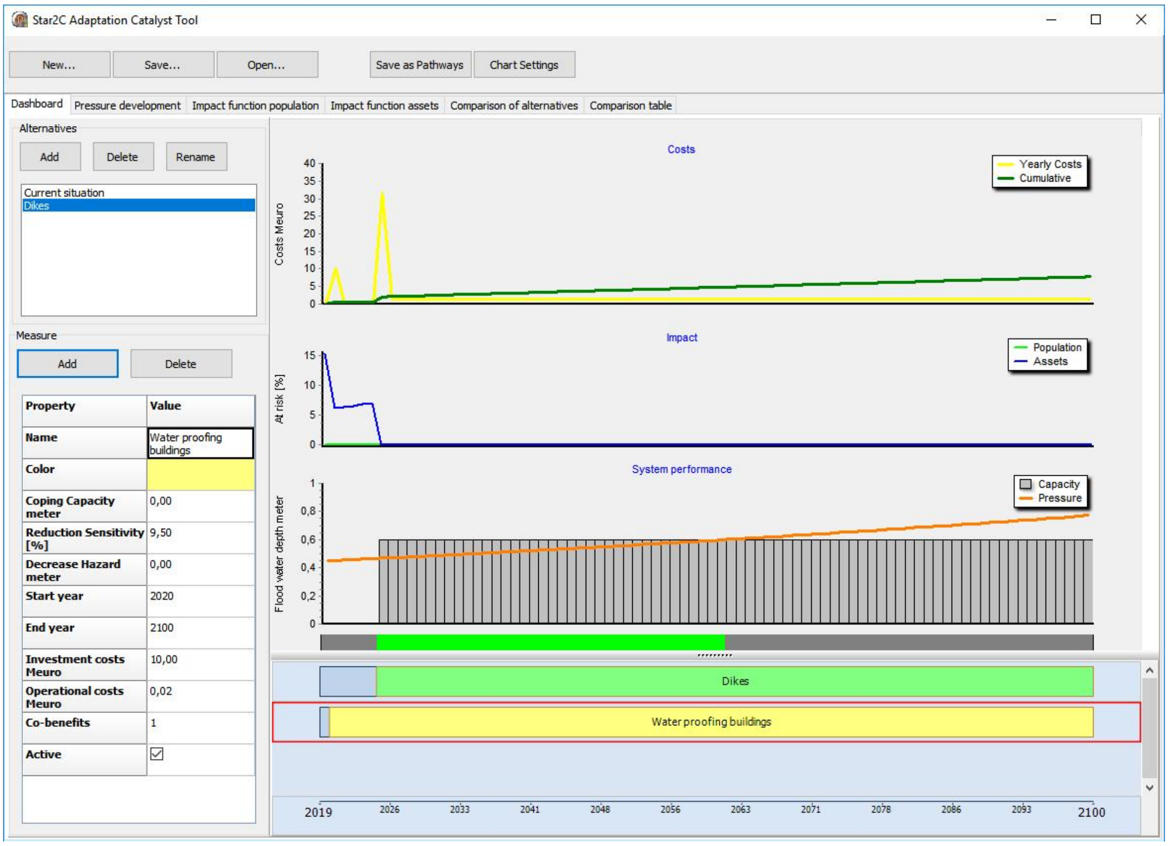
The dashboard shows that the dikes can deal with the increase of pressure until about 2060. At that moment other measures or an increase of the dike height is needed.



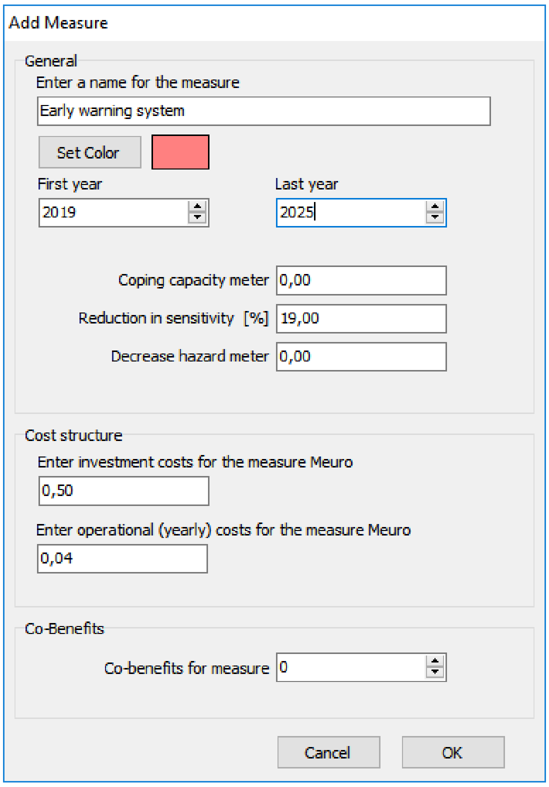
The choice is made to add waterproofing vital buildings in 2020 to half of the vital buildings that are affected in the current situation (which is 19% of the total, see impact curve settings, so half is 9,5% of the total amount of the buildings that would be affected). This decreases the sensitivity of these buildings and lowers the total impact. A co-benefit is the added value of the houses. This is reflected by setting the co-benefit value to 1.


Add Measure
General
Enter a name for the measure
Water proofing buildings
Set Color
First year
2020
Last year
2100
Coping capacity meter
0,00
Reduction in sensitivity [%]
9,50
Decrease hazard meter
0,00
Cost structure
Enter investment costs for the measure Meuro
10,00
Enter operational (yearly) costs for the measure Meuro
0,02
Co-Benefits
Co-benefits for measure
1
Cancel
OK

This measure reduces the impact on assets after 2060, but the dashboard shows that there is still impact in the period before the dikes are in place.

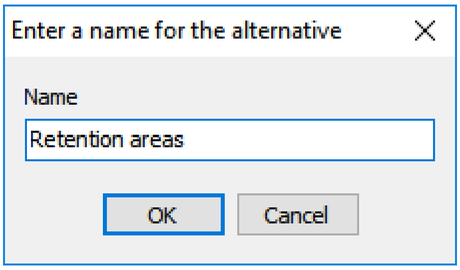


To bridge this gap, a temporarily early warning system is added as a measure until the dikes have been completed. These are meant to warn all residents well in advance so they can protect their assets, e.g. by using sand bags. This measure works in the same way as water proofing buildings. It reduces the sensitivity of all the assets that can be affected in the current situation. The reduction of sensitivity is therefor set to 19%. Investment costs consist of hardware and software. The yearly operational costs are for maintaining the system but also for the temporary water proofing of assets. This is the main and relatively high component of the yearly costs.

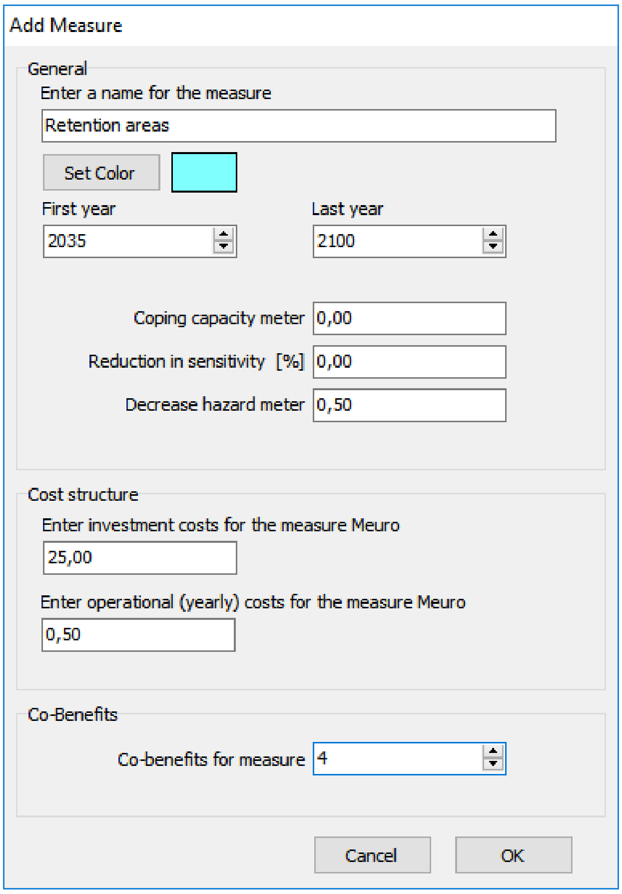


The dashboard shows that this combination of measures will reduce the impact to zero over the entire timespan.

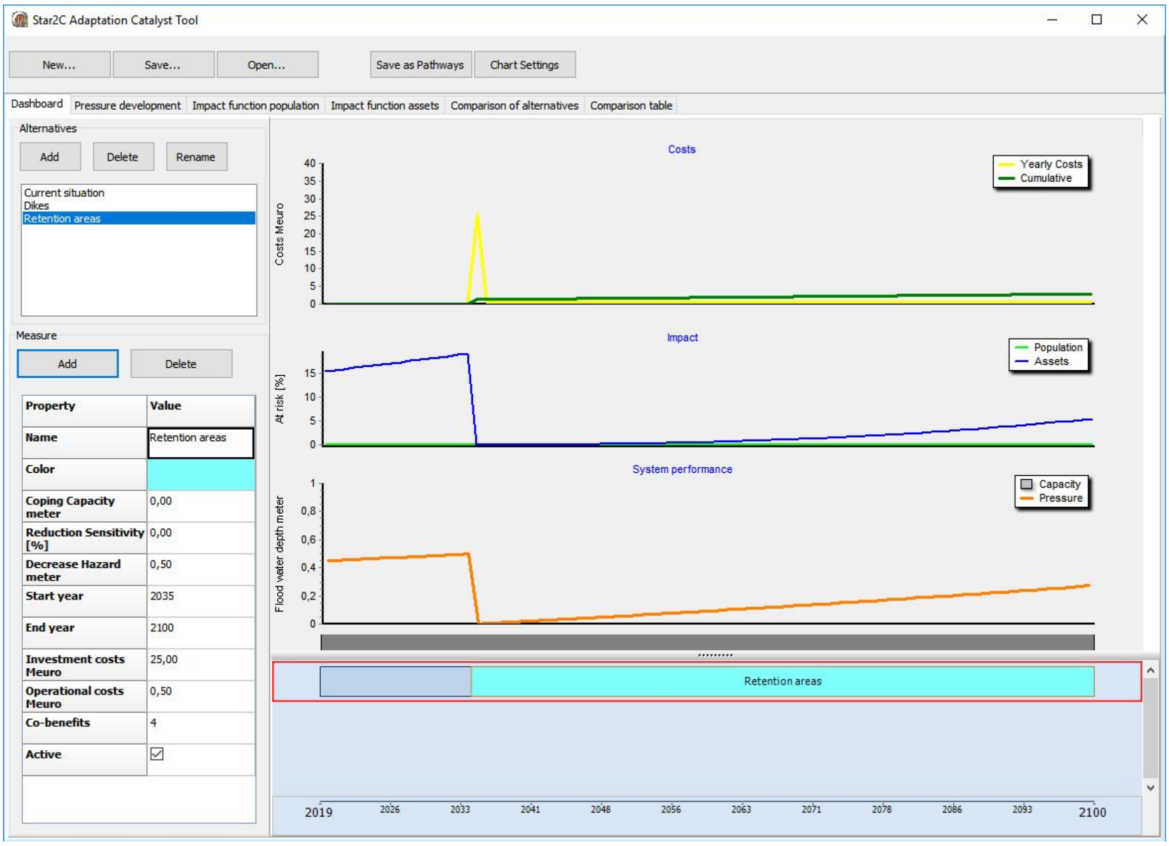
The second alternative uses retention areas for water storage as the main measure. These take up a lot of space and require alterations in spatial planning.



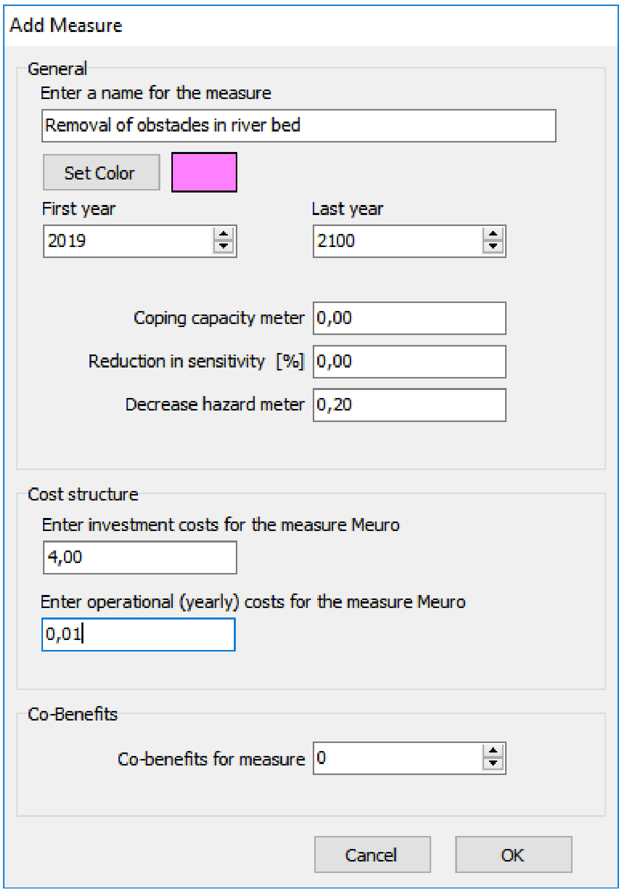
In retention areas, water is stored temporarily during peak discharge. This extra space for river water leads to a decrease of the flood water depth in nearby areas (mainly downstream). In this case it is possible to find enough retention areas to decrease the hazardous water depth with 0,5 meter. It takes some time to arrange the spatial planning. They can be operational in 2035. The investment costs are 25 million Euro. Yearly maintenance is 0,5 million Euro. Co-benefits are considerable for nature development and expressed with the value 4.



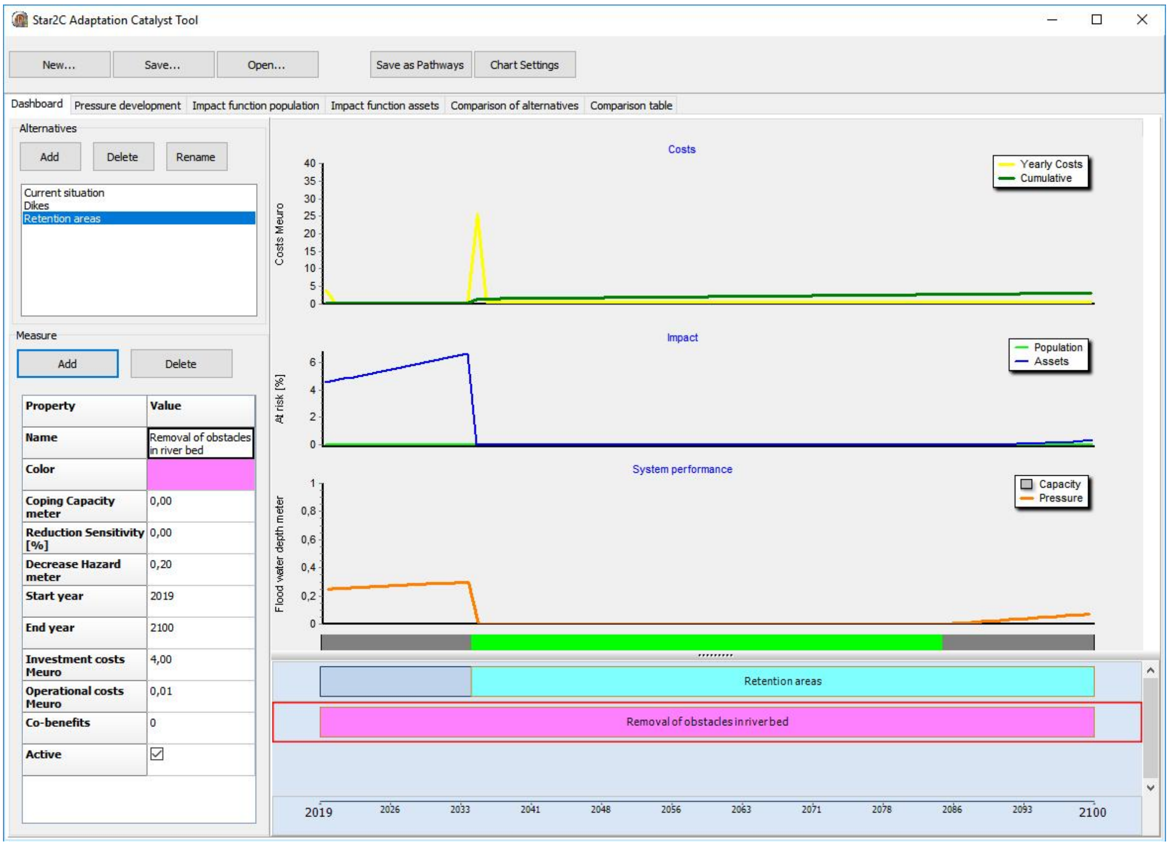
The dashboard shows that this measure does not eliminate the hazard. The impact drops considerably after completion but does not reach zero and rises again afterwards.



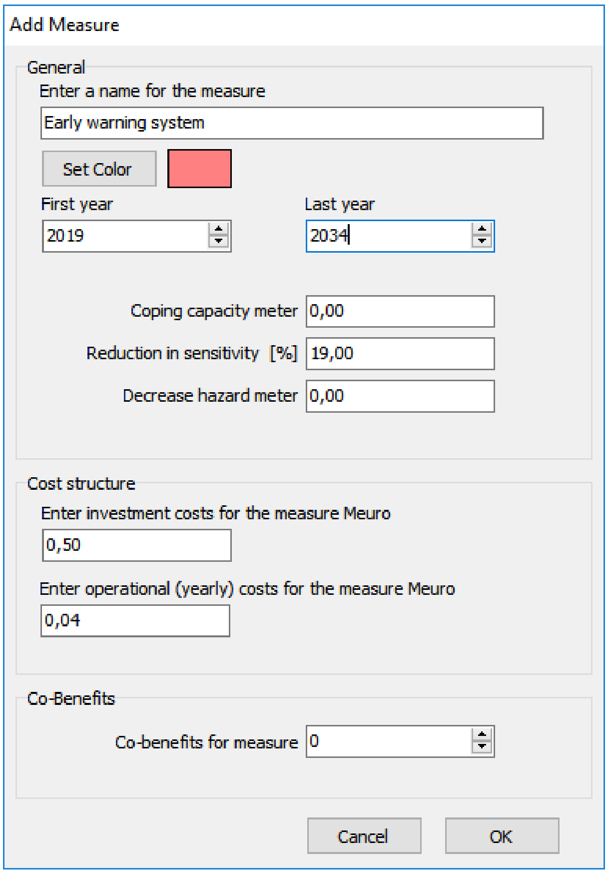
To reduce the hazard further, obstacles in the river bed that obstruct river discharge are removed. This can be done immediately and reduces the water depth by 0,2 meter. Investment costs are 4 million Euro. Operation costs just 0,01 million Euro per year.

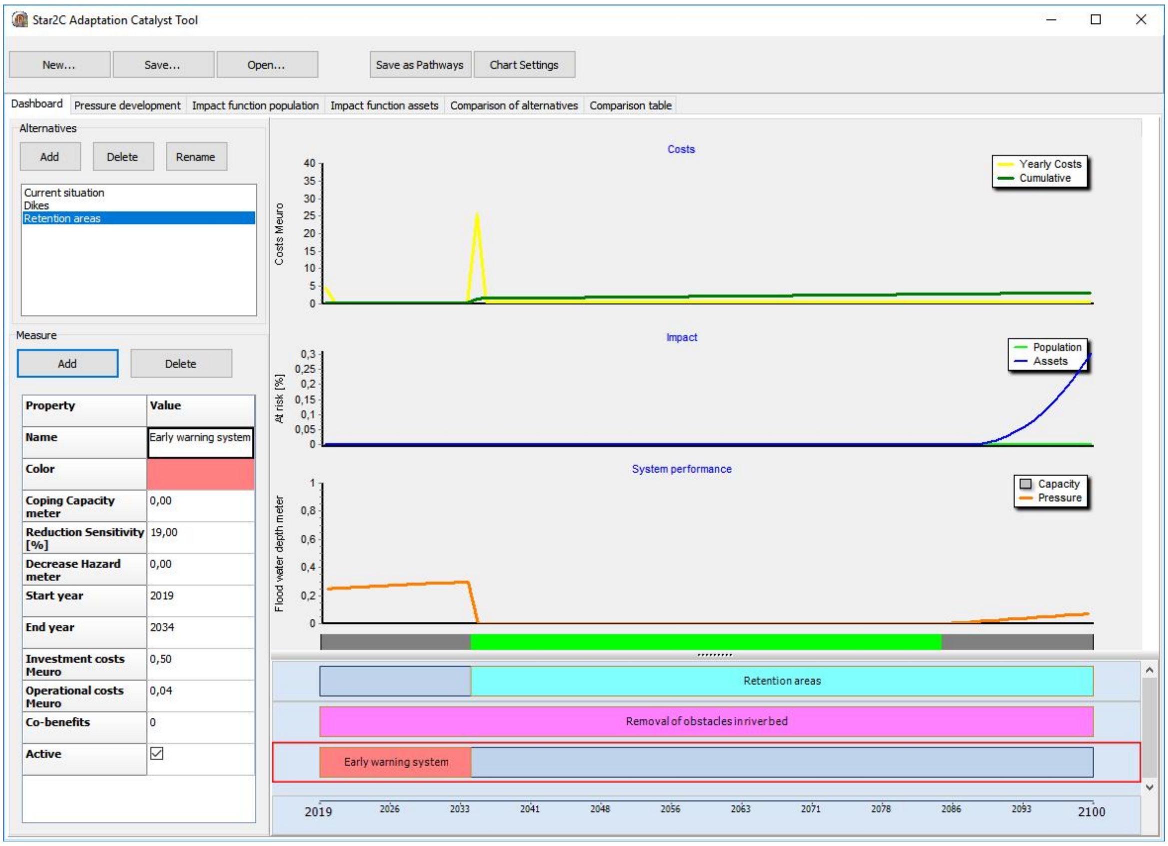


The dashboard shows that adding this measure lowers the mean flood water depth to zero until about 2085.



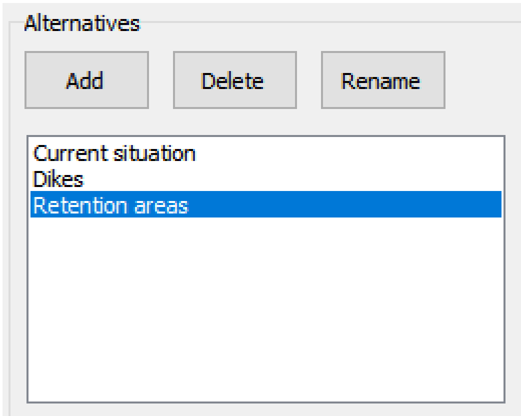
To decrease the impact in the period before the retention areas are operational, a temporarily early warning system is added as a measure. For this measure the same values apply as in the dikes alternative.


Add Measure
General
Enter a name for the measure
Early warning system
Set Color
First year
2019
Last year
2034
Coping capacity meter
0,00
Reduction in sensitivity [%]
19,00
Decrease hazard meter
0,00
Cost structure
Enter investment costs for the measure Meuro
0,50
Enter operational (yearly) costs for the measure Meuro
0,04
Co-Benefits
Co-benefits for measure
0
Cancel
OK


Star2C Adaptation Catalyst Tool
New...
Save...
Open...
Save as Pathways
Chart Settings
Dashboard
Pressure development
Impact function population
Impact function assets
Comparison of alternatives
Comparison table
Alternatives
Add
Delete
Rename
Current situation
Dikes
Retention areas
Measure
Add
Delete
Property
Value
Name
Early warning system
Color
Coping Capacity meter
0,00
Reduction Sensitivity [%]
19,00
Decrease Hazard meter
0,00
Start year
2019
End year
2034
Investment costs Meuro
0,50
Operational costs Meuro
0,04
Co-benefits
0
Active
Costs
Costs Meuro
Yearly Costs
Cumulative
Impact
At risk [%]
Population
Assets
System performance
Flood water depth meter
Capacity
Pressure
Retention areas
Removal of obstacles in riverbed
Early warning system
2019
2100

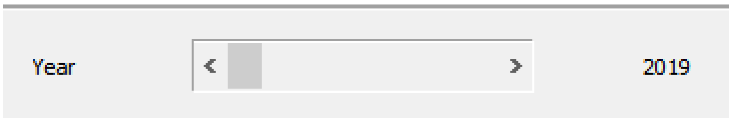
Compare alternatives and measures

Alternatives and measures can be compared by switching between the alternatives in the Dashboard.



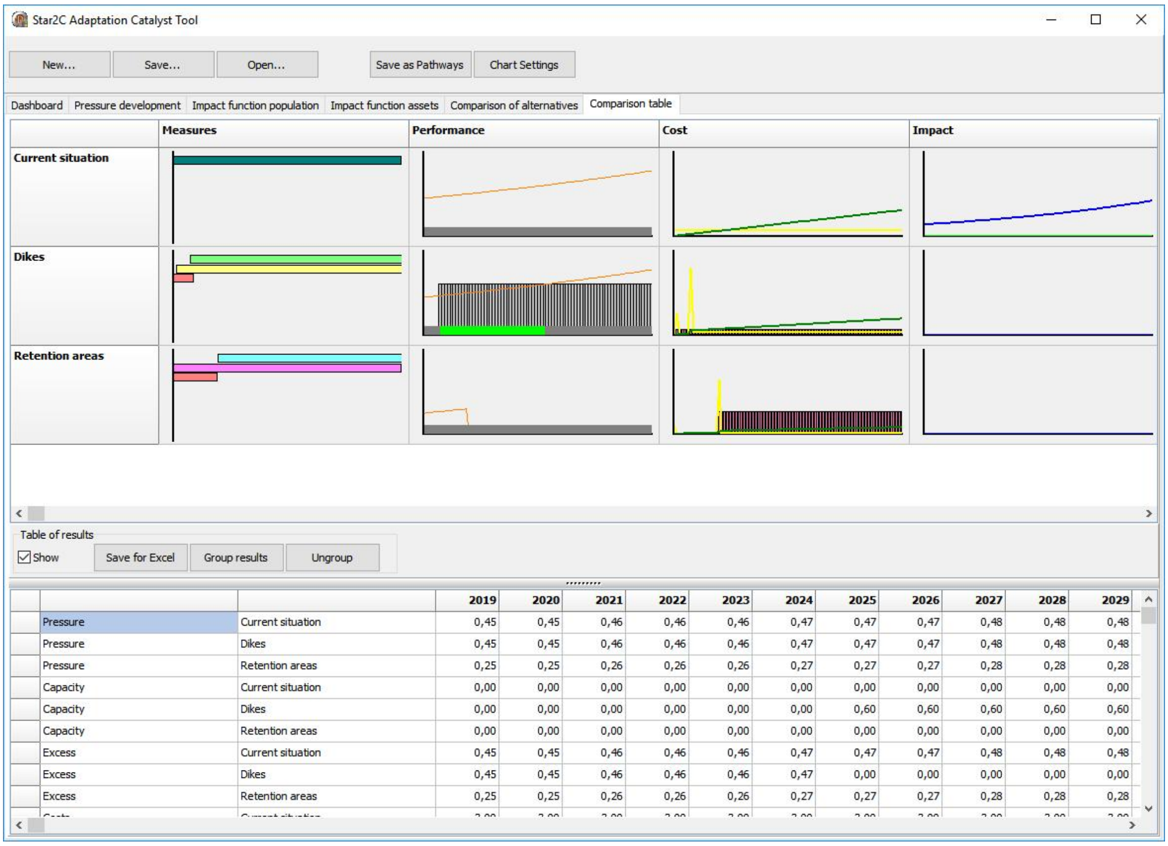
Or by using the ‘Comparison of alternatives’ and ‘Comparison table’ tabs. Alternatives can be compared based on performance (how effective are the measures in adapting to the pressure), on costs (what are the differences in cumulative costs over a certain period) and the expected impact on people and assets.

The Comparison of alternatives tab gives an overview of the performance of the alternatives in certain years. Years can be set by adjusting the slider.



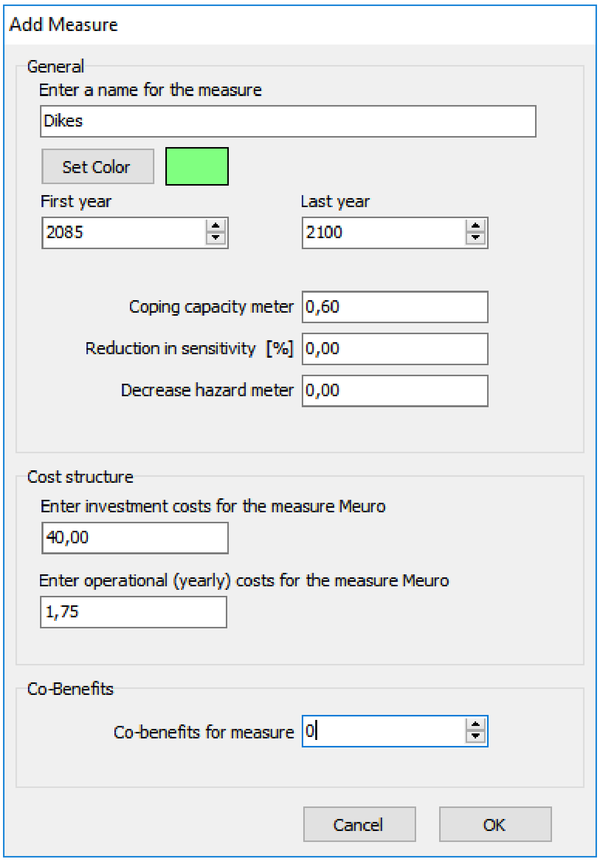
….dashboard voorbeeld laten zien en toelichten

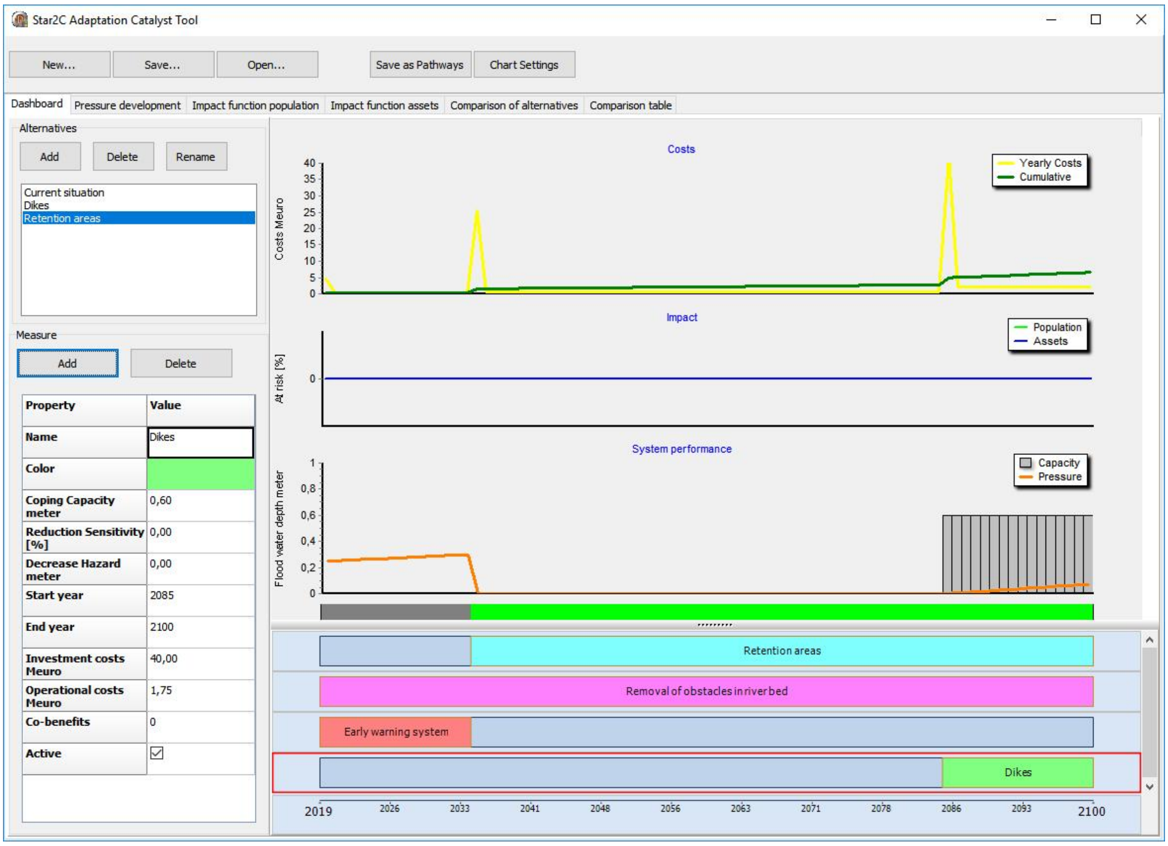
The Comparison table tab provides an indicative overview of all graphs and a complete table of results that contains the values that are visualized in the graphs. This table can be exported to Excel for further calculations (e.g. combining the results with more detailed cost data) or the construction of custom graphs.



In this case, there is already impact in the current situation. The alternatives strive for reducing the current impact and the future impact under climate change, to zero. In the dikes alternative this is managed beyond 2100. In the retention areas alternative, the impact starts to rise with a marginal amount around 2085. When 2085 is chosen as the reference year for the comparison of costs, the cumulative costs of dikes are about 134 million Euros and the cumulative costs of retention areas 56 million Euros. But after 2085 it is likely that added measures are needed in the retention areas alternative, which leads to some added investment costs and operational costs.

Optimize alternatives and measures
To assess the possibilities, dikes are added to retention areas alternative in 2084. This will increase the coping capacity with 0,6 meter. Costs in 2084 are 40 million Euro. Operational costs are 1,75 million Euro.



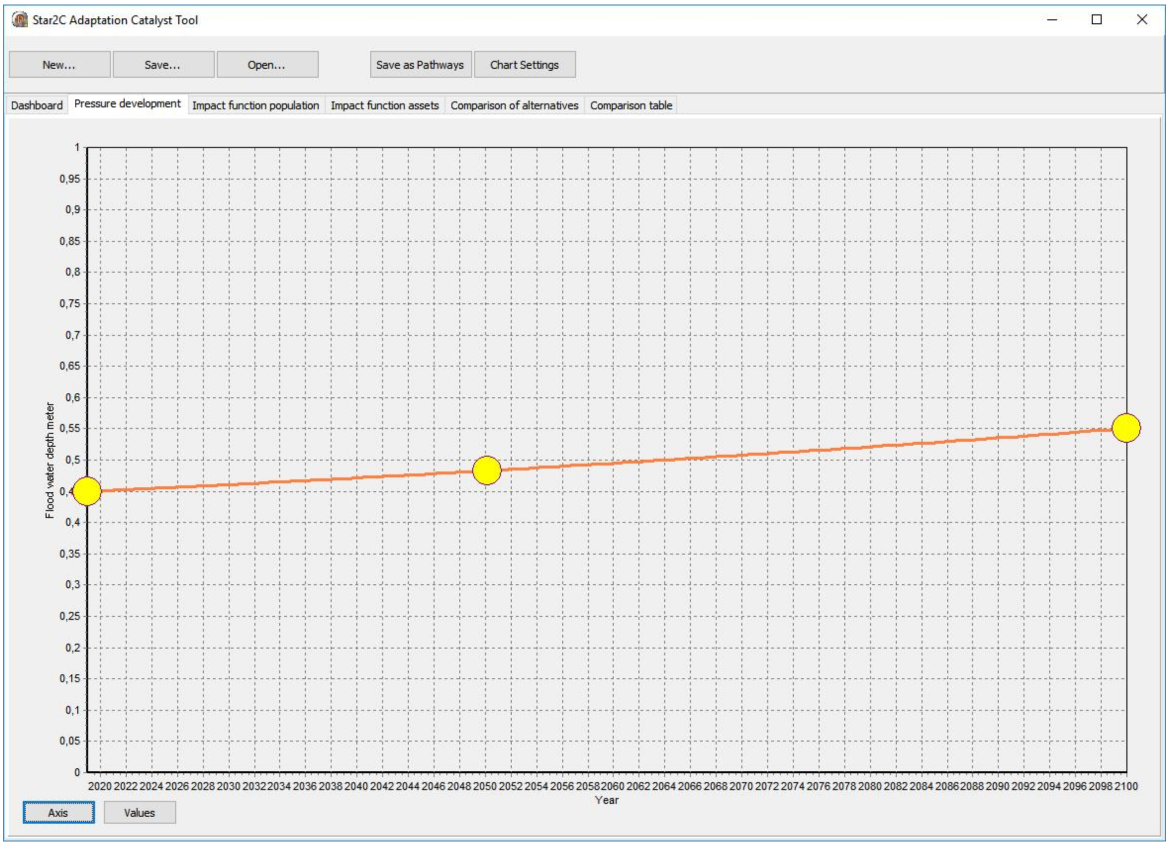


This results in a high adaptive capacity that will last well beyond 2100. In the Comparison table tab the development of the costs can be reviewed in detail. This shows that in 2100 the total costs of the Retention areas alternative is still lower than of the Dikes alternative.

4.2.4 Explore different scenarios

Explore performance under different pressures and/or different impact functions
Changing the curves that represent how the pressure develops over the years and what percentage of people or assets is affected by excess pressure, can have a big impact on the outcomes. It is useful to explore some scenario to gain insight in the sensitivity of alternatives or measures to other circumstances.

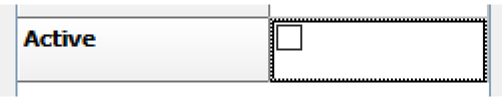
Pressure
The settings that were used in the former paragraph are related to the worst case climate scenario. To test another scenario, the pressure value in 2100, the mean maximum water depth in a 1:1.000 flooding event, is decreased from 0,77 to 0,55 meter.



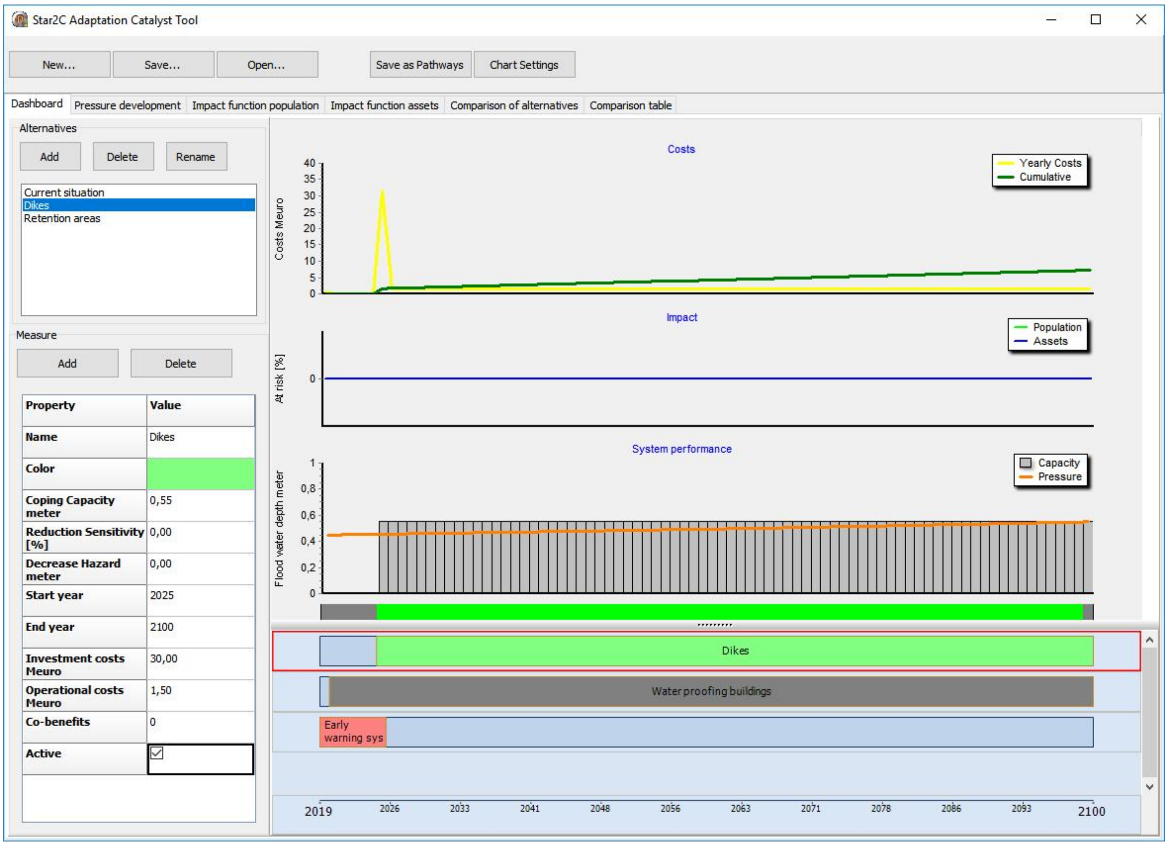
Impact function population and assets
The function of the impact on population is not changed. The criteria for impact remain the same in the future.

Changing settings to a lesser increase of the pressure over time offers the possibility to decrease the adaptive capacity of alternatives and measures, and thereby decrease the costs.

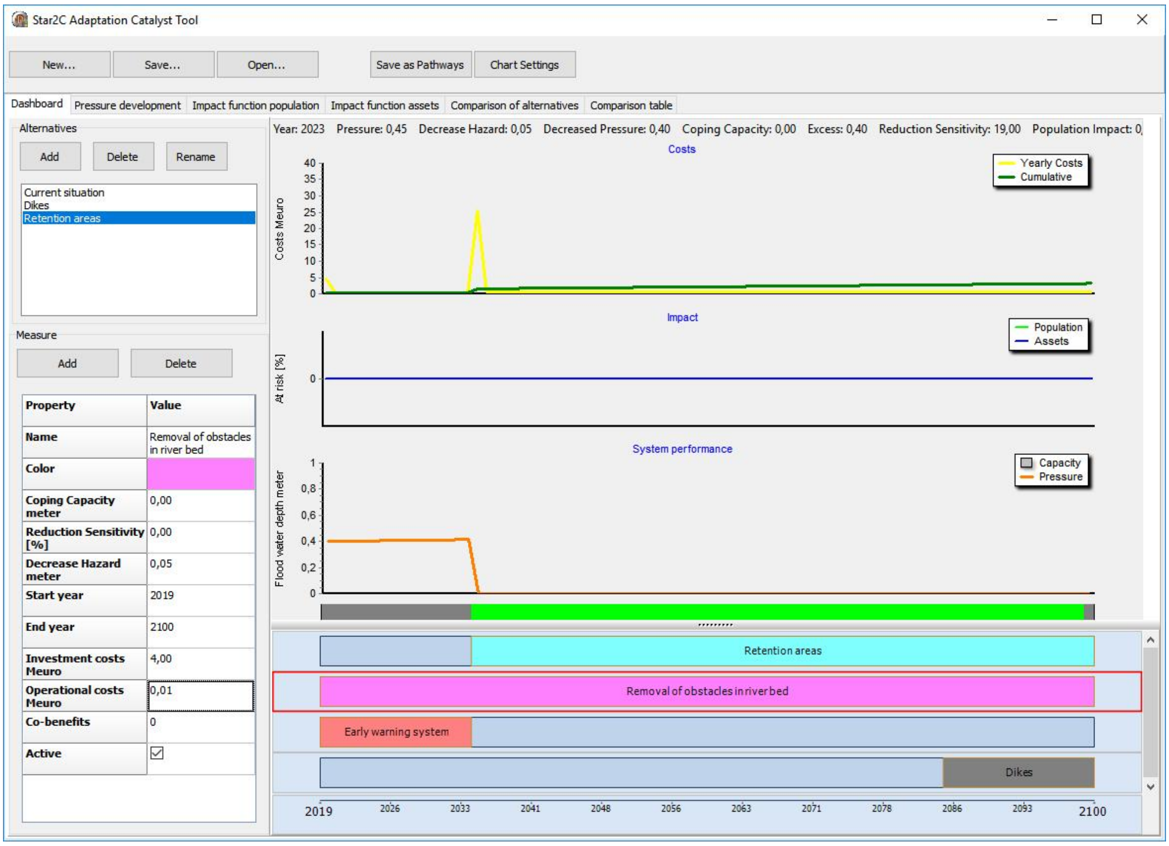
In the dikes alternative, the dike height can be reduced to a coping capacity of 0,55 meter and the water proofing of buildings measure can be discarded. This is done in the dashboard by deactivating this measures.



The early warning system stays in place.

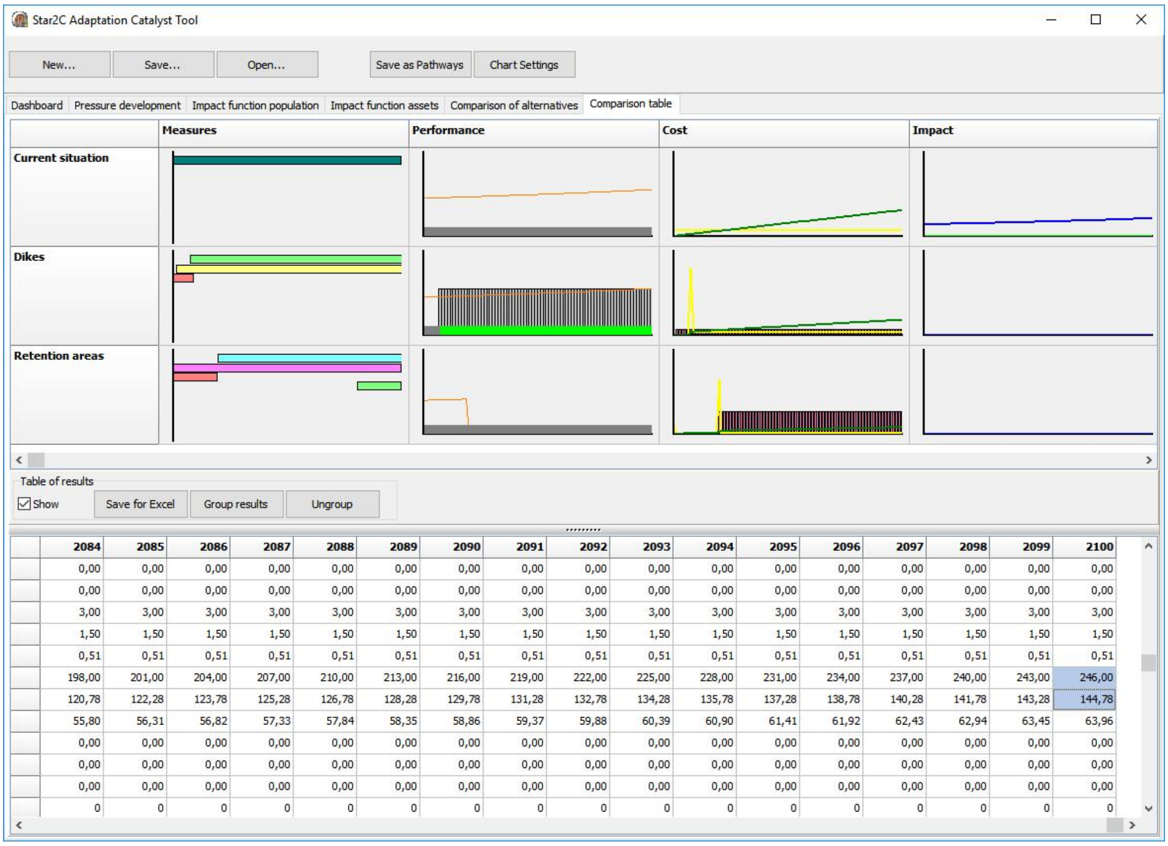


In the retention areas alternative, these areas can decrease the water level (the hazard) with 0,5 meter. This is just not enough to deal with the increase in pressure until 2100. Removal of obstacles adds more than enough adaptive capacity to overcome this. Only one fourth of the original measure is needed to reach the needed adaptive capacity of this alternative. This decreases the hazard with 0,05 meter. The early warning system must stay in place, but the dikes are not needed anymore (deactivated in the dashboard) to keep the impact level at 0.



Compare alternatives and measures

In this scenario with less pressure of the flooding hazard that is caused by climate change, the amount of adaptive capacity that is needed can be reduced considerably. This is reflected in the cumulative costs. In 2100 the cumulative costs of the dikes alternative have risen to 144 million Euros. Although dikes with a lesser height are needed in the scenario, constructing the dikes is still relatively expensive. The costs of the retention areas alternative are much less, about 64 million Euros.



	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00
	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50
	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51
	198,00	201,00	204,00	207,00	210,00	213,00	216,00	219,00	222,00	225,00	228,00	231,00	234,00	237,00	240,00	243,00	246,00
	120,78	122,28	123,78	125,28	126,78	128,28	129,78	131,28	132,78	134,28	135,78	137,28	138,78	140,28	141,78	143,28	144,78
	55,80	56,31	56,82	57,33	57,84	58,35	58,86	59,37	59,88	60,39	60,90	61,41	61,92	62,43	62,94	63,45	63,96
	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

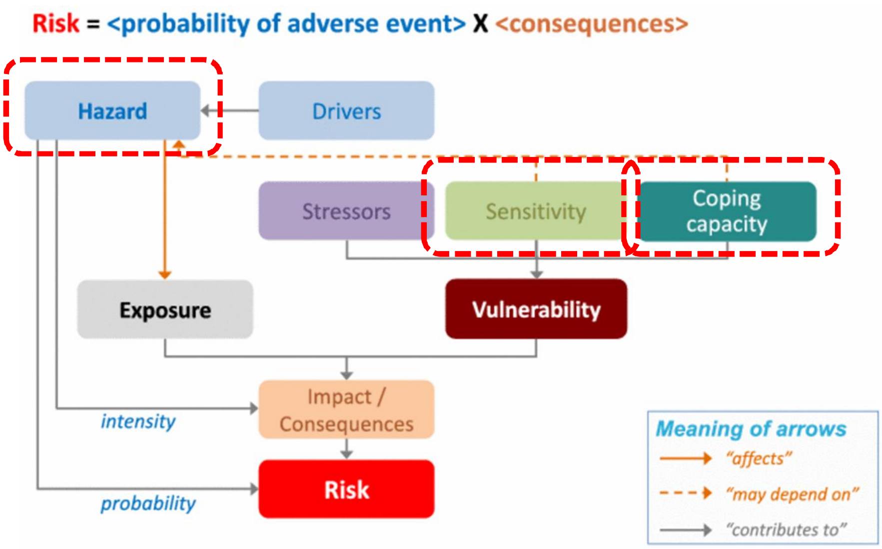
Annex A: Three different adaptive effects of measures

The tool must be able to handle three main types of adaptation measures that work in different ways:

1 measures that cope with the increase of the pressure (the hazard) (e.g. bigger pump)
2 measures that reduce the sensitivity to the pressure (e.g. placing a house on stilts)
3 measures that decrease the pressure, the hazard (e.g. reducing speed of subsidence with water infiltration measures, or river bed widening to reduce water levels).

These 3 types of measures influence the pressure, impact and costs curves in different ways.

The AC functionality follows the outcomes of the EU RESIN project:
http://wiki.resin.itti.com.pl/phase-1/step-1-4-risk-assessment/aspect-1-4-1-determine-exposure-vulnerability-and-risk/



Functionality
In the 'Measures' table, underneath 'Color', give three variables that allow the user to define the effect of the measure:

1 Coping capacity (is already present in current functionality, rename), default value = 0
2 Reduction of sensitivity, default value = 0
3 Decrease of hazard, default value = 0

Type 1

Capacity of measure is compared to pressure directly.
The unit of the capacity is the same as the unit of the pressure.
The impact is calculated based on the fraction-excess curves (with increasing excess, the faction (percentage) of assets and people that are affected, rises):

```
If
  Type3Pressure > 0
then
  Pressure = Type3Pressure

Excess = Pressure – Ccap

Impact [%] = (Fraction @ Excess) * 100%
```

Type 2

A reduction of the sensitivity can be represented by a certain increase of the coping capacity of a certain fraction of assets/people.
The user must define Values for the variables 'Coping capacity' (Ccap) and 'Reduction of sensitivity' (Sred [%]).

Coping capacity is defined in the unit of the pressure. If the sensitivity is completely resolved for any amount of pressure, Ccap is set to maximum amount of pressure by the user.
Reduction of sensitivity is defined as the percentage of the present assets/people for which the coping capacity is enlarged. This is only useful if the Ccap of this percentage of assets/people is bigger than the pressure or excess pressure if other measures are also active in this year.

The effect is reflected in a reduction of the impact on assets and population (the curves in the Main tab). So for each year in which the measure is present, the Impact has to be recalculated, using the Ccap and Sred:

```
If
  Type3Pressure > 0
then
  Pressure = Type3Pressure

Excess = Pressure – Summarized Coping capacity of all Type 1 measures in this year

Type2Excess = Excess – Ccap

if
  Type2Excess <= 0
then
  Impact [%] = ((Fraction @ Excess) * 100%) – Sred [%]
else
  Impact [%] = ((Fraction @ Excess) * 100%)
```

Note1: Ideally you would use separate factors for assets and people.

Note2: Calculation of impact could be done bit more advanced, but for sake of clarity, if the reduction of sensitivity is not coping with the pressure, we do not include it in the impact calculation.

Type 3

Type 3 influences the pressure directly, which means that in the AC, the pressure curve has to be lowered when this measure is applied.
The user defines the Value for the amount (floating point number) of pressure/hazard decrease that this measure delivers (Hdecr), in the Measures table, in the same unit as the unit of the pressure.
From the starting year of the measure, the curve of the pressure drops accordingly, and rises again to the original value (which is defined by the curve in the Pressure tab) after the end-year of the measure.

Type3Pressure = Pressure – (Summarized Hdecr of all Type3 measures in this year)

Excess = Type3Pressure – Summarized Coping capacity of Type 1 measures in this year

Impact [%] = (Fraction @ Excess) * 100%

So, the Type3Pressure value is used to draw the Pressure curve in the Main tab in the years that the measure is active.

The shape of the pressure curve is not altered. This can only be done by altering the shape of the curve in the screen of the 'Pressure' tab.

Combination type

There are measures that do two or three things. In such a case, a user can define Values for two or three variables.

Annex B: Example settings in AC for different climate effects

This annex offers example settings that can be used in the Adaptation Catalyst to express pressure of climate change and the adaptive capacities of different types of measures. This adaptive capacity can be expressed in the AC in three ways:

1. Increase of capacity to cope with pressure
2. Reduction of the sensitivity of people and assets to the pressure
3. Reduction of the pressure.

In Figure 0.1 this is illustrated for a situation with an embanked (levees) river flood plain.

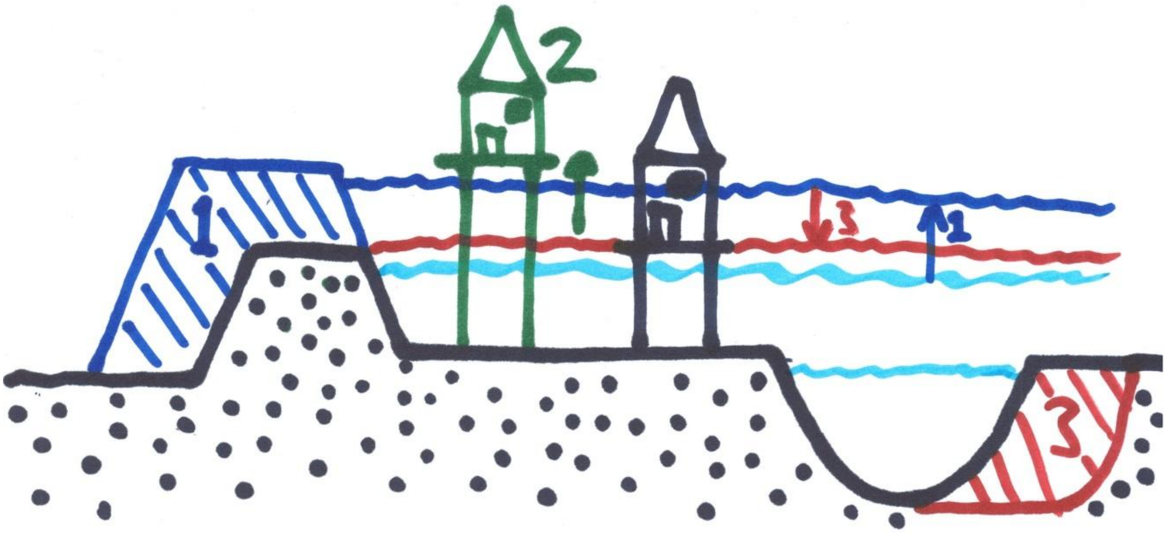


Figure 0.1 The three different types of adaptation measures, illustrated for the rise of the river flood level in embanked areas. Black lines portray the current situation. Light blue lines depict the current low and high river levels. Measure 1: increase coping capacity for increased flood water levels by raising the height and strength of the levees. Measure 2: decrease sensitivity of buildings in the flood plain by raising the building height. Measure 3: decreasing the flood level (and therefor decreasing the pressure) by widening the river bed.

A key point to consider when using the AC is how the pressure and adaptive capacity of measures can be compared with each other directly.

The following tables describe examples of how the pressure can be expressed for different adaptation issues. The adaptive effect of the example measures that are given can be expressed in the same unit as the pressure. Possible measures are by no means limited to the given examples. A letter code indicates in which way these measures can deal with the pressure. Some measures work in more than one way. Possibilities are not limited to what is described in the tables.

(c) = increase of capacity to cope with pressure
(s) = reduction of the sensitivity of people and assets to the pressure
(p) = reduction of the pressure.

An overview of measures can be found here: http://www.climateapp.nl/

Adapt to: pluvial (rain) flooding		
Expression of pressure	**Example unit**	**Example measures that fit with expression of pressure**
Increase of water level in public space at certain frequency	Meter	Increase building ground level height (c, s) Wet proofing houses (s) Lower street profile (c, s) Rainwater retention ponds and squares (p) Water storage below buildings (p) Green roofs (p)
Increase of rainfall intensity at certain frequency (e.g. 1/10 year)	Mm/hour	Increase discharge capacity of sewer (c) Improve soil infiltration capacity (c) Drainage below surface level (c) Pumps (c) Water storage below buildings and street (c) Deep groundwater infiltration (c)

Adapt to: fluvial (river) flooding		
Expression of pressure	**Example unit**	**Example measures that fit with expression of pressure**
Increase of flood level	Meter	Amphibious (floating) buildings (s) Artificial islands (c) Increasing river bed volume (p) Dikes (c) Constructions on piles (s) Water retention areas (p) River bypass (p) Remove obstacles (p) Temporary flood barriers (c)
Increase of flooded area	Hectare	Increasing river bed volume (p) Dikes (p) Compartments (dike rings) (p) River bypass (p) Remove obstacles (p) Increase catchment water retention (p) Early warning system (s) Relocation of buildings/functions (s)

Adapt to: coastal flooding		
Expression of pressure	**Example unit**	**Example measures that fit with expression of pressure**
Sea level rise (increase of storm surge level)	Meter	Storm surge barriers (c) Increase wetlands (e.g. mangroves) (c) Dikes and dunes (c) Constructions on piles (s) Temporary flood barriers (c) Relocation of buildings/functions (s) Warning and evacuation systems (s) Artificial surface level increase (c)

Adapt to: heat		
Expression of pressure	**Example unit**	**Example measures that fit with expression of pressure**
Increase of outside/inside temperature	0C	Adding green in landscape (p) Adjusting behavior vulnerable people (c, s) Adjusting buildings (p) Cooling with water elements (p) Air-conditioning (c, p) Thermal insulation (p)

Adapt to: drought		
Expression of pressure	**Example unit**	**Example measures that fit with expression of pressure**
Decrease in regular fresh water supply (e.g. river, rain fed basin)	m3/second	Increase storage capacity for dry periods (c) Limit water use (c) Only distribute to vital functions (c) Increase pump capacity (p) Increase waterway capacity (p) Alternative water resources (p) Drought tolerant agriculture (s)
Increase of salinization	> Cl concentration mg/l	Block saltwater intrusion in estuaries (c) Relocate water intake points upstream (c) Salt tolerant agriculture (s) Flush irrigation waterways with fresh water (p)
Increase of precipitation deficit: decrease of groundwater level	Meter	Active groundwater level management (p) Improve soil infiltration capacity(p) Drought resistant plants (s)

Increase of precipitation deficit: decrease of soil moisture content	pF	Irrigation (p) Drought resistant plants (s)
Subsidence: increase of cumulative subsidence	Meter	Periodic raise of surface level (c) Increase maintenance (c) Light weight foundations (p, c) Subsidence tolerant constructions (s) Raising groundwater level (p) Limit groundwater extraction (p)