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van de Ven, Frans H M; van de Ven, Frans H M; Snep, Robbert P H; Koole, Stijn; Brolsma, Reinder; van der Brugge, Rutger; Spijker, Joop; Vergroesen, Toine

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Adaptation Planning Support Toolbox: measurable performance information based tools for co-creation of resilient, ecosystem-based urban plans with urban designers, decision-makers and stakeholders

Dr. Frans H.M. van de Ven[1, 4]
Dr. Robbert Snep[2]
Stijn Koole MSc.[3]
Dr. Reinder Brolsma[1]
Dr. Rutger van der Brugge[1]
Joop Spijker MSc. [2]
Toine Vergroesen MSc.[1]

1. Deltares, P.O. Box 85467, 3508 AL Utrecht, the Netherlands
2. Alterra Wageningen University & Research Centre, P.O. Box 47, 6700 Wageningen, the Netherlands
3. Bosch Slabbers landscape architects, 1e Sweelinckstraat 30, 2517 GD Den Haag, the Netherlands
4. Delft University of Technology,Dept. Water Management, Stevinweg 1, 2628 CN Delft, the Netherlands

Corresponding author: frans.vandeven@deltares.nl

Bio of authors:

Dr. Frans H.M. van de Ven is team leader urban land & water management at Deltares, the Netherlands' institute for delta technology, and associate professor urban water management at the Faculty of Civil Engineering and Geosciences of Delft University of Technology.

Dr. Robbert Snep is senior researcher on green cities at Alterra - Wageningen University & Research centre in the Netherlands. With a background in ecology, he specialized in applied research on optimizing urban ecosystem performance for conservation, climate adaptation and health purposes.

Stijn Koole MSc. is senior landscape architect and partner at Bosch Slabbers landscape architecture and urban planning. He has extensive experience with climate adaptation and design in the Netherlands, New Orleans, New York, Ho Chi Minh City and Brisbane.

Dr. Reinder Brolsma is senior researcher in urban water management at Deltares. With his background in physical geography and eco-hydrology he pairs hydrological expertise with tool development for sustainable urban development and climate resilience.

Dr. Rutger van der Brugge works with Deltares and is expert in the field of transition processes and adaptive water management. He is interested in the governance issues of complex problems related to climate adaptation and sustainability.

Joop Spijker MSc. is working at Alterra - Wageningen University & Research centre in the Netherlands as senior researcher on urban green management. Important issues are nature & health, nature & water management, biomass from urban green and benchmarking management urban green.

Toine Vergroesen MSc. is senior researcher hydrology at Deltares and is modeller of urban water system models under influence of climate change.

Abstract

Currently, most tools, guidelines and benchmarks for urban adaptation raise awareness on climate change impacts, assess the city's vulnerability and/or address the need for adaptation on a policy-level. However, tools that have the ability to implement adaptation solutions in the actual urban planning and design practice seem to be missing. We developed and tested the Adaptation Planning Support Toolbox (APST) to fill this gap. This toolbox supports local policymakers, planners, designers and practitioners in defining the program of demands, in setting adaptation targets, in selecting from more than 60 blue, green and grey adaptation measures and with informed co-creation of conceptual adaptation plans. The APST provides quantitative, evidence-based performance information on (cost)effectiveness of adaptation measures regarding climate resilience and co-benefits. The APST can be used design workshops, to feed dialogues among stakeholders on where and how which ecosystem-based adaptation measures can be applied. Applications of the AST in various settings and context in cities on different continents have illustrated the added value of the toolbox in bringing policy and practice together with help of science. With more and more cities worldwide that will make the step from policymaking to actual adaptation-inclusive urban (re)development practice we foresee a growing demand for such tools.

Keywords:

Urban climate adaptation, collaborative planning, green infrastructure, ecosystem-based adaptation, planning support system, performance indicators

Highlights:

- Tools to support collaborative climate resilient urban planning are so far lacking.
- New: Adaptation Planning Support Toolbox (APST) with >60 blue, green and grey adaptation measures.
- Evidence-based, quantitative performance information is appreciated by APST users.
- Climate-proofing workshops in several countries showed APST as effective support tool.
- APST-like tools essential for actual adaptation-inclusive urban (re)development practice.

1. Introduction

1.1. Adaptation of urban areas

The need for adaptation of urban areas to changing climatic conditions is widely recognized [Deltaprogramma, 2015; IPCC, 2007, 2012; PROVIA, 2013]. Flooding, drought, heat stress and related problems with water quality, water supply and land subsidence, aggravated by the UHI effect, are increasing hazards threatening the liveability of our urban areas as well as our social and economic urban systems [Albers et al., 2015; Jha et al., 2012; Rovers et al., 2014; World Bank, 2010; Zevenbergen et al., 2010]. Risks are further increased by on-going urbanization[Nicholls et al., 2007; UN DESA, 2014] and by intensification of urban land use; the invested capital and the asset value of buildings, infrastructure and industrial facilities has increased drastically over the past decades [Kind, 2013]. Although the need for adapting our urban environments is clear, in practice adaption is difficult. Opportunities for adaptation are often limited to new development projects, to large infrastructural renovation and renewal projects or to initiatives from individual residents [Van der Brugge and De Graaf, 2010].

Adaptation requires the construction of structural or “hard” adaptation measures [Hallegatte, 2009; Pelling, 2011]. Such measures are physical or technological interventions, constructed facilities that require space and therefore are subject of spatial planning and design [Taylor and Wong, 2002]. This article will focus on the right design of structural adaptation measures, as embedded in a planning process that leads to a decision on a spatial adaptation plan.

The pallet of adaptation measures has extended dramatically over the past decades. Earlier, Sustainable Urban Drainage Systems (SUDS)[CIRIA, 1998; Svenske Vatten- och Aflopsverksföreningen 1983] and Water Sensitive Urban Design(WSUD) for urban drainage [Brown et al., 2008; Engineers Australia 2006], nowadays also known as green or blue-green infrastructure, were introduced. Maksimovic et al. [2014] recently argue that a new concept of Multiple-Use Water Services (MUS) is emerging. MUS solutions enhance the synergy of urban water (blue) infrastructure with green assets and ecosystem services, are economically viable and climate (environmental) adaptive.

Ecosystem-based Adaptation (EbA) is at the heart of this MUS development. EbA- measures integrate the use of biodiversity and ecosystem services into an overall strategy for helping people adapt to climate change [Munroe et al. 2012]. In addition to flood control, drought mitigation and heat stress reduction they provide e.g. aesthetic quality, recreational and restorative capacity and health benefits [Opdam et al., 2009; Van den Berg et al., 2007; Van den Berg et al., 2015]. This article shows how planning ‘blue-green’ EbA measures is used to advance climate resiliency, while maximizing their co-benefits.

1.2. Adaptation planning

Urban planning exists of a series of more or less consecutive phases starting from system analysis and program development (initiative phase), via conceptual, preliminary and final design (design phase) up to implementation (Figure 1). The process ends with a final decision on an adaptation or (re)development plan. Although shown as a straightforward, stepwise process in theory, the process in practice often reiterates to an earlier stage to investigate alternative adaptation pathways.

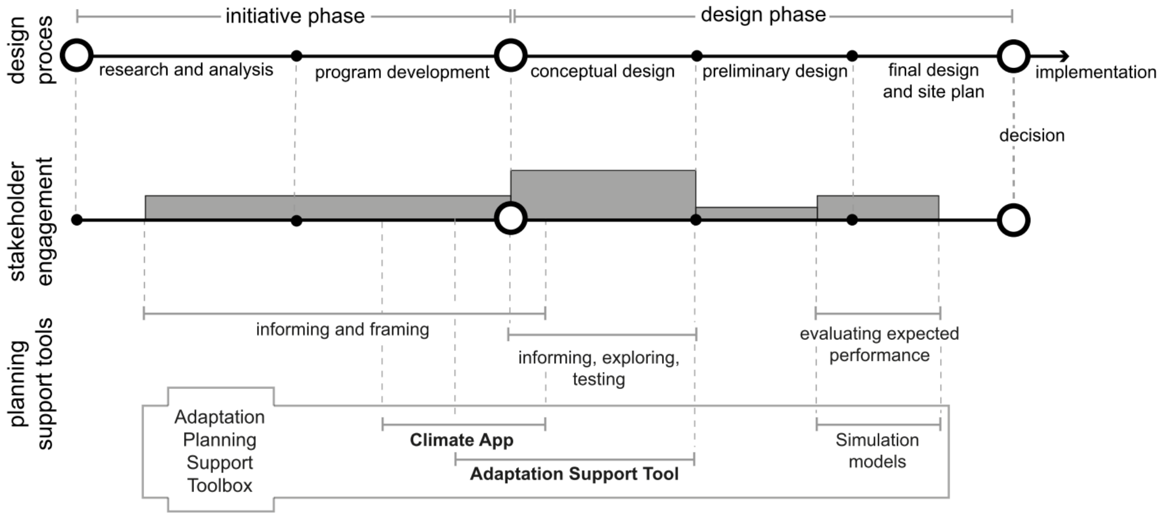

Figure 1 *Adaptation planning process, stakeholder engagement and planning support tools. Both tools (**bold**) in the Adaptation Planning Support Toolbox will be discussed in this article.*

Many guidelines on climate resilient urban planning provide procedures for hazard, exposure and vulnerability analysis and an overview of potential solutions and/or best practices [Challenge for Sustainability; Climate-ADAPT; Deltaprogramma N&H, 2014; EPA; Great Lakes and St. Lawrence Cities Initiative; PROVIA, 2013]. They however lack guidance where it comes to the selection of appropriate packages of adaptation measures during the initiative and design phases [Voskamp and Van de Ven, 2015]. For these phases tools seems unavailable to support stakeholders to make hard choices which adaptation measures are attractive and effective for the project area [Bours et al., 2014; PROVIA, 2013];this while complex simulation models to evaluate the expected hydraulic and hydrological performance of the final plan are readily available [Lerer et al., 2015]

In the initiative phase, urban planners are often in the lead of the process. Eliasson [2000] showed that climatology so far has a low impact on the planning process; urban planners' use of climatic information is unsystematic as the urban climatologists fail to provide them with good arguments, suitable methods and tools. This underlines the need for a planning support system that bridges the gap between urban planners and engineers; she makes a plea for a "communicative approach" to the planning process.

1.3. Adaptation support tools for collaborative planning

Involvement of local stakeholders, land & water engineers, experts from other disciplines and decision-makers is considered essential in particular in planning reconstruction of existing urban areas. Each of them not only has different interests, agendas and roles in the process. They differ in their sense of urgency of the problem, their approach to the problem, their language and knowledge level, and their rationality regarding potential solutions [Van Stigt et al., 2015]. Design workshops during the initiative phase are meant to get to know each other, to share each other's knowledge and understanding of the problems and to collectively identify interesting adaptation solutions.

Question is how to support the planners, stakeholders and decision-makers in this analysis – dialogue- design-engineering process with knowledge and information, in order to get a converging learning process that leads to a final positive decision on an adaptation plan? Such planning support tools should raise awareness, present the broad range of adaptation options, let participants explore the impact of different design choices on the climate resiliency of their project area [Pelzer et al. 2013] and maximize the co-benefits of adaptation measures.

Goal of our study was to develop a toolbox that supports the incorporation of climate adaptation in the actual planning and design practice in cities. This Adaptation Planning Support Toolbox was developed to provide urban planners, landscape architects, civil engineers and local stakeholders and decision makers with quantified, evidence-based information on the climate resilience of their ideas in early phases of the planning process and to facilitate decision-making during conceptual design workshops. In design workshops the toolbox should supports them in how to share their knowledge and discuss alternative measures, including location, size, costs and (co)benefits.

2. Toolbox to support adaptation planning

2.1. An integrated 'dialogue – design – engineering' planning process

The Adaptation Planning Support Toolbox was developed to effectively support the collaborative planning process in the phases of program development and/or conceptual planning. See Supplementary Material part A for underlying principles and concepts. Two actual tools were developed to support the 'dialogue – design – engineering' planning process (Figure 1). The Climate Adaptation App (climateApp) informs participants about more than 120 potential adaptation measures and produces a long list of relevant measures. The Adaptation Support Tool (AST) guides stakeholders in the next step, the conceptual design. Resulting conceptual plans are input for urban planners and designers, to make detailed preliminary designs.

The climateApp and the AST are both web-based software tools running on touch enabled hardware. This because a touch table facilitates 'reasoning together', is community supportive, empirically based, experimentally oriented and information and knowledge disseminating [Geertman, 2006].

2.2. Climate Adaptation App

The Climate Adaptation App was developed to start the design workshop with overview and pre-ranking of potential measures for all participants (www.climateapp.org or Appstore / Playstore). From different publications [Pötz en Bleuzé, 2012; Van de Ven et al., 2009; Vergroesen et al., 2013] a list of over 120 structural adaptation measures was composed. The app provides information on each measure and ranks measures for potential applicability based on local circumstances and preferences by toggling the different filters (Figure 2).

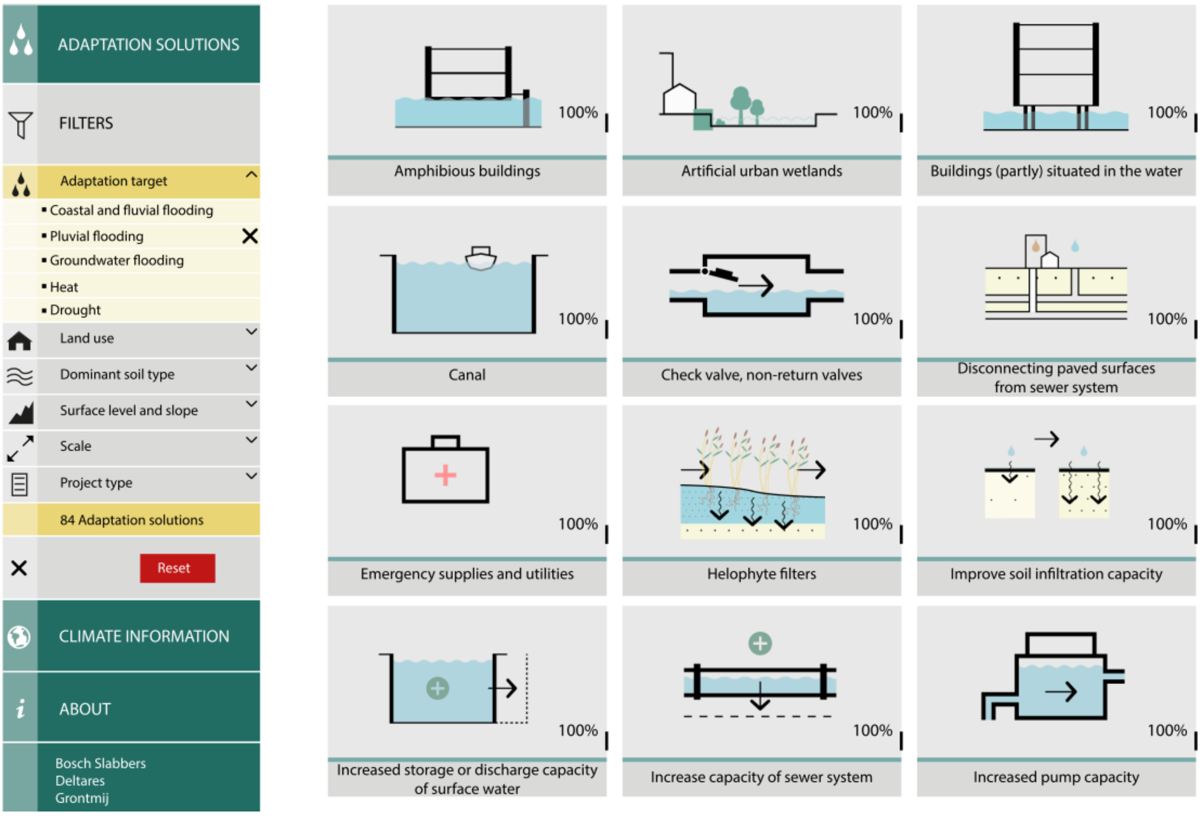

Figure 2 *Screen of the Climate Adaptation App (www.climateapp.org). Adaptation measures are ranked by toggling the filters. More information on a measure is obtained by clicking the tile.*

Design workshop participants go through the list and discuss applicability and attractiveness of potential measures to create a long list for their project area.

2.3. Adaptation Support Tool

The Adaptation Support Tool (AST) is a touch-table based platform that design workshop participants may use to select adaptation interventions, situate them in their project area and immediately see an estimate of their effectiveness and costs (Figure 3). The AST consists of a left panel for input, a middle panel for design (map of project area) and a right panel as an "AST dashboard" for output.

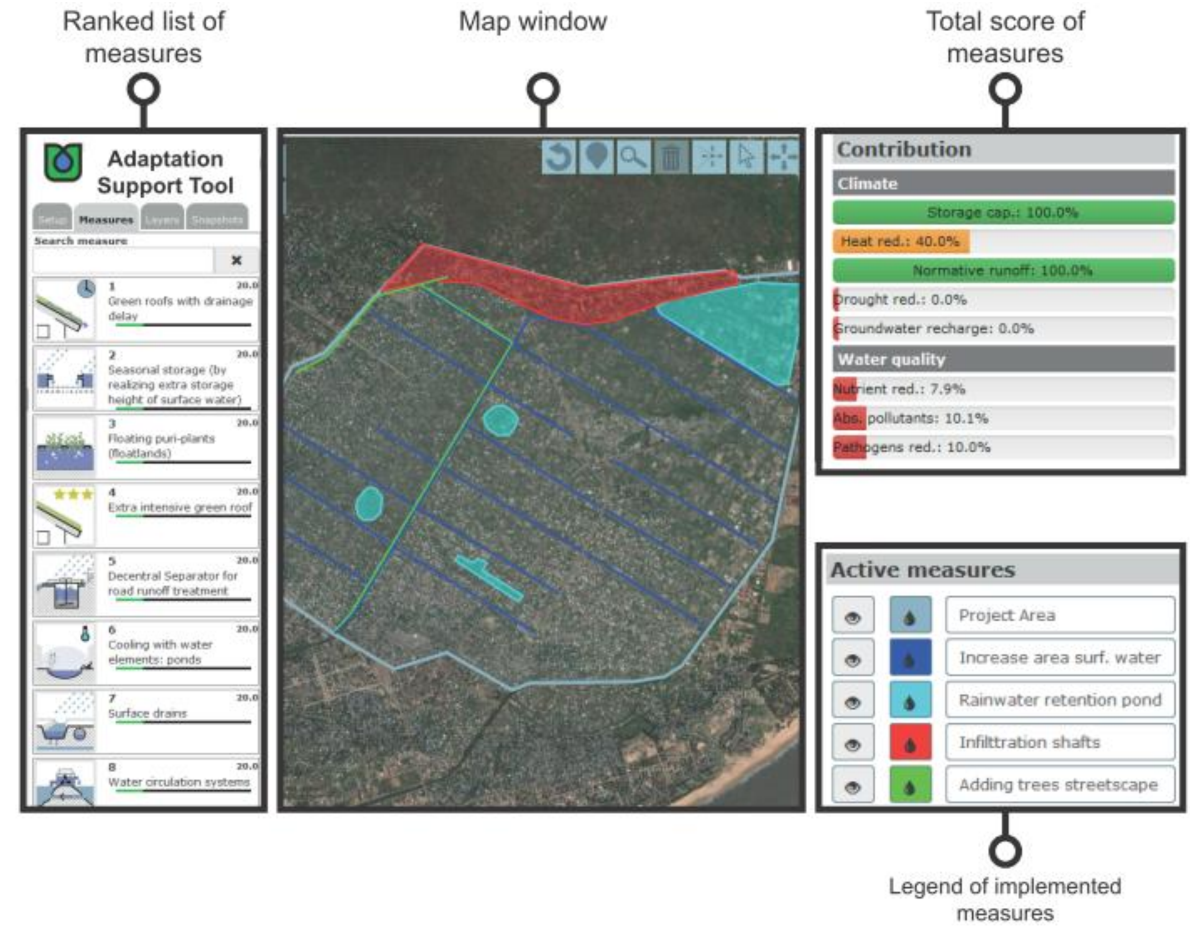

Figure 3. *Screen components of the Adaptation Support Tool. Left on the touch screen is the ranked list of 62 adaptation measures. Selected measures are planned in the project area (middle). At the right side the AST dashboard, showing the resilient performance of the total package of measures and of each active measure. Shown is the application in of the AST in Beira, Mozambique.*

The current AST version includes a long list 62 blue, green and grey adaptation measures for reduction of pluvial flooding, drought and heat stress (see supplementary material C), a selection assistant for ranking their applicability and an assessment tool to estimate the effectiveness of applied measures. The left panel shows a ranked list of adaptation interventions. The long list of measures has been composed from multiple inventories found in literature. The selection of measures was based on criteria that differ for blue-green and for grey adaptation interventions. As many blue-green interventions were included that the authors and project partners are aware of from both literature and practice. We however selected traditional/grey solutions in such a way that a comparison between traditional and blue green solutions can be made when planning alternative solutions and because traditional interventions can enhance the effectiveness of blue-green interventions. Based on local common practice additional interventions can be added. Ranking of the measures is determined on characteristics of the area and adaptation targets [Voskamp and Van de Ven, 2015]. These targets differentiate between threshold capacity for damage prevention and coping capacity for damage minimization in case of a failing protection system [De Graaf et al., 2007].

In the central panel different map layers can be shown. Default a Google Earth and OpenStreetMap layer are provided, with layers like surface elevation, land ownership, flood depth, heat stress maps or future land use as additional. Design workshop participants can now select a measure from the list left and draw it in the project area on a map layer, on the location where they think that it would provide added value. For example, the user can apply a green roof on a large flat roof, install permeable pavement on sidewalks and artificial wetlands near the outlet of a tributary drain. Next, the tool requests the water storage depth of the measure and the additional contributing inflow area.

On the basis of this input, the AST estimates a number of performance indicators, e.g. storage capacity, normative runoff, heat stress reduction, water quality effects, costs and additional benefits. These performance estimates are shown on the right panel. Under the Details tab (not shown) the contribution of each proposed measure to the adaptation targets is given in combination with the estimated costs for realization and maintenance. Users can also switch to the Overview tab of the right panel, as shown in Figure 3, to get a summary of the measures and their total effectiveness in relation to the adaptation assignment.

Results of a session can be saved as snapshots and re-opened at a later moment. This way alternative plans can be created and compared. The tool is web-based and can run both on a webserver and standalone.

2.4. Adaptation performance indicators

The current selection of performance indicators was based on the demand of participants of the design workshops and the role of water as the key to a climate resilient urban environment. The indicators are listed and explained extensively in the Supplementary Material part B, including underlying scientific evidence. The quantified performance indicators include estimated changes of physical characteristics that are relevant for damage reduction, resilience, public health and feasibility.

- Prevention of flooding due to extreme rainfall requires effective storage (retention) of water as well as peak flow reduction. Created storage volume is shown, as this has to comply with the target volume that our water managers set to reduce pluvial flood risk. The normative runoff frequency allows for estimation of flood risk reduction in terms of a reduction in frequency of a certain peak flow. Estimates of these flood prevention indicators are based on the result of simulation of the effect of a specific adaptation measure, using long time series of rainfall and evaporation – 30 years or more - , a climate change scenario, a multi-reservoir rainfall-runoff water balance simulation model, a theoretical design of the intervention and extreme value analysis to quantify changes in effective storage capacity and peak flow reduction. Parameters characterising the hydrological performance of the specific adaptation measures were taken from experimental results reported in the international scientific literature.
- Drought control requires groundwater recharge information and inter-seasonal storage of water, in particular in areas prone to land subsidence or a lack of replenishment due to soil sealing. On the other hand, in case of very shallow groundwater tables high recharge rates would lead to the need for subsurface drains. Estimated groundwater recharge also results from output of the multi-reservoir simulation model and a theoretical design of the intervention. Average annual recharge change is calculated as a performance indicator.
- Heat stress reduction is achieved by provision of shade and evaporative cooling from vegetation and water surfaces; though, to that end vegetation has to have enough water available, which is related to groundwater recharge. Heat stress reduction is based on the reported observed cooling effect of blue-green infrastructure in Dutch urban areas and scaling based on the dimensions of the measure.
- The quality of the water is essential for the functions and services it can provide. To evaluate potential functionality water quality improvement of the blue, green and grey adaptation measures is expressed by three indicators: nutrient reduction, absorbed pollutants reduction and pathogen reduction. These water quality performance indicators are determined as a pollution reduction factors based on recorded effectiveness of treatment processes in a facility and scaling based on the dimensions of the measure. Nature based treatment processes included in the pollution reduction factor include natural degradation, settling and soil filtration. For intensive green roofs fertilization was included as a negative pollution reduction factor for nutrients.

- Average costs of construction and costs of management and maintenance are estimated for each adaptation measure based on unit prices on the Netherland's market.

The purpose of the AST is to provide estimates on the effectiveness and costs of adaptation interventions in the early planning phase of urban (re)development projects, in order to meet adaptation targets. Such targets can be met by different packages of measures. No framework or guidelines are provided for the selection specific adaptation measures; the AST allows for any strategy to reduce its vulnerability [De Graaf et al., 2007]. The actual effectiveness and costs will depend on the implementation which is determined by exact local physical conditions, and specific wishes and ambitions of the stakeholders.

3. AST applications

In the period 2014-2015 the Adaptation Planning Support Toolbox has been used in adaptation processes in different cities (Table 1). Being both AST developers and participant, we learned valuable lessons concerning the optimal use of the Toolbox for local adaptation process. Two examples are briefly addressed here.

Beira, Mozambique

The city of Beira (Mozambique) frequently floods by heavy rain, having serious health and economic impacts for the 0.5 million residents. Blue-green adaptation measures may increase water retention capacity and will improve the liveability. Discussing adaptation strategies with local Beira stakeholders in a workshop setting has been done based on the following steps [Picketts et al. 2012]:

Building capacity

Municipal civil servants, representatives of the Chota neighbourhood (pilot area), and local university staff (UCM) were briefed by the authors (acting as facilitators) on climate adaptation and the key role the workshop participants have in adaptation planning as experts with important local knowledge.

Identifying local impacts and vulnerabilities

Climate information was distributed before and during the workshop. It included information on hydrology in urbanized delta regions, flooding maps of Beira based on 3D aerial information, historical climate information and future predictions. The maps and explanation provided a good overview of the impacts and vulnerabilities of Chota and surroundings, including underlying mechanisms. For most workshop participants especially the hydrodynamic information was new, enabling them to better identify the causes of flooding and the ways flooding can be prevented.

Table 1 Overview of applications of the Adaptation Planning Support Toolbox.

Area	Project area type and size	Type of project / spatial planning process	Climate challenges	Phase of planning process	Participants	Experiences, Lessons learned
Chota- Beira (Mozambique)	788 ha, district + detail	Redevelopment & development	Flooding	Program formulation	Municipality, citizens, politicians, local university, NGOs	Stakeholder sessions including non-professionals demand a combination of high tech (AST) and low tech process tools
Decoy Brook,London (United Kingdom)	292 ha district + detail	Research	Flooding	Conceptual design	Environment Agency, Borough repres., university	Make plans for both total area and detailed design for specific hot spots
Oaxaca (Mexico)	195 ha district	development &redevelopment	Flooding, drought	Program formulation	State and municipal authorities, citizens, university, NGOs,	AST is a very handy tool as a catalogue of possibilities in district zones with different characteristics.
Utrecht (Netherlands)	49 ha neighbourhood	Redevelopment	Flooding, heat stress	Conceptual design	Municipality, real estate owners, architect; urban water and green experts;	Participants go for urban quality rather than for cost reduction
Dordrecht (Netherlands)	65 ha neighbourhood	Student Climate Resilient Urban Design workshop	Flooding, heat stress	Conceptual design	Students,	AST toolbox is effective training tool
Tilburg (Netherlands)	46 ha, neighbourhood	Research	Flooding, heat stress	Program formulation	Municipality; urban water experts	The AST can also be applied as a quick-scan method to assess if e.g. green roofs have an added value for specific urban areas.

Determining priorities and outlining implementation

The workshop participants defined short and long term targets to prevent frequent and large-scale flooding of their residential areas in the future. The facilitators calculated the overall retention capacity to achieve these goals. The facilitators then explained about the AST: the goal, the lay out of the AST tools, the range of measures and underlying data. Based on local knowledge the participants selected a number of measures that fit local physical conditions and culture: surface water bodies (channels, small lakes, lagoon), multifunctional green (public green fields that can be inundated temporary). Measures demanding high-level construction and maintenance (e.g. green roofs, technical installations) were rejected, not fitting the local possibilities in water management. Locations within the Chota area where measures could be implemented were identified (Fig.3). For each location and accompanying measures the AST calculated water retention capacity and other parameters, based on local meteorological data. By doing so, it became clear for the participants that additional retention nearby Chota was needed, resulting in a proposal for a lagoon development adjacent to Chota. Through field visits the workshop participants together with the municipal board verified whether implementation of the measures (including lagoon) was indeed possible. Most of the recommended interventions were accepted by the municipal council; in one occasion however a land development claim became the topic of discussion, because this development would decrease retention opportunities for the larger area. The mayor of Beira expressed his intention to reject that claim. The total set of measures was further elaborated on a map and – together with the other information – presented in a report [Kalsbeek et al. 2015]. See this report for more details and background information on this case. The Chota adaptation plan as composed by the workshop participants and their facilitators was also welcomed at an international financing meeting in September 2015; it now serves as the outline for detailed design of drainage improvement works.

<u>Utrecht, the Netherlands</u>

In the redevelopment of the Utrecht City Centre - West, there is a need for a more climate resilient, attractive and pleasant accommodation area. Using the AST, stakeholders sketched three alternative plans, selecting different adaptation measures they deemed applicable and effective. Two of these alternatives can be seen in Figure 4. To make the area more attractive and to reduce the heat stress emphasis was put on greening the area, both at street level and by creating green roofs and urban agriculture on the roofs of the large exhibition halls in the area. Stormwater retention capacity was also created by installing rain tanks, a water square and application of porous pavements. The design workshop participants managed to meet the climate adaptation targets they had set in advance, while creating substantial co-benefits for themselves, for future residents and for the numerous visitors of this area [Van de Ven et al.,2016].

Building capacity

Representatives of different municipal offices (including urban planning, health, water management, urban green and project development) and representatives of the private stakeholders participated in the Climate KIC Smart Sustainable District project on the sustainable and climate resilient redevelopment of the Utrecht Centre West area and two design workshops. These parties learned about the vulnerability of the area for flooding, drought and heat stress and about the many potential solutions that can be used to strengthen resilience, meanwhile delivering substantial ecosystem, economic and social services.

Identifying local impacts and vulnerabilities

National climate change scenarios are available for the Netherlands [KNMI, 2015]. Flood hazard maps and heat stress maps showed significant climate risks in the project area. Drought however turned out to be less of an issue. An attempt to map all critical and vulnerable objects, networks and population groups for a risk assessment turned out to be complicated. Information is scattered over

very many desks. Impacts and vulnerable spots were recognized by the participants of the design workshop.
Adaptation targets for stormwater retention, peak flow reduction and heat stress reduction were quantified on the basis of these climate and land use projections. These targets, though negotiable, are used to evaluate performance of the packages of adaptation measures.

Determining priorities and outlining implementation

The workshop participants first used the climateApp to get an overview of potentially applicable solutions; most of them were not familiar with the large variety of potential adaptation measures They discovered and learned about other solutions. After that first step they started discussing the applicability and attractiveness of implementing specific adaptation measures on specific sites in the project area. Two alternative plans emerged from this discussion: a blue-green alternative and a high density urban alternative. Both alternatives did not completely meet adaptation targets. That is why a third alternative was produced, the Plus alternative. This alternative combines measures from both the Green and the Urban alternative and meets the adaptation targets on storage / retention capacity and peak flow reduction. Heat stress reduction targets are met at all places where people stay, walk or bike. A first analysis was made of the ecosystem services, the economic and social benefits of the proposed alternative adaptation plans as well as a qualitative analysis of who benefits from implementing the Plus alternative and in which way.
The blue-green adaptation plans are now being merged with the mobility adaptation plan and the energy transition plan for the project area to produce comprehensive redevelopment plan alternatives. These alternatives will be used in 2016 (a) to evaluate if adaptation targets are still being met, (b) as input for public engagement sessions and (c) as basis for a value case analysis. This value case analysis is meant to specify the benefits and the beneficiaries of the redevelopment plan in more detail and use this as a basis for a fair distribution of investment and maintenance costs. Results of this value case analysis are meant to support final decision making in 2017 by the City of Utrecht and private stakeholders and project developers on the urban and economic development of the Utrecht City Centre-West area.

Figure 4 *Example of AST application: Two of the alternative conceptual adaptation plans for the Utrecht City Centre - West, each with its own set of adaptation measures and, consequently, a different contribution to adaptation targets and co-benefits. The Green alternative (right) proved less effective than the Plus alternative (left)[Van de Ven et al. 2016]*

4. Discussion

4.1. Addressing adaptation in city planning and design

Local adaptation of our urban infrastructure, buildings and environment is required to minimize negative consequences of climate change. A wide variety of blue, green and grey infrastructural measures is available to strengthen resilience against flooding, drought and heat stress. Decisions are to be taken about adaptation targets and about where and how which adaptation measures are to be located. Such an adaptation plan is to be produced in a collaborative planning process of urban planners, engineers other experts, local stakeholders and political decision makers.
Overall, more and more cities recognize the need for adaptation at a policy-level, but lack the practical instruments to go from vulnerability assessments towards adaptation-inclusive urban planning – see e.g. [ND-GAIN, 2016] - and lack of support for adaptation investments. Moreover, adaptation is a relative new phenomenon, not considered by everyone as his/her responsibility [Nalau et al., 2015]. Investors seem to focus on cost reduction rather than on long term benefits of implementing adaptation measures. The fact that most ecosystem-based adaptation measures not only reduce vulnerability of the urban environment to extreme weather events but also produce substantial economic, ecological and social benefits for the citizens is often overlooked, let alone

maximized in spatial planning, partly due to the fact that these benefits are hard to quantify. This lack of quantitative information is partly overcome by implicit evaluations that take place while the participants in this collaborative planning process evaluate the performance information produced by the AST.

4.2. Role of tools in planning for climate resilience

Urban planning and design routine is not equipped yet to easily incorporate climate proofing. To gain public support, there is a need for stakeholder participation when addressing adaptation in city practice [Hurlbert and Gupta, 2015]. In a collaborative planning workshop based setting local stakeholders are able to provide their implicit knowledge of the area and of the community's preferences [Picketts et al., 2012; Van Stigt et al., 2015]. Many stakeholders however are not aware of the large variety of adaptation options to choose from- the AST contains 62 -, each with their own pro's and con's. Planning and decision support tools for climate resilient urban design should therefor support knowledge sharing and collaborative exploration of alternative adaptation solutions in community-based meetings. To effectively support policy making, planning support tools should bridge the gap between the worlds of scientific expertise and self-organised adaptation in urban reality [Larsen et al., 2012; Löschner et al., 2016] and that of the creative urban planner. Pyke et al. [2007] conclude that the existing decision support systems are more effective when they balance the provision of information with concern for organizational and political processes.

4.3. Application experiences with the Adaptation Planning Support Toolbox

The Adaptation Planning Support Toolbox has effectively supported climate-proof planning in several cases on different continents. Participants of the design workshops expressed their satisfaction with the way the planning process was structured, with the ranked overview of potential blue, green and grey adaptation measures and with the estimates of the effectiveness and the costs of proposed measures; this information supported a learning process and informed decision making. Concerns on organizational or political issues around details of the plan were discussed among participants at the design table. As such there seemed no need to include such issues explicitly in the tool.

The toolbox builds on the results of vulnerability assessments and on the willingness to adapt, as e.g. analysed with the Uniform Adaptation Assessment [Chenchen, 2015] or the Climate Stress Test [Deltaprogramma N&H, 2014]. Flood hazard maps, heat stress maps and water balance calculations provide valuable information on where to concentrate adaptation efforts. In practice it turned out to be hard to formulate adaptation targets for drought and heat stress. The AST was in such cases used to explore the feasibility of a certain impact reduction.

The use of the AST in design workshops requires skilled facilitation. The dialogue that takes place around the design table benefits from an independent facilitator. Moreover, the use of the AST proved to be complex for participants that are not familiar with design workshops and/or with the wide range of potential adaptation measures. In practice, the facilitator or another professional that is trained in the use of the tool assists the application. The Climate Adaptation App is available as a stand-alone tool, because this tool can be used for individual learning by professionals and non-professionals around the globe.

And although decisions on the application of adaptation measures suffer from deep uncertainties on expected climate change and exposure, we have seen in practice that many adaptation measures are selected because of the expected co-benefits of the blue, green and grey measures for the liveability and economic functioning of the urban environment; climate resilience was dealt with as a valuable co-benefit rather than a primary target – as long as adaptation targets were met.

As concluded by Pelzer et al. [2013], the use of a touch table during the design workshops proved to be effective in supporting the planning process. The use of the touch table supports learning processes and stimulates thinking beyond the own professional roles. Moreover, the performance indicators shown on the touch table forced participants to be explicit about their proposed interventions and the expected effectiveness. The struggle they reported of the urban planners with the application of the touch table is interesting. Designer's working practice, to which intuitive sketching and visualization are central, is disrupted by the use of the touch table. This was solved by having regular maps, transparent and drawing pens next to the touch table, so that they could sketch their ideas when they felt the need for it. According to Pelzer et al. [2013] designers also felt the integral approach as a barrier to their creativity. This could not be confirmed in our workshop, potentially because the objective of our workshop was more specific than the objective of their workshop – create a more climate resilient and attractive urban area versus planning a more sustainable new urban area.

4.4. **Usability and reliability**

Performance indicators produced by the AST and used to select and plan adaptation measures are based on evidence-based key figures on the characteristics, performance and costs of each adaptation measure retrieved from international literature [De Jong et al., 2014, 2015; Geisler and Barjenbruch, 2015; Kosteninformatie.nl, 2015; Vergroesen et al. 2013]. They are also based on conceptual modelling of the measure's performance using local climate and land use conditions. Although the accuracy is limited we argue that this information is reliable enough to compare different measures and different alternatives and to find a common preference with all participants. Arguments to decide on a specific choice are exchanged, while keeping an eye on their contribution to the adaptation targets and on their cost-effectiveness. Conceptual designs are so far made without quantified information on performance of proposed adaptation measures; the availability of a more or less reliable performance and cost estimation is a valuable contribution to informed decisions on the selection and design of adaptation measures.

The Toolbox is used for planning problems at building to district scale; use at larger scale level is questionable because the tools do not consider interconnections and flow capacities between adaptation measures. Estimated performance at larger scale could consequently be misleading. Moreover, the AST shows only performance indicators regarding climate resilience in relation to the water system and estimated costs; other benefits and co-benefits of the measures – e.g. landscape quality, added economic and social value - are not quantified, but in practice play an important role in the dialogue and selection decisions of the workshop participants. Quantified information would give the benefits a more equal treatment in the selection and decision making process as compared to the costs. Research to find out which information on co-benefits session participants would like to see on the AST dashboard is on-going.

Measures against heat stress tend to have local effects. In order to evaluate heat stress control measures we would like to visualise the local cooling effects of planned blue green measures in a map instead of presenting a general decrease in average areal temperature as a figure on the dashboard. We planned to realise this functionality in 2016.

Another relevant question is who should participate in the design workshops. Participation of urban planners, landscape architects, water managers, civil engineers, local stakeholders and other experts is evident. But how about participation of city council members and commercial developers? The fact that city council members participated in the design workshop in Beira turned out very effective for further decision making. In other cases political decision makers were not invited by the host of the design workshop; further study is required to evaluate the impact of their participation.

The toolbox was used both in the Netherlands and abroad. For the applications in Beira and London the key figures for calculating the performance indicators of each measure had to be calculated with the local climate and local land use data. So far this has been done manually and has required substantial effort. For easier applications abroad this process could be automated. Cost figures remained unchanged so far; if local unit cost figures are available these can be brought in the tool without much effort. Moreover a stronger coupling (export-import function) of the AST with hydraulic and hydrological simulation models for plan evaluation would be convenient.

5. Conclusions

There is a gap in the tools available to support resilient, climate-proof urban planning. Tools and procedures are available for climate vulnerability assessment and for evaluating the performance of final designs with the help of simulation models. But tools that have the ability to support implementing adaptation in the actual urban planning and design practice, i.e. to support defining the program of demands, setting adaptation targets, for selecting adaptation measures from a wide variety of blue, green and grey adaptation measures and for informed co-creation of a conceptual design, seem to be missing.

To close this gap and support the planning of a climate resilient urban environment we developed and tested an Adaptation Planning Support Toolbox. The toolbox contains a Climate Adaptation App (climateApp) and the Adaptation Support Tool (AST). From our applications so far we conclude that this Toolbox meets the demands of local policymakers, planners, designers and practitioners to provide evidence-based support for their collaborative analysis –dialogue- design-engineering (= planning) sessions. Participants appreciated the AST because its overview and pre-ranking of a wide range of potential adaptation measures, the possibility to create different adaptation design options (scenarios) for their own project area, and to explore the contribution of these options on adaptation targets and co-benefits. Discussions on the design table were focussed on the opportunities and the benefits of specific interventions, rather than on the costs. The combination of informing, exploring and testing at the same time, and doing this in a collaborative dialogue with relevant stakeholders, is considered as of added value to current adaptation planning practice. Essential is that urban planners, landscape designers, water managers, urban green managers have to learn how to combine their working practice in such a collaborative planning and design process. This transition requires courage and perseverance from all parties, and will lead to further development of the toolbox or similar tools. With more and more cities worldwide that will make the step from climate policymaking to an actual adaptation-inclusive urban (re)development practice we foresee a growing demand of tools like the climateApp and the AST to ensure that adaptation will be seriously adopted by the local actors while maximizing the social and economic co-benefits of the adaptation measures.

Acknowledgement

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Supplementary material

Supplementary material to the article

Adaptation Planning Support Toolbox: measurable performance information based tools for co-creation of resilient, ecosystem-based urban plans with urban designers, decision-makers and stakeholders

Dr. Frans H.M. van de Ven
Dr. Robbert Snep
Stijn Koole MSc.
Dr. Reinder Brolsma
Dr. Rutger van der Brugge
Joop Spijker MSc.
Toine Vergroesen MSc.

CONTENTS

A. Criteria for development of the Adaptation Support Toolbox
B. Definition of AST performance parameters
C. Long list of adaptation measures included in the AST

A. Criteria for development of the Adaptation Support Toolbox

Building on the structure of an urban planning process and on the lessons learned in climate resilience design workshops we formulated several principles and concepts as criteria for effective climate-proof urban planning and for an effective planning support toolbox. These criteria are:

- Consequences of climate change are to be addressed in an integrated way: coastal, fluvial, pluvial and groundwater flooding, drought, heat stress, water quality problems and land subsidence are analysed as one coherent process; impact on both public and private stakeholders is studied comprehensively, considering aspects such as direct and indirect economic damage, costs of recovery, health, social impact and psychological impact. The long term perspectives are to be leading in the analysis, in order to avoid maladaptation [Bours et al., 2014; Deltaprogramma N&H, 2014];
- The future quality of the urban environment is the central planning theme (MUS-concept [Maksimovic et al., 2014], not the impact of changing climatic conditions on lives and livelihood alone. Issues and existing problems that are hardly or not related to climate change, e.g. the shortage of parking lots, a playground for children or a place to sit outdoors during lunchtime, can be brought up. Their solution could be included in the final adaptation plan to balance advantages and disadvantage for some stakeholders ;
- Climate resilience is essential, as frequent damage and nuisance due to extreme weather conditions lead to social and economic decay of districts. Critical/vital objects and networks and vulnerable population groups require extra protection against such adverse conditions; Resilience, public health and wellbeing, social safety and equity are supported by introduction of a blue-green urban environment [Van den Berg et al., 2007; Maas et al. 2009];
- Water, and the control over it, is the key to a climate resilient urban environment. Water quality, land subsidence and heat stress have direct relation with the availability and the flows of water in the urban environment. Lack of evaporation enhances the urban heat

island [Rovers et al., 2014]. Low groundwater levels induce land subsidence and oxidation of peat. And water quality is influenced by dilution or concentration by evaporation;

- Adaptation measures deliver ecological and economic services and contribute cultural and emotional values; such “additional” services and values are to be maximized in the adaptation plan. On the other hand adaptation planning should also be used to minimize the damage of a failing protection system, resulting in flooding, drought damage, heat stress victims and other detrimental effects. This in line with the Three Point Approach to planning [Fratini et al, 2012];
- Adaptation planning is an ill-defined, complex planning problem. Design is the only solution strategy to such a problem [Team Urban Water Management, 2009], meaning that the analytical frame (engineering), the design frame (planning) and the negotiation frame (dialogue) are to be bridged in a coherent and goal-oriented planning process [Van de Ven et al., 2005; Pelzer et al., 2013]. Tools to support this process should provide quantified insight in the effectiveness and in added values of proposed adaptation measures.

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B. Definition of AST performance parameters

The Adaptation Support Tool produces a number of performance indicators for each projected adaptation measure and for the proposed package of measures in a plan. A definition and a brief description of the way these indicators are calculated is given below:

The storage capacity of an applied measure is the maximum water volume (m^3) that a facility (adaptation measure) can contain. During a rainstorm the available storage of the measure is filled, either partly or completely, depending on the size of the rainstorm, the resulting runoff volume that flows into the measure and the outflow of such a facility. Before the measure can be used again at its full storage capacity, the stored water needs to be removed. How the stored water is removed and how much time that takes depends on the measure. This can be done by evaporation, gravity outflow, infiltration, pumping, etc. All these processes take time, during which the available storage for the next rainstorm is less than the storage capacity of the measure.

The available storage of a measure at the start of a rainstorm, that is the effective storage capacity (m^3), depends on the elapsed time since the previous rainstorm and the outflow and can vary between zero and its maximum. The average effective storage capacity of a measure depends on the local climate and the time it takes to remove the water from the measure. Effective storage capacity is always smaller than the storage capacity of the measure. The effective storage capacity is determined by a water balance simulation with a rainfall-runoff model of the facility, using long time series of meteorological data, preferably with hourly data or smaller for at least 30 years. To account for climate change this series could be modified according to the expected climate change scenario.

Normative runoff denotes the return period (year) of a rainfall-runoff event that occurs in a certain area at a certain frequency. For instance, in The Netherlands limited pluvial flooding that does not cause damage or disruption is allowed to occur once every two years. By implementing an adaptation measure the return period of the normative rainfall-runoff event in the same area can be extended (Figure B1). For instance after implementation of the measure the return period of the normative runoff is extended from once every two years to once every three years, implying that the damage or disruption occurs 50% less frequent. The Adaptation Support Tool shows on its dashboard how the once per 2 years normative runoff changes to a once per X years peak flow due to the measure. See also Figure B1: for the effect of a blue roof with 30 mm storage capacity T =2 changes to T = 3.5 years, for average historic climate conditions in the Netherlands.

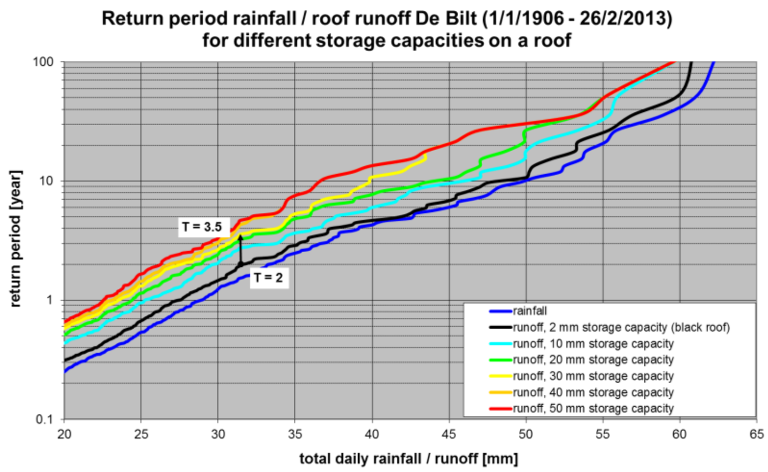

Figure B1 Change in return period of roof runoff for different blue roof storage capacities

Groundwater recharge is defined as the average net annual flux (mm/year) from the unsaturated zone towards the saturated zone (P_gw in Figure B2). It is calculated based on the same reservoir model that is used for calculating effective storage and is also forced with the same meteorological data.

Drought reduction is quantified as the extra water that is stored within the system. For water that is stored as surface water this is the extra volume of water that is stored for long time within the measure, e.g. in a rain tank or in an increased surface water level at the start of the summer period. For water that is stored in the soil this is the difference of water that infiltrates into the soil and the water that percolates towards the groundwater, plus the water that recharges the unsaturated zone by capillary rise from the saturated zone. Over a year this approximates the transpiration of vegetation.

Multi-reservoir water balance model

The *effective* storage capacity of a measure, the normative runoff frequency reduction as well as groundwater recharge and drought reduction calculations are made for each adaptation measure using a multi-reservoir water balance rainfall-runoff. model (Figure B2) forced by the above mentioned long (30 years or more) time series of meteorological data. Parameters characterising the hydrological performance of the specific adaptation measures were taken from experimental results reported in the international scientific literature [Boogaard, 2015; Geisler and Barjenbruch, 2015].

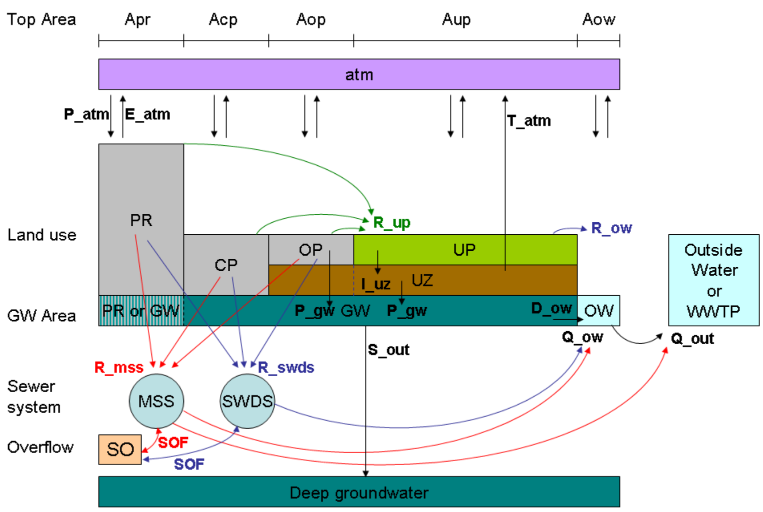

Figure B2 Overview of applied multi-reservoir water balance rainfall-runoff model. A more detailed description of this model, its components and flow paths can be found in Van de Ven et al. [2016]

Hydrological boundary conditions of the water balance model are based on local conditions. For measures with varying storage depths and rainfall events with varying intensities with known return periods the consequent runoff is calculated. Based on the depth and the area of the adaptation measure, the size of the area that runs off to the measure (inflow area) and the size of the total area (area of interest), the change in return period for the normative runoff from the total area is calculated for each individual measure (Figure B3).

T-norm [year]	2	Area of interest	950000 m2		
		Measures:	Area	Capacity	Return period [year]
inflow area [m2]	T-factor		[m2]	[m3]	normative runoff
6000	50.00	Bioswales/Infiltrating filter swales on silty soil	4000	1000	2.62
50000	1.80	Green roofs (extensive)	50000	1000	2.08
16000	50.00	Rainwater retention ponds, with or without infiltration possibilities	4000	1000	3.65
200000	1.40	Rainwater retention tank	1000	1000	2.17
50000	50.00	Green roofs with drainage delay	50000	1000	7.16
		Total effect measures:	**109000**	**5000**	**9.68**

Figure B3 Example of calculation of return period of normative runoff for multiple measures

The inflow area is the area that is draining towards the measure. Generally it is equal or larger than the measure area. The T-factor is the multiplication factor of the normative runoff return period (T-norm, in this case set to 2 year) for the inflow area that is related to the effective storage depth of the measure (i.e. the measure storage depth multiplied by the measure area divided by the inflow area). T-factors have been determined by long term (≥ 30 year) water balance calculations for single measures with different storage depths (i.e. vertical water column that can be stored over the measure area). Initially, for the Dutch situation, the T-factors for individual measures have been maximized at 50, because the urban storm water drainage systems in The Netherlands are designed for rainstorms with return periods of 2 year where urban surface water systems are designed for rainstorms with return periods of 100 year.

The return period of the normative runoff (from the area of interest) for a single measure is calculated by:

$$Return\ period\ measure = Tnorm \cdot Tfactor \cdot \frac{inflow\ area}{area\ of\ interest} + Tnorm \cdot \frac{area\ of\ interest - inflow\ area}{area\ of\ interest}$$

For the return period of the applied bioswales in Figure B3 this is:

$$2 \cdot 50 \cdot \frac{6000}{950000} + 2 \cdot \frac{950000 - 6000}{950000} = 2.62\ year$$

By assuming independent effectiveness of the individual measures the total effect of the measures on the areal runoff is calculated according:

$$Return\ period\ measures = \left(\sum_{i=1}^{n}\left(Tfactor_i \cdot \frac{inflow\ area_i}{area\ of\ interest}\right) + 1 \cdot \frac{area\ of\ interest - \sum inflow\ areas}{area\ of\ interest}\right) \cdot Tnorm$$

For the applied measures in Figure B3 this is:

$$\left(50 \cdot \frac{6000}{950000} + 1.8 \cdot \frac{50000}{950000} + 50 \cdot \frac{16000}{950000} + 1.4 \cdot \frac{200000}{950000} + 50 \cdot \frac{50000}{950000} + 1 \cdot \frac{950000 - 322000}{950000}\right) \cdot 2 = 9.68\ year$$

The heat reduction is expressed as an average temperature reduction (°C) for the complete project area. It is calculated as cooling effect at the location of the intervention multiplied by the area of the intervention and divided by the project area. The cooling effect at the location of the intervention is based on values derived from literature [Albers et al. 2015]. In case no literature value was found, the effect of the most similar measure was used, e.g. bioswales are assumed to be equally effective heat reduction as a field with grass.

Water quality improvement is expressed by three indicators, nutrient reduction, absorbed pollutants reduction, and pathogen reduction. Each of these indicators is determined according to the following steps: First, for all interventions the relevant processes that influence water quality are indicated by scoring them relevant or irrelevant. These processes can be capturing, settling, filtering, degrading pollution. For intensive green roofs fertilizing was included – leading to a negative improvement. Next for each of these processes and for each pollution group (nutrients, absorbed pollutants and pathogens) the fraction is read that is not removed by each of these processes. These effectiveness values have been determined by expert judgement of water quality experts, based on observed performance figures reports in literature. [Langeveld et al. 2012, Boogaard, 2015, Geisler and Barjenbruch, 2015]. Next the effectiveness of a measure is determined as 1 minus the multiplication of fractions of remaining pollutant per process and as a fraction of the inflow surface area of the intervention and the total area. The effect of multiple measures can then be calculated as a summation of the effect when it is assumed that measures do not overlap in space.

Cost estimates for construction and for maintenance are based on unit cost figures. For each adaptation measure average unit costs of construction and unit costs of management and maintenance were estimated. All costs include the costs of construction materials, labor, depreciation of building equipment, fuel, insurances and taxes. The costs presented in the tool are indications for an average urban situation in Northwestern-Europe in 2015. For the costs of maintenance important sources of information were the Databank Gemeentelijk Groen, a benchmark of about 60 Dutch municipalities with data of on their actual costs of urban green [De Jong et al. 2015], the website Kosteninformatie.nl [2015] and overviews of De Jong et al. [2014] and IMAG [2001]. These sources however contain no information on the costs of innovative green adaptation measures like green roofs, green facades, special infiltration measures such as boxes and vegetated swales. To fill this gap we have used published costs in the literature in Western Europe, the USA and Canada. [Geisler and Barjenbruch, 2015].

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C. Long list of adaptation measures included in the AST

Measure	Type
Adding grass/herbs in streetscape	Blue/Green
Adding shrubbery in streetscape	Blue/Green
Adding trees in streetscape	Blue/Green
Artificial urban wetland	Blue/Green
Bank infiltration	Blue/Green
Bioswales	Blue/Green
Bioswales/Infiltrating filter swales on sandy soil	Blue/Green
Building without a crawlspace	Grey
Cool paving and building materials	Grey
Cooling with water elements	Blue/Green
Cooling with water elements: ponds	Blue/Green
Decentral Separator for road runoff treatment	Grey
Deep groundwater infiltration	Blue/Grey
Disconnecting paved surfaces from sewer system	Grey
Ditch or infiltration-strip	Blue/Green
Extensive green roof	Blue/Green
Extra intensive green roof	Blue/Green
Floating puri-plants (floatlands)	Blue/Green
Green facades	Blue/Green
Green roofs with drainage delay	Blue/Green
Green shores and riverbanks	Blue/Green
Green ventilation grids	Blue/Green
Gutter	Grey
Helophyte filter	Blue/Green
Improve soil infiltration capacity	Blue/Green

Inclination of roads	Grey
Increase area of surface water	Blue/Green
Increase height difference between street level and ground floor level	Blue
Infiltration and Transport-sewer	Blue/Grey
Infiltration boxes	Blue/Grey
Infiltration field	Blue/Green
Infiltration trench	Blue/Green
Infiltration shafts	Grey
Intensive green roof	Blue/Green
Lowering embankments	Blue/Green
Park or urban forest	Blue/Green
Porous pavement	Blue/Grey
Private green garden	Blue/Green
Pumping station (Increased capacity)	Grey
Rainwater retention pond	Blue/Green
Rainwater storage below buildings	Blue/Grey
Rainwater tank	Blue/Grey
Raised curbs/ hollow roads	Grey
Reconstruct combined sewer systems to separated sewer systems	Grey
Reconstructing (wooden) foundations	Grey
Replacing leaking/draining sewers	Grey
Retention soil filter	Blue/Green
Seasonal storage (by realizing extra storage height of surface water)	Blue/Green
Sewer system (increase capacity)	Grey
Shallow infiltration measures; infiltration boxes -sand	Blue
Smart irrigation measures	Blue
Smart-drain (groundwater)	Grey

Specific seasonal storage facility	Blue/Green
Storage/settling tank and storage basins	Grey
Surface drains	Blue
Swale	Blue/Green
Systems for rainwater harvesting	Blue/Grey
Tree pit bio-retention	Blue/Green
Urban agriculture	Blue/Green
Use of groundwater (aquifer storage and recovery)	Blue
Use of treated wastewater	Blue
Water circulation systems	Blue
Water inlet systems	Blue
Water roof	Blue/Grey
Water squares	Blue/Grey
Wet proofing (water resistant construction)	Grey
Wetting surfaces (of gardens, roofs, roads)	Blue

References

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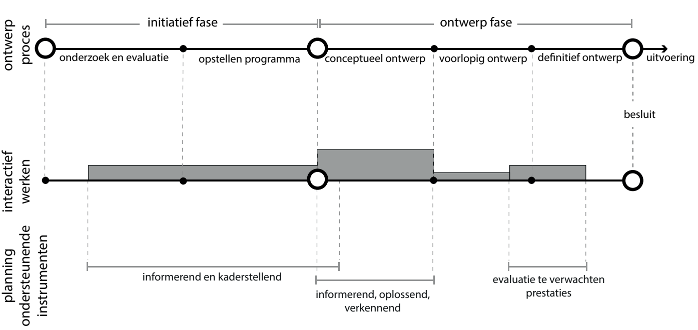
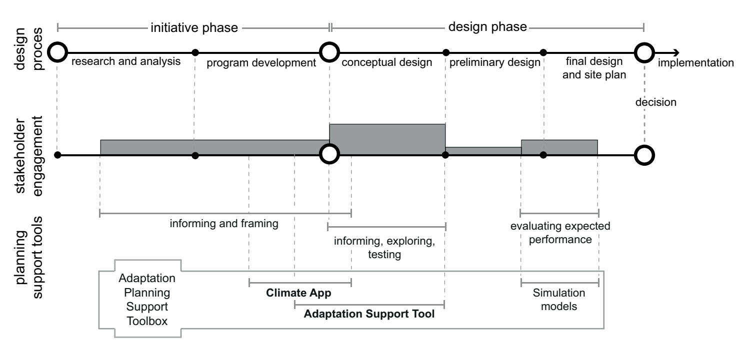
Table(s)

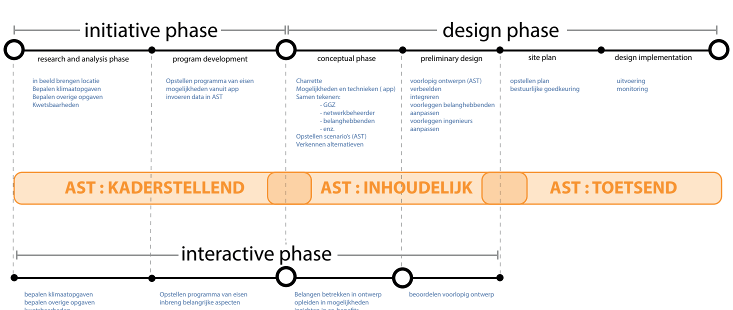
Table 1 Overview of applications of the Adaptation Planning Support Toolbox.

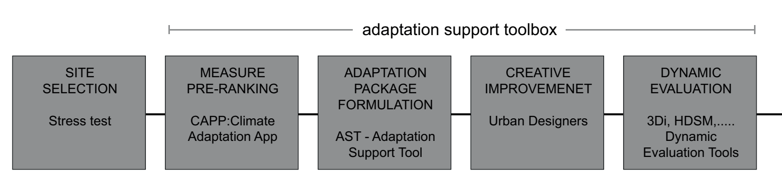
Area	Project area type and size	Type of project / spatial planning process	Climate challenges	Phase of planning process	Participants	Experiences, Lessons learned
Chota- Beira (Mozambique)	788 ha, district + detail	Redevelopment & development	Flooding	Program formulation	Municipality, citizens, politicians, local university, NGOs	Stakeholder sessions including non-professionals demand a combination of high tech (AST) and low tech process tools
Decoy Brook,London (United Kingdom)	292 ha district + detail	Research	Flooding	Conceptual design	Environment Agency, Borough repres., university	Make plans for both total area and detailed design for specific hot spots
Oaxaca (Mexico)	195 ha district	development &redevelopment	Flooding, drought	Program formulation	State and municipal authorities, citizens, university, NGOs,	AST is a very handy tool as a catalogue of possibilities in district zones with different characteristics.
Utrecht (Netherlands)	49 ha neighbourhood	Redevelopment	Flooding, heat stress	Conceptual design	Municipality, real estate owners, architect; urban water and green experts;	Participants go for urban quality rather than for cost reduction
Dordrecht (Netherlands)	65 ha neighbourhood	Student Climate Resilient Urban Design workshop	Flooding, heat stress	Conceptual design	Students,	AST toolbox is effective training tool
Tilburg (Netherlands)	46 ha, neighbourhood	Research	Flooding, heat stress	Program formulation	Municipality; urban water experts	The AST can also be applied as a quick-scan method to assess if e.g. green roofs have an added value for specific urban areas.

Figure(s)

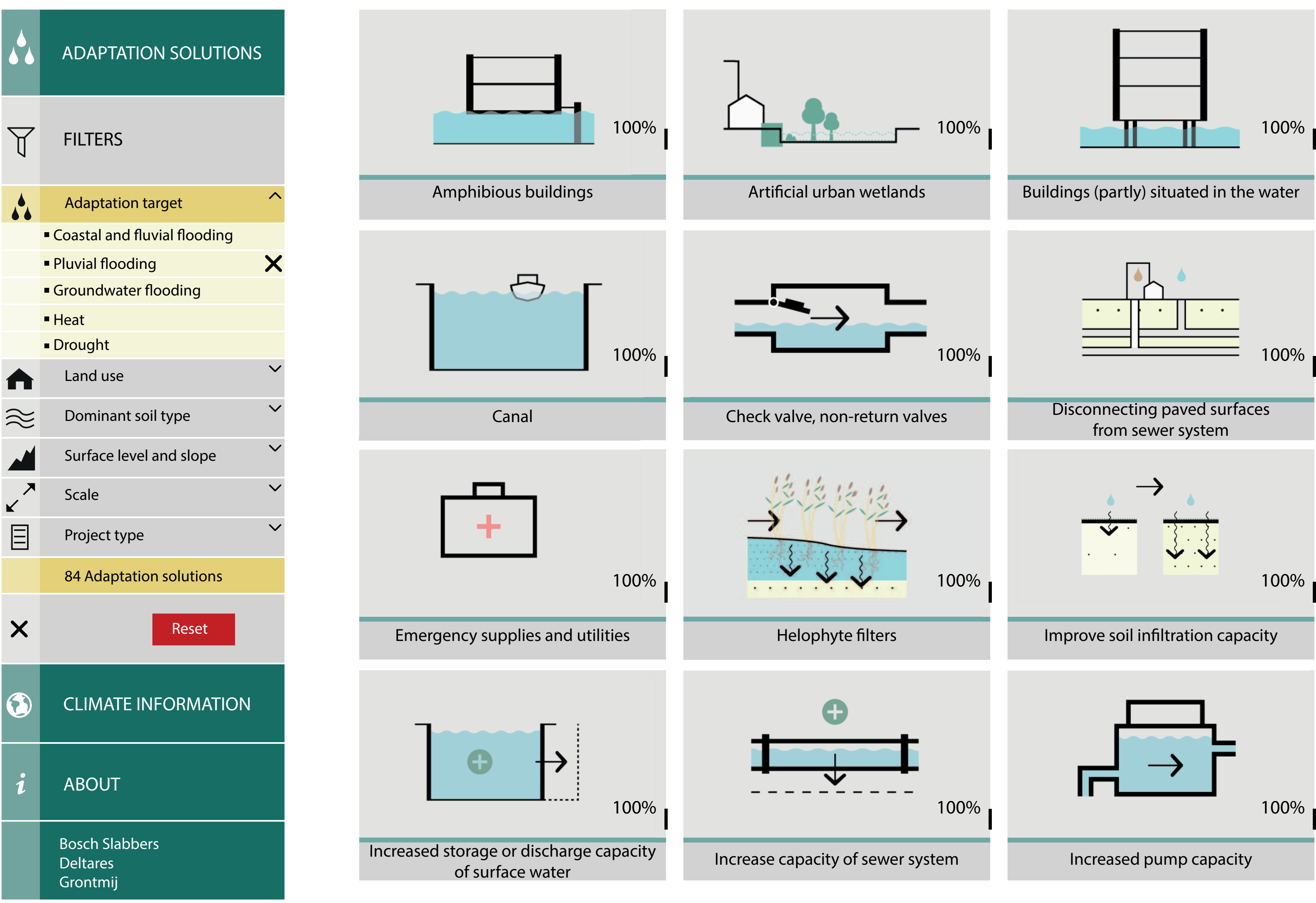

ontwerp proces
initiatief fase
ontwerp fase
onderzoek en evaluatie
opstellen programma
conceptueel ontwerp
voorlopig ontwerp
definitief ontwerp
uitvoering
besluit
interactief werken
planning ondersteunende instrumenten
informerend en kaderstellend
informerend, oplossend, verkennend
evaluatie te verwachten prestaties


design proces
initiative phase
design phase
research and analysis
program development
conceptual design
preliminary design
final design and site plan
implementation
decision
stakeholder engagement
planning support tools
informing and framing
informing, exploring, testing
evaluating expected performance
Adaptation Planning Support Toolbox
Climate App
Adaptation Support Tool
Simulation models

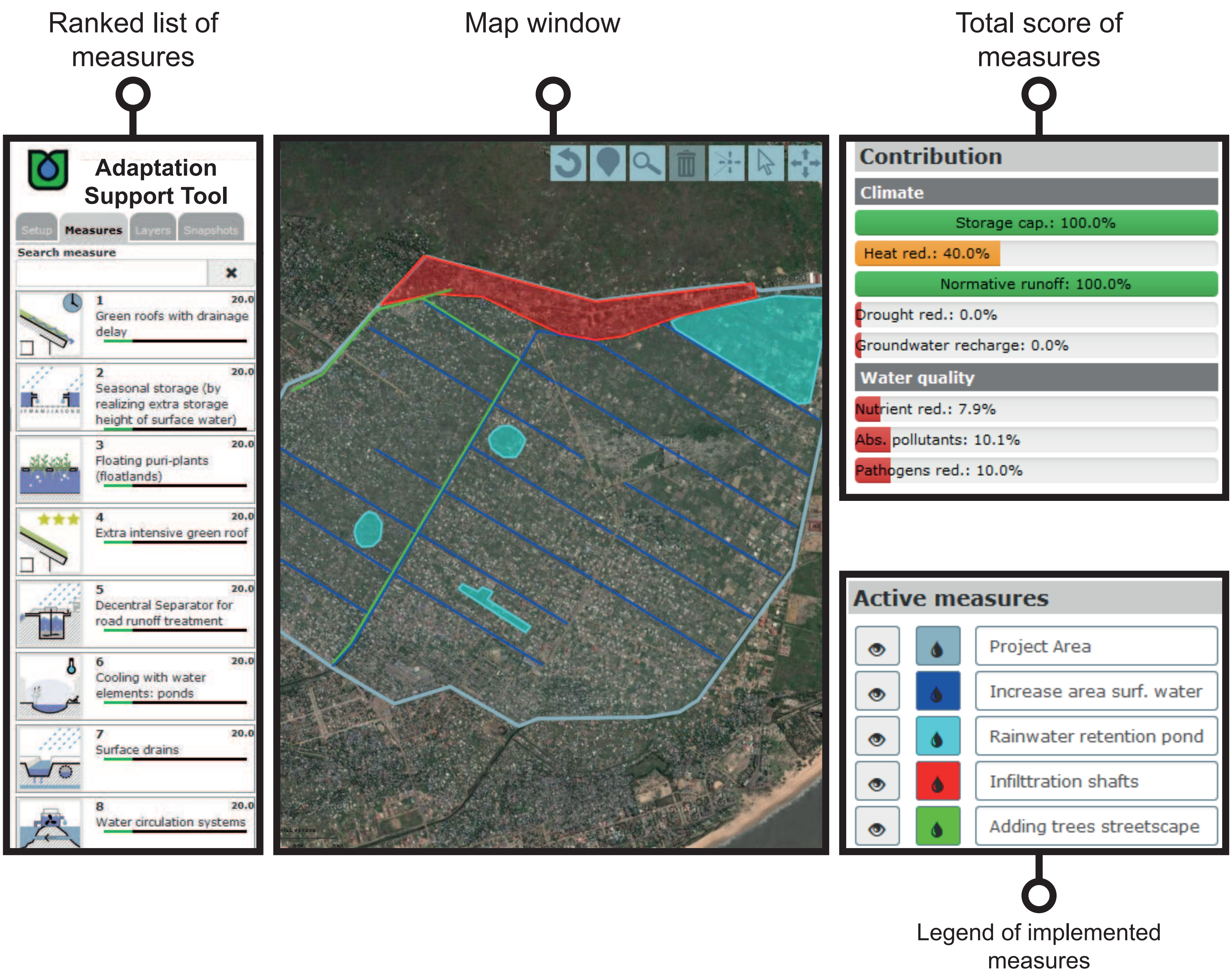

initiative phase
design phase
research and analysis phase
program development
conceptual phase
preliminary design
site plan
design implementation
AST : KADERSTELLEND
AST : INHOUDELIJK
AST : TOETSEND
interactive phase


adaptation support toolbox
SITE SELECTION
Stress test
MEASURE PRE-RANKING
CAPP:Climate Adaptation App
ADAPTATION PACKAGE FORMULATION
AST - Adaptation Support Tool
CREATIVE IMPROVEMENET
Urban Designers
DYNAMIC EVALUATION
3Di, HDSM,..... Dynamic Evaluation Tools

Figure(s)


ADAPTATION SOLUTIONS
FILTERS
Adaptation target
Coastal and fluvial flooding
Pluvial flooding
Groundwater flooding
Heat
Drought
Land use
Dominant soil type
Surface level and slope
Scale
Project type
84 Adaptation solutions
Reset
CLIMATE INFORMATION
ABOUT
Bosch Slabbers
Deltares
Grontmij
100%
Amphibious buildings
100%
Artificial urban wetlands
100%
Buildings (partly) situated in the water
100%
Canal
100%
Check valve, non-return valves
100%
Disconnecting paved surfaces from sewer system
100%
Emergency supplies and utilities
100%
Helophyte filters
100%
Improve soil infiltration capacity
100%
Increased storage or discharge capacity of surface water
100%
Increase capacity of sewer system
100%
Increased pump capacity

Figure(s)



Ranked list of measures
Map window
Total score of measures
Adaptation Support Tool
Setup
Measures
Layers
Snapshots
Search measure
1 Green roofs with drainage delay 20.0
2 Seasonal storage (by realizing extra storage height of surface water) 20.0
3 Floating puri-plants (floatlands) 20.0
4 Extra intensive green roof 20.0
5 Decentral Separator for road runoff treatment 20.0
6 Cooling with water elements: ponds 20.0
7 Surface drains 20.0
8 Water circulation systems 20.0
Contribution
Climate
Storage cap.: 100.0%
Heat red.: 40.0%
Normative runoff: 100.0%
Drought red.: 0.0%
Groundwater recharge: 0.0%
Water quality
Nutrient red.: 7.9%
Abs. pollutants: 10.1%
Pathogens red.: 10.0%
Active measures
Project Area
Increase area surf. water
Rainwater retention pond
Infilttration shafts
Adding trees streetscape
Legend of implemented measures

Figure(s)


Project Area
Green roofs with drainage
Green shores and riverba
Park or urban forest
Increase area of surface v
Adding trees in streetscap
Extra intensive green roof
Water squares
Porous pavement
Urban agriculture
Extensive green roof
Rainwater tank

Supplementary Material
Click here to download Supplementary Material: D-5142 The Adaptation Planning Support Toolbox Suppl Mat R2.docx