Horizon 2020 Societal challenge 5: Climate action, environment, resource efficiency and raw materials

BINGO

Bringing INnovation to onGOing water management –

a better future under climate change

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**Changes with respect to the DoA**
Not applicable

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**Short Summary of results (<250 words)**
This report summarises the results on climate change adaptation measures at all BINGO research sites. Case studies to define, explore, assess and compare risk reduction measures to a variety of water supply, water quality and urban drainage risks have been conducted. Those risks may be aggravated by future climate change. The case studies therefore followed an interdisciplinary approach to explore the economic and societal impacts of the proposed measures. The case studies in Germany (Große Dhünn reservoir), Cyprus (Peristerona watershed), Portugal (Targus) and The Netherlands (Veluwe) studied water scarcity risks. In Norway (Bergen) and Spain (Badalona) risk reduction for combined sewer overflow threats have been studied. Furthermore, flood risks have been in focus in Germany (Wuppertal) and Spain (Badalona). All case studies have been conducted in close cooperation with local stakeholders ensuring an applied science approach. A variety of frameworks were used to assess and compare adaption measures at the research sites, including cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis and customized decision support approaches. Additionally a questionnaire was answered by every research site for adaptation measure studied, focussing on social effects.

**Evidence of accomplishment**
This Report

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ACA | Catalan Water Agency |
| AEPV | Annual Equivalent Present Value |
| ARBVS | Associação de Regantes e Beneficiários do vale do Sorraia (Association of Irrigators and Beneficiaries of Sorraia Valley) |
| ARH | Administração da Região Hidrográfica (River Basin District Administration or Hydrographic Region Administration) |
| ARH_TO | Administração da Região Hidrográfica do Tejo e Oeste (River Basins District Administration of Tagus and West) |
| AWSW | Agency for water and sewerage works |
| BAU | Business As Usual |
| BINGO | Bringing INnovation to onGOing water management |
| CAP | Common Agricultural Policy |
| CAPEX | Capital expenditures |
| CBA | Cost-Benefit Analysis |
| CC | Climate Change |
| CCA | Climate Change Adaptation |
| CCS | Insurance Compensation Consortium |
| CEA | Cost-Effectiveness Analysis |
| CGA | Comissão de Gestão de Albufeiras (Reservoirs Management Commission) |
| CoP | Community of Practice |
| CSO | Combined sewer overflows |
| CY | Cyprus |
| CYI | The Cyprus Institute Limited |
| D | Deliverable |

| | |
|---|---|
| DCIA | Directly Connected Impervious Area |
| DGADR | Direção-Geral de Agricultura e Desenvolvimento Rural (Directorate General for Agriculture and Rural Development) |
| EAD | Expected Annual Damage |
| EDP | Eletricidade de Portugal (Electricity of Portugal) |
| EPAL | Empresa Portuguesa das Águas Livres – Grupo Águas de Portugal (EPAL – Public Water Supply Company to Lisbon and all the right margin of lower Tagus river) |
| EU | European Union |
| EWS | Early Waring System |
| FRC | Future Rainfall Conditions |
| GIS | Geographical Information System |
| GMST | Global Mean Surface Temperature |
| HQ | Flood |
| IACO | I.A.CO Environmental and Water Consultants LTD |
| InterSus | InterSus Sustainability Services |
| IPCC | Intergovernmental Panel on Climate Change |
| ISO | International Organization for Standardization |
| IWW | Rheinisch-Westfälisches Institut für Wasserforschung gemeinnützige GmbH |
| KOSTRA | Koordinierte Starkniederschlags-Regionalisierungs-Auswertungen (Coordinated, regionalized extreme precipitation assessments) |
| KWR | Water Research Institute (KWR Water B.V.) |
| LGVFX | Lezíria Grande de Vila Franca de Xira |
| LNEC | Laboratório Nacional de Engenharia Civil |
| LVT | Lezíria do Vale do Tejo |
| MCA | Multi-criteria analysis |
| MCA | Multi-Criteria-Analysis |

| | |
|---|---|
| MCDA | Multi-Criteria Decision Analysis |
| NPV | Net Present Value |
| NTNU | Norwegian University of Science and Technology |
| OCCC | Catalan Office of Climate Change |
| OPEX | Operational expenditures |
| PIP | Public Irrigation Perimeter |
| PRC | Present Rainfall Conditions |
| PT | Portugal |
| PV | Present Value |
| PWS | Public Water Supply |
| RCP | Representative Concentration Pathway |
| RCP | Representative Concentration Pathway |
| SUDS | Sustainable Urban Drainage Systems |
| SWMM | Storm Water Management Model |
| UNFCC | United Nations Framework Convention on Climate Change |
| WDD | Water Development Department |
| WFD | Water Framework Directive |
| WP | Work Package |
| WRM | Water Resources Management |
| WWTP | Waste Water Treatment Plant |

# 1 INTRODUCTION AND REPORT STRUCTURE

This report highlights the work conducted and results produced from different case studies in relation to BINGO task 5.2, the economic and social analysis of the impacts of measures for each research site.

Chapter 2 illustrates in brief the background of the impact assessments in relation to risk treatment within BINGO cases and BINGO's generic framework for the assessment of measures' impacts.

The following chapters 3 to 8 summarize the results from each research site. This includes a separate introduction, explanation of case specific methods, data and assessment approaches, presentation of the adaptation measures studied as well as a site specific conclusion. The cases emphasised different key aspects in accordance with the BINGO Description of Work (DoW) to cover a broad range of climate change adaptation issues. Thus, the study-depth varies across research topics and cases, resulting in different chapter lengths.

# 2 IMPACT ASSESSMENT OF ADAPTATION MEASURES IN BINGO

## 2.1. Risk treatment within BINGO Cases

In the last decades a significant change of climate could be observed, indicated inter alia by an increase of the Global Mean Surface Temperature (GMST). In the timeframe from 2006 to 2015, the GMST lay around 0.87°C above the average temperature in the reference period from 1850 to 1900. This increase already caused observable aggravations in the occurrence and consequences of extreme weather events like heatwaves or heavy precipitation events. Therefore, also risks related to the occurrence of extreme weather events have increased, indicating the necessity to develop adaption strategies to climate change related risks. As the temperature increase described above is a mean temperature increase, the regional manifestations of climate change might differ. Subsequently, also the occurrence of temperature maxima and the manifestation of extreme weather events differ from site to site. Thus for example some sites might face an increase of drought related risks while other sites will face increased risks caused by heavy precipitation events. (Hoegh-Guldber et al. 2018)

In 2015, the United Nations Framework Convention on Climate Change (UNFCC) worked out the so called “Paris Agreement”. By signing this agreement, so far 197 nations commit to the aim to limit the temperature increase to 2°C above pre-industrial level. Although there is also a commitment in the agreement to make efforts for a reduction of temperature increase to 1.5°C above pre-industrial level, still a significant rise of temperature compared to the actual 1°C above pre-industrial level has to be expected. These expected higher temperatures will be accompanied by the aggravation of weather extremes and other adverse climate change effects compared to present conditions. (Hoegh-Guldber et al. 2018, UNFCC 2015, UN 2019)

As the further aggravation of climate change and related risks seems to be inevitable, it is important to think about adaption strategies to deal with the expected impacts. For this purpose it is not possible to develop a universal adaption strategy that ensures a sufficient risk reduction for all affected sites and regions. It is rather necessary to think of tailor-made adaption measures for each investigated site, considering the local conditions, the expected climate change manifestations and so on. An IPCC report on global warming of 1.5°C summarizes this requirement as follows:

> *Adaptation refers to the process of adjustment to actual or expected changes in climate and its effects. Since different parts of the world are experiencing the impacts of climate change differently, there is similar*

*diversity in how people in a given region are adapting to those impacts. (de Coninck et al. 2018)*

The BINGO project aims to produce practical solutions for water managers, end-users, decision makers and policy makers to deal with climate change impacts causing the increase of water related risks. Therefore, short-term (decadal) climate predictions have been generated in working package (WP) 2 of the project which serve as input for water cycle models that have been run in WP 3 for each case study. By these models, the impacts of the forecasted climate trends on the water cycle could be determined, serving as basis for the work conducted in the subsequent working packages 4 & 5. In WP 4 an extensive risk assessment was performed which is described in more detail below. WP 5 aims to develop and evaluate a suitable risk treatment framework for the reduction of risks that were identified in WP4. This risk treatment is an integral step of the overall risk management framework that is described e.g. in ISO 31000 (2018) and that is illustrated in Figure 2.1.

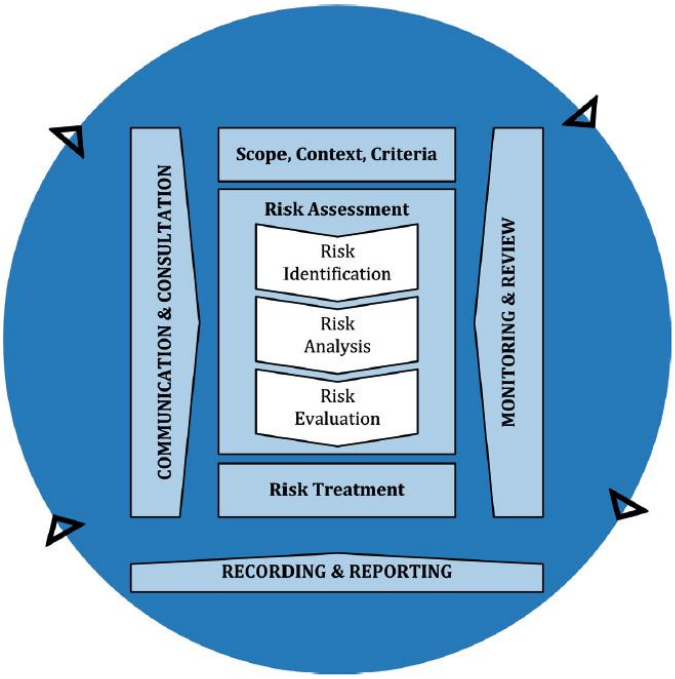


**Figure 2.1: Risk management process from ISO 31000 (2018)**

The first part of the risk management framework was realized in WP4. Deliverable (D) 4.1 defined the context of the risk assessment at the six respective research sites and thus set the basis for all subsequent investigations (Viseu et al. 2016). By general descriptions of the research sites and the establishment of the external and internal contexts, an overview of the research sites was provided to ensure a common understanding of the important framework conditions. With regard to the ISO 31000 framework, this step can be assigned to the required definition of the “scope, context [and] criteria”. The information summarized in D4.1 is very important for a profound understanding of the risks identified in D4.2 (Russo et al. 2017). In the latter deliverable, potential risk events, risk sources and risk factors caused by extreme weather events and climate change were identified and described. The results from D4.2 represent the basis for all investigations of WP5 (Developing risk treatment and adaption strategies for each of the six research sites) as the adaption measures investigated in this WP aim to reduce the risks identified beforehand. Further steps of the risk management process have been applied in D4.3 (Risk Analysis – Likelihood and consequences of each extreme weather event at the six research sites) and D4.4 (Risk Evaluation – Estimated level of risk of each event and each scenario at the six research sites) (Rocha et al. 2018a) (Rocha et al. 2018b). In these deliverables, the likelihoods of the different risk events as well the as resulting damages to people, nature and properties were assessed. Thus the determination of the final level of risk in current state and under consideration of climate change predictions was enabled. These investigations serve as reference for the effectiveness evaluation of the adaption measures in this deliverable. By the comparison of the level of risk under consideration of different adaption measures with the levels of risk from WP4, the measure’s effectiveness might be estimated and set in relation to the respective costs and efforts necessary for the measure’s implementation.

Risk treatment within BINGO cases is a complex task as the risks

- have varying risk sources (e.g. water scarcities, heavy rainfall events or sea floods)
- have varying impacts depending on the respective risk and research site (e.g. monetary damages, injuries to people, destroyed cultural heritages or image losses)
- affect different groups of people (e.g. inhabitants living in the affected area, farmers or governmental institutions)

Additionally, the agreement on specific adaption measures between affected stakeholders might be complicated by the questions who will carry the costs and who might suffer under potential negative side-effects of the respective potential measures. Therefore, the aim of this deliverable is to conduct a comprehensive assessment of the economic and social impacts of different proposed adaption measures. The methodologies applied for the assessment shall serve as blueprint for future water managers and decision makers who face similar risks and who are in need of a decision support tool. As the boundary conditions are always varying from case to case, the methodologies must be designed in an adaptable and scalable way. To ensure this adaptability and scalability, all methodologies applied in this deliverable are described and explained in a sufficient degree of detail to enable necessary adjustments.

The investigated adaption measures may be assigned to different categories like administrative, technical or societal measures. Therefore, in many cases the involvement of a large variety of stakeholders is mandatory to ensure an effective risk treatment process. Relevant stakeholders might be governmental authorities, environmental agencies, water utilities, farmers or customers, respectively depending on the nature of the investigated measure. The quality of the methodological outcomes of the adaption measure assessment is highly dependent on the degree of stakeholder involvement as the latter have to provide important data input for the assessment process. In general, the higher the amount and quality of input data for the assessment of different measures is, the more detailed and reliable will be the outcomes.

## 2.2. Generic framework for the assessment of measures' impacts

The implementation of a measure to reduce a risk does only make sense if the gained benefits predominate the required costs and efforts for its realization. To investigate the ratio of costs or efforts for the measure's implementation and the gained benefits, a variety of assessment methods was proposed in the BINGO MS22-report (Suitable assessment methods for the evaluation of adaption strategies and/or measures to climate change) (Koti et al. 2017). The proposed measures of this "BINGO-Toolbox" are illustrated in figure 2.

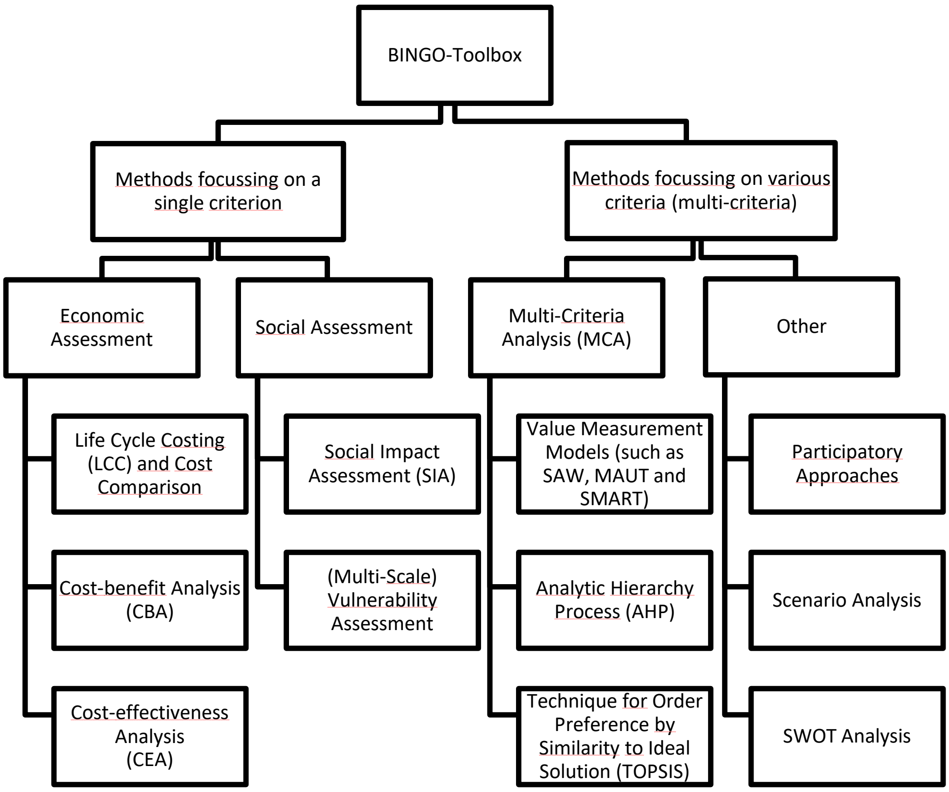


**Figure 2.2: BINGO-Toolbox of proposed assessment methods (Koti et al. 2017)**

The choice of assessment methods applied for the case studies is based on the respective site-specific conditions, data availabilities and the general focus of the case study. In some cases, non-monetary factors were considered to be relevant for the analysis so that in these cases an assessment method like a cost-effectiveness analysis (CEA) was chosen. An example is the case study "DE2 – Too much water", where the number of people and the number of sensitive objects affected by urban floods were part of the analysis in addition to monetary parameters. However, there are also case studies that chose a cost-benefit analysis (CBA) and thus consider only monetary data. Here the Badalona case study may serve as an example. However, independently from the chosen assessment method, the overall systematic is always based on the same thinking. Each methodology compares two general parameters, the mandatory efforts needed for the implementation and maintenance of the measure and the expected benefits from that implementation. Only if the benefits from the implementation of a certain adaption measure predominate the needed efforts it should be considered as a potential option. Any further evaluations of adaption measures, determining how high the benefits predominate the necessary efforts for implementation and maintenance, are conducted to enable a comparison of different rewarding adaption measures and thus to further support the decision process.

To ensure a meaningful assessment, it is important that all relevant data for the assessment methodology is made available. The data requirements and availability are inter alia dependent on

- the applied assessment method,
- the degree of involvement of relevant stakeholders,
- the degree of confidentiality of the required data and
- the assessed adaption measures.

These dependencies underline the importance to set up a thought out concept for the adaption measure assessment at the beginning of the process. Only then it can be ensured that the assessment will work as planned without major disturbances due to data unavailability, a lack of stakeholder engagement or similar.

Although the tools proposed for the assessment are planned to consider and evaluate several characteristics and impacts of the measures, many of them have a strong focus on economic analyses. However, it is important to investigate synergies, non-climate related benefits and negative impacts or trade-offs as well. These investigations allow a prediction of the public acceptance of a measure which is an integral factor for its successful implementation. (Roy et al. 2018)

Therefore, additionally to the conduction of one of the assessment methods proposed in the M22-report, also a social justice questionnaire containing 9 questions was distributed to all case study partners and filled in for each investigated measure. The answers given to this questionnaire enable a more detailed assessment of the different adaption measures. The original empty and all filled in questionnaires can be found in annex I and annex II.

By the answers given to the social justice questions it becomes possible to estimate if social inequalities might be strengthened or reduced by the implementation of an adaption measure. Although a measure might show an excellent ratio of benefits compared to the necessary implementation efforts, their might exist a variety of negative side effects that were not considered in the primary assessment. These side effects could be an uneven distribution of the financial burdens, non-monetary side effects like a reduction of the quality of life by measures with an unattractive appearance or a risk reduction at the expense of increasing risks at other locations. The questionnaire aims to determine such social impacts of the different measures in a qualitative way. It shall help decision makers to estimate the impacts of different measures with regard to a variety of dimensions.

Concluding, the assessment of the different measure's impact conducted in this deliverable aims to consider a large variety of influencing factors from the economic and the social perspective. Although there might still be some important parameters that are not or not sufficiently regarded, the assessment methods provide an appropriate overview of the measure's impacts to support decision makers in their work. The assessment methods should be seen as scalable and adaptable blueprints that, before applying them in different research sites, should be adapted to the site-specific conditions.

# 3 ADAPTATION MEASURES AT WUPPERVERBAND RESEARCH SITE

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## 3.1. Case Study Große Dhünn reservoir – Not enough water

### 3.1.1 *Brief introduction to the case study*

The Wupper basin has an area of 813 km$^2$ and a population of approximately 950,000 inhabitants. In this area 14 reservoirs are located with a total volume of 114 Mio. m$^3$. One of those reservoirs is the Große Dhünn reservoir with a total volume of 81 Mio. m$^3$. This reservoir fulfils a variety of functions like the provision of raw water for drinking water purposes, the provision of process water to contractual partners for industrial purposes and the provision of water to ensure a minimum ecological flow in the downstream Dhünn river. A detailed description of the Dhünn catchment area can be found in (aus der Beek et al. 2016).

As pointed out already in (aus der Beek et al. 2019), the water level in the Große Dhünn reservoir is likely to fall below a critical threshold for security of water supply in future climate decadal predictions. Also the risk assessment within the BINGO work package No. 4 and respective deliverables (Rocha et al. 2018b) pointed out a considerable risk for the reservoir to drop below the critical water level threshold more often in the future.

Thus, the main aim of the case study presented in this report, was to explore adaption measures to reduce this risk. More specifically the objectives were to define, assess and compare alternative adaptation measures.

### 3.1.2 *Stakeholders involved*

The results presented here, are based on a series of workshops conducted along the BINGO project (details can be found in the extensive workshop documentation conducted for BINGO work package No. 6). The raw water supply from the "Große Dhünn" reservoir supplies several drinking water treatment plants as well as water towers per transfer pipe. Thus, stakeholders involved in the complex raw water supply scheme around the reservoir have been collaborating in the workshops: regional water utilities / water boards and municipal or government representatives from the cities Wuppertal, Solingen, Remscheid, Leverkusen and Düsseldorf. The primary involved stakeholder of this study was the Wupperverband, which is the regional water board in charge of operating the Große Dhünn reservoir.

### 3.1.3 Measures, data and assessment methods

**Assessment approach**

The approach followed to compare risk reduction measures was supposed to be a quantitative, indicator based assessment. It needed to incorporate the economic perspective as well as the effectiveness of each measure, in terms of risk reduction. Since the risk reduction effectiveness as primary aim of any adaptation could be condensed in one single criteria, the water availability from the Große Dhünn reservoir, the cost-effectiveness analysis offered a good fitting framework for the comparison. Methodological details about the CEA can be found in the BINGO toolbox (Koti et al. 2017).

In order to evaluate the risk reduction per measure and to apply the CEA, different indicators have been necessary to be calculated. To assess the risk reduction effectiveness, the risk without any measure needed to be comparable to the delta risk with a measure. The central indicator used for that was defined as “number of days below the critical water level threshold” which is defined as “n < 35 Mio. m³”, meaning a water level below that in the Große Dhünn causes major problems in raw water supply. This threshold is based on expert’s knowledge from the reservoir managing staff at the Wupperverband. The basic approach to quantitatively assess the risk reduction effectiveness was consequently followed by calculating the difference in “n <35 Mio. m³” for a scenario without and with a measure. Straightforward, a positive value means a risk reduction and the higher the value the better the measure in comparison to other ones.

For the cost calculation, the annual costs have been estimated for each measure, following the annuity method (DWA 2012). For infrastructural risk reduction measures the investment and operational expenditures have been incorporated in this calculation. For non-infrastructural measures relevant opportunity costs or plausible assumptions have been used as basis for the cost calculation.

In order to compare all measures with a single cost-effectiveness indicator, the ratio of annual costs to additional annual raw water as provided by the measure was calculated (€/m³). This calculation gives a straightforward decision support indicator, easy to understand and interpret by any stakeholder or decision maker.

To complement the quantitative analysis based on technical and economical data also a social justice analysis was conducted. Therefore a social justice questionnaire was filled out by the Wupperverband. Based on the answers further pros and cons of the different adaptation measures of the case study have been qualitatively analysed, especially in light of their social impacts.

**Measures studied and their effectiveness**

To explore the potential of risk reduction four different measures to adapt the raw water supply system based on the Große Dhünn reservoir have been studied:

1. Reduction of low water elevation
2. Transfer pipeline from the Kerspe reservoir to the Große Dhünn reservoir
3. Horizontal well
4. Water saving and emergency schemes

The first measure, the reduction of low water elevation, is a non-infrastructural measure which means a reduction of the water outflow of the reservoir downstream in the river Dhünn. If this measure is taken for specific time frames, it means less outflow and thus a greater accumulation of raw water in the reservoir, to the expense of the low water elevation further downstream. In other words, it is a straightforward measure to enhance the raw water availability in the reservoir.

The second measure, the transfer pipeline, is a infrastructural measure, which would connect the Kerspe reservoir with the Große Dhünn reservoir. The piepe, with a diameter of 600 mm would transfer water from the Kerspe to the Große Dhünn reservoir, meaning an additional inflow of raw water. Thus, the transfer pipeline would also enhance the raw water availability in the reservoir.

In contrast to the first two measures, the horizontal well would be a measure “substitute” raw water from the Große Dhünn reservoir. Thus, in other words, it would not enhance the water availability in the reservoir, but reduce the demand from the reservoir by offering an alternative water source (ground water). The horizontal well is an infrastructural measure, with the need for detailed hydro-geological and technical planning.

By the use of the forth measure, water saving and emergency schemes, the water availability in the reservoir would not be enhanced nor would the water be substituted by an alternative source. Instead, water demand would be reduced, either by new, more efficient household technology (e.g. more efficient washing machines, water saving taps and alike) or by emergency schemes which would mean an official restriction in water use by customers to reduce demand.

Measure No. 1 and 2 have been simulated in their effectiveness to enhance the water availability in the reservoir by the Wupperverband, using a software called TALSIM.

The expectable effectiveness for measure No. 3 and 4 have been based on expert's knowledge and literature values. For the horizontal well an original, existing asset could be used as example to extrapolate the expectable water availability from ground water, more specifically bank filtrate from the river Rhine. The river Ruhr is the biggest river close by the Große Dhünn reservoir.

Climate change and water cycle data from work package 2 and work package 3 within BINGO was used to simulate a time series of the water level in the Große Dhünn reservoir. The simulation was conducted for the base line (no measure / no adaption) from 2015 until 2024 for three ensemble members: R1, R7 and R9. By simple means, R1 represents a scenario with high precipitation, R7 with medium precipitation and R9 with low precipitation. For risk reduction measure No. 1 and 2 the same scenarios have been simulated again, including to mind the effects of the respective solution. For Measure No. 1 (reduction of low water elevation) it was assumed that the water outflow could be reduced from 1 $m^3/s$ at a gauge station downstream (called Manfort) to 0.7 $m^3/s$ in the simulation. For the simulation of measure No. 2 (transfer pipeline) an inflow of 0.2 $m^3/s$ was assumed by the water transfer into the Große Dhünn reservoir. The simulated data was aggregated to daily mean values of the water level to run the subsequent calculations. To be able to compare all four measures calculating a cost-effectiveness ratio as explained above, in terms of annual costs per additional annual $m^3$, the average additional annual raw water was derived from the simulated time series, using the respective simulation data for measure No. 1 and No.2. Since measure No. 3 (horizontal well) is based on an existing asset, its true capacity in $m^3/a$ was used as theoretical maximum effectiveness. For measure No. 4 an average theoretical capacity, based on five different water saving scenarios from literature, calculated for the case studies area with approx. 870.000 inhabitants served and a daily water demand of 120 l (DVGW 2008) without any savings.

**Cost data**

For the measure No. 1 (reduction of low water elevation) the opportunity costs of producing less energy from hydropower, due to a reduction of water outflow and less water pressure reaching the hydro power plant at the dam of the reservoir have been assessed. The data basis used was provided by the Wupperverband (energy generation time series).

Since measure No. 2 is already in a conceptual planning phase, it was possible to base a detailed cost estimation on the route, pipe-diameter, material, construction machine usage and alike, as well as necessary tree felling works and land acquisition. The technical data relevant for the cost estimation has been based on common technical rules (DIN-4124 2012) and necessary values are based on common German standard values for water infrastructural projects (Baur et al. 2019).

The cost data for measure No. 3 (horizontal well) is based on the existing exemplary horizontal well and its technical parameters, combined with the common standard cost values for well construction (Baur et al. 2019).

The cost assessment for measure No. 4 was based on assumption (costs for water saving campaigns).

### 3.1.4 *Assessment results and discussion*

**Risk of raw water shortage and risk reduction effectiveness of measures**

As stated above “the number of days below the critical water level threshold” which is defined as “n < 35 Mio. m³” have been calculated for the base line (no measure) based on three ensembles, R1, R7 and R9. The table below shows the result:

**Table 3.1: Risk of water level in GDT below critical threshold in days with no measure**

| | **Scenario** | | |
|---|---|---|---|
| **Indicator** | R1 (high precipitation) | R7 (medium precipitation) | R9 (low precipitation) |
| Days ↓ (< 35 Mio. $m^3$) | 78 | 317 | 1090 |

The risk for water shortage is considerably high according to the simulation, especially for the climate change scenario with the lowest precipitation. According to the simulated data the lowest water volume simulated of all time series is 10 Mio. $m^3$, which is only 12% of the full capacity (81 Mio. $m^3$). The lowest water volume on average from all three scenarios is 18.6 Mio. $m^3$.

The results of the simulation of risk reduction are summarized in the following table for measure No. 1 and No.2.

**Table 3.2: Risk reduction by measure No. 1 and 2**

| | No measure (base line) | | | Reduction of low water elevation (measure No. 1) | | | Transfer pipeline (measure No. 2) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Indicator** | R1 | R7 | R9 | R1 | R7 | R9 | R1 | R7 | R9 |
| Days ↓ (< 35 Mio. m³) | 78 | 317 | 1090 | 0 | 18 | 32 | 0 | 0 | 750 |

The Table 3.2 shows, that for both measures "the number of days below the critical water level threshold" in the GDT can be reduced considerably, according to the simulations including each of the risk reduction measures. For instance for R1 the indicator can be reduced from 78 to 0 by both measures, and for R7 from 317 to 18 (measure No. 1) or also even 0 (measure No. 2). The lowest relative risk reduction can be overserved from the simulation of measure No. 2 for R9 (from 1090 down to 750). The average lowest daily water level in the reservoir rises from 18.6 Mio. m³ (no measure) to 33.6 Mio. m³ (average from all six risk reduction time series). The preliminary conclusion is, that both simulated measures can serve as good adaptation measure, even though measure No. 2 has the highest residual risk for the "worst case" climate change scenario (R9 – low precipitation).

### Annual costs and cost-effectiveness of measures

The following table illustrates the calculated annual costs for each of the four measures. Additionally it shows the theoretically maximum raw water capacity to either enhance the water storage in the GDT, substitute it or reduce the demand. The latter equals to saving raw water from the GDT.

**Table 3.3: Annual costs, maximal capacity and cost-effectiveness**

| | Annual costs [€ / a] | Annual maximum capacity [m³ / a] | Cost-effectiveness [€/m³] |
|---|---|---|---|
| Reduction of low water elevation | 10,559* | 9,460,800 | 0.001 |

| | | | |
|---|---|---|---|
| Water transfer pipe from Kerspe reservoir | 253,708 | 6,307,200 | 0.040 |
| Horizontal well | 376,534 | 7,007,930 | 0.054 |
| Water saving and emergency schemes | 100,000 | 516,741 | 0.194 |

For the extrapolation of the maximal annual raw water capacity of each of the four measures these figures have been used:

- Reduction of low water elevation: 300 l/s (as used by the Wupperverband for the simulations in general)
- Transfer pipeline from the Kerspe reservoir to the Große Dhünn reservoir: 200 l/s (as used by the Wupperverband for the simulations in general)
- Horizontal well: 222,22 l/s (which is the empirical capacity of the existing well, serving as exemplary asset for the study)
- Water saving and emergency schemes: 328 l/s and assuming that emergency schemes are only feasible throughout 5% of the year (average value, based on several, literature based scenario calculations)

The cost-effectiveness for measure No. 1 is by far the best in comparison to the other measures when looking at the theoretically maximum annual capacity. The two infrastructural measures (No. 2 and No. 3) are similar, still the water transfer pipeline scores slightly better, offering more water per € than feasible with the horizontal well. According to the theoretically maximum, each cubic meter water costs less than one Euro for all measures.

The results for the actual simulated capacities is summaried in Table 3.4 below.

**Table 3.4: Cost-effectiveness based on actual simulated capacity**

| | **Average simulated capacity [m³ / a]** | **Cost-effectiveness [€/m³]** |
|---|---|---|

| | | |
|---|---|---|
| Reduction of low water elevation | 1,776 | 5.946 |
| Water transfer pipe from Kerspe reservoir | 1.886 | 134.523 |
| Horizontal well | 1,776* | 212.059 |
| Water saving and emergency schemes | 1,776* | 56.319 |

* Since the measure “horizontal well” and “water saving” have not been simulated and in order to have a fair comparison, the same average annual capacity as for the “reduction of low water elevation” was used for the calculation.

The results quite clearly illustrate, that once taking in to account not the maximum capacity, but the average annual capacity as given by the model output (simulations from TALSIM), each cubic metre of water for risk reduction bears considerable costs. Still, measure No. 1 offers the best cost-effectiveness, followed by measure No. 2. The two infrastructural measures are revealed to be quite expensive measures, if not operated on the theoretically capacity. Nevertheless, it is important to note, that the non-structural measures (No. 1 and 4) do offer less additional redundancy. In contrast, the infrastructural adaptation measures, like constructing an additional horizontal well, e.g. at the river Rhine, broaden the raw water supply scheme overall, thus enhancing also the overall potential capacity. This in turn can be a valuable investment in a worst case scenario.

**Results derived from the social justice questionnaires**

Apart from the detailed exploration of risk reduction measures, quantitative data analysis and assessment results as presented in the paragraphs above, also an additional so called “social justice analysis” has been conducted, based on three questionnaires about the Große Dhünn reservoir and respective adaptation measures (see annex I for the empty questionnaires and annex II for the answers). The results are presented in this section.

*Social justice analysis – Reduction of low water elevation*

Apart from main aim, ensuring the provision of supply with raw water according to contracts with drinking water suppliers, the measure reduction of low water elevation (reduction of ecological minimum water discharge) has side effects enhancing the social justice for general public (solidary principle), due to the fact that the water is used to provide drinking water to all of the inhabitants without increasing the water price.

The greatest negative side effect that comes with the reduction of ecological minimum water discharge is that less water is passing the dam, so less energy can be produced by the water flow. This maybe leads to less revenue than expected, The general public can be affected, because the lower water level in the rivers behind the dam can lead to a reduced ecosystem services due to the intervention in the ecosystem e,g, reduced $O_2$-level or worse living conditions in general.

*Social justice analysis - Substitution with alternative water sources or water savings*

Apart from main aim, ensuring the provision of supply with raw water according to contracts with drinking water suppliers, the measure substitution with alternative water sources or water saving has side effects enhancing the social justice for general public (egalitarian principle), due to the fact that the water is used to provide drinking water to all of the inhabitants, with possible increase of inequalities due to increasing water prices. As they increase in the same amount for everyone, especially poor people will be relatively more affected by the financial burden.

The increase of the water price is the greatest negative side effect that comes with the measure substitution with alternative water sources. The increase of the water price could have several reasons, depending on the actual realized measure. In the first place the operating costs could increase, if the water supplier has to by additional water from another water supplier. Also building of a new water extraction process is possible, In addition there is maybe a new softening or water treatment process necessary. To cover this costs the water supplier could increase the water price. As a result of possible potential water savings the piping system has to be flushed more frequently, which also leads to higher costs for the water supplier and may affect the water price.

The general public benefits from the main measure in dry periods, because the drinking water quantity is ensured.

*Social justice analysis – Transition between reservoir catchments*

Apart from main aim, ensuring the provision of supply with raw water according to contracts, the measure transition between reservoir catchments has several side effects enhancing the social justice for general public (egalitarian principle), due to the fact that the water is used to provide drinking water to all of the inhabitants, including a minimum price increase for all.

The greatest side effect of the transition between reservoir catchments are the direct costs and the resulting additional cost. The Wupper Association will probably be pay the direct costs of the measure which might lead to increasing costs for the contractual partners and this in turn might lead to increasing costs for the consumers (higher water prices).

The properties affected by the pipe/channel route will probably reduce in value, because of the decrease of the land‘s “recreational value” due to a less attractive landscape. This in turn can also lead to cost for the municipality or again the Wupper Association, since maybe compensation payments for land owners are claimed. The pipe/channel route can also cause potential negative effects on the landscape and on the environment, which affects the general public and maybe also the municipality.

### *3.1.5 Conclusions and outlook*

The results revealed the measure "reduction of low water elevation" to be a very cost-effective solution Furthermore, the infrastructural measures are very expensive measures compared to the non-infrastructural measures, at least in relation to the actually required amount of water for risk reduction, according to the simulated results. Among the infrastructural measures, the “transfer pipe from the Kerspe reservoir” is the more cost-effective solution. "Water saving" is a realistic and sufficient emergency measure, but less cost-effective than the measure "reduction of low water elevation".

In summary, the results suggest to be the "reduction of low water elevation" the preferable measure. However, here it is very important to note, that without infrastructure measures no redundancy remains as a "risk buffer" in the future. This means, if a conservative, precautions (risk averse) climate change adaptation strategy is preferred, then additional infrastructural measures like the ones explored and presented above, are strongly recommended to be considered. As an outlook and straightforward next step for the Wupperverbands adaptation to climate change and reduction of raw water availability risk, the discussion and more detailed review of whether and how additional infrastructure measures can be financed is important.

## 3.2. Case Study Wuppertal – Too much water

### *3.2.1 Brief introduction to the case study*

The case study "Wuppertal – Too much water" deals with the risk of urban flooding that is caused by heavy precipitation events along the Mirke Creek. The Mirke Creek is a ca, 6 km long stream that runs from the northern part of the city Wuppertal southbound until it disembogues into the river Wupper. The route of the Mirke Creek is visualized in Figure 3.1. The management of the Mirke Creek lies within the responsibility of the Wupperverband that is currently wishing for a decision support methodology to prioritize different adaptation measures. The work described in this chapter shall serve this wish and support the Wupperverband in prioritizing potential adaptation measures. A more detailed description of the internal and external context of the research site can be found in D4,1 (Viseu et al. 2016).

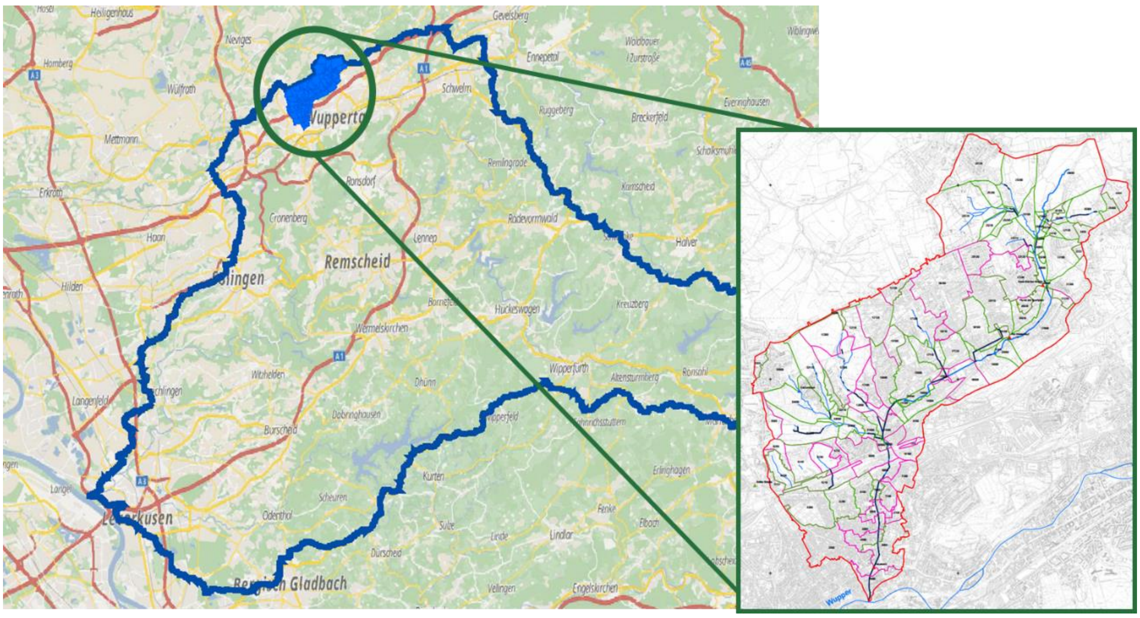


**Figure 3.1: Route of the Mirke Creek in the city of Wuppertal (source: Wupperverband)**

The majority of the Mirke Creek runs through highly urbanized parts of the city with several subsurface sections of the stream. By local stakeholders, several hotspots could be identified along the Mirke Creek that are susceptible to urban flooding as result of heavy precipitation events. Seven of these hotspots were chosen for an in-depths analysis of existing risk levels and the potential to mitigate these risks with suitable adaptation measures. An overview of the investigated hotspots is shown in Figure 3.2.

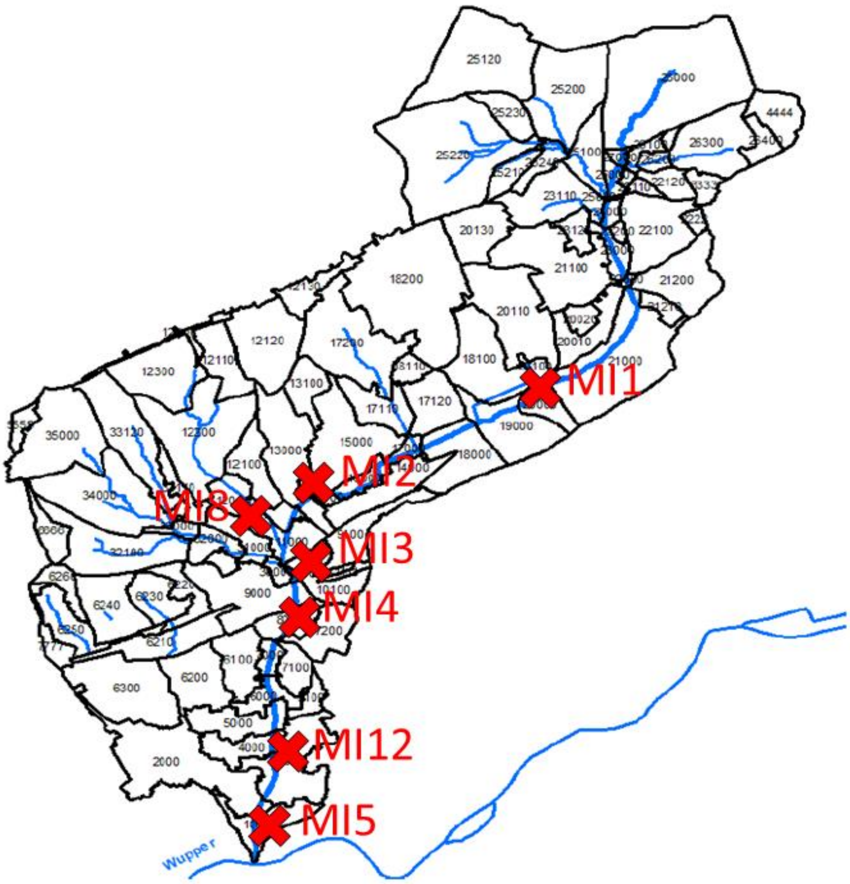


**Figure 3.2: Overview of the investigated hotspots in the case study "Wuppertal – Too much water", based on (Hydrotec 2018-2019)**

The focus of the work conducted in T5,2 lies on the determination and socio-economic analysis of potential adaptation measures to reduce existing and potentially emerging risks. Therefore the actual risk levels at the different hotspots are compared to the expected remaining risk levels after the implementation of the potential measures. As the prioritization of adaptation measures should also take into account their economic feasibility, two different indicators have been developed that take into account the amount of risk reduction as well as the related costs of the respective measures.

Based on the climate change projections that were generated in WP2 of the BINGO project, it may be expected that heavy precipitation events will occur more often in the future (a more detailed and quantitative analysis we be conducted later in this chapter). This increase of heavy precipitation events may in turn cause an increase of urban floods. To determine the expected aggravation of heavy precipitation events leading to urban floods, climate change data sets from WP2 in two different resolutions have been evaluated. This climate change data covers the timeframes 2006-2100 for daily precipitation intensities and 2070-2100 for 5-min precipitation intensities.

### 3.2.2 Stakeholders involved

For a comprehensive socio-economic analysis of the adaptation measures in the case study “DE2 – Too much water”, a variety of different stakeholders has been integrated in the discussions and the concept for prioritizing the measures. The following list gives an overview of the involved organizations in the workflow for this case study:

- Wupperverband (Wupper Association)
- Hydrotec GmbH (Hydrotec Engineering Office)
- Untere Wasserbehörde Wuppertal (Lower Water Authority)
- Wasser und Abwasser Wuppertal (Water and Wastewater Department of the city of Wuppertal)
- Climate Protection Department of the city of Wuppertal
- Wuppertaler Stadtwerke (Municipal Utility of Wuppertal)
- IWW Water Centre

There cannot be one stakeholder or a limited number of stakeholders determined that can be designated as risk owner. The risk owner is rather any person, company or similar that is living or located in the periphery of one of the hotspots. Therefore, also the responsibility for the implementation of adaptation measures cannot be designated to one stakeholder.

The responsibility for the implementation of adaptation measures depends inter alia on the measure that is regarded. While the responsibility for the construction of a retention basin is clearly located at organizational level like the Wupperverband, this is not the case for object protection measures. For the latter, the affected inhabitants carry a large portion of the responsibility as here the Wupperverband is only active in consultative function. However, the implementation of adaptation measures against urban floods and climate change is one important task of the Wupperverband and other public bodies that are connected to the subject.

### 3.2.3 Measures, data and assessment methods

In the socio-economic analysis of adaptation measures for the case study “DE2 – Too much water”, three different measures have been investigated, These three measures are

- a line protection for the implemented at hotspot MI 1,
- a retention basin for the protection of the hotspots MI 2-5 and MI 12 and
- the implementation of object protection measures at hotspot MI 8.

The mechanism to reduce the risk differs from measure to measure. An object protection works by avoiding that water from an occurring flood can enter a building or rather by increasing the water level that leads to damages in a building.

A line protection acts relatively similar to an object protection, Instead of increasing the critical water level specifically per object, it is increased in the direct environment of the water body. Thus the critical water level in the creek which is leading to urban floods is increased.

A retention basin is built to store a surplus of water from heavy precipitation events. Thus this surplus water does not lead to urban floods and can be released in a controlled way once the precipitation event is over. This measure differs from the other measures especially by the fact that it affects all downstream hotspots and not only the hotspot where it is implemented. In the following the approach for the socio-economic analysis shall be described.

**Analysis approach**

The socio-economic analysis conducted aims to support the responsible stakeholders to take a decision on which adaptation measures should be implemented. This is realized by assessing them with two different indicators. These two indicators are

1. the annual monetary benefit gained by the implementation of the measure, calculated with equation (1).

$$Monetary\ benefit = Reduced\ monetary\ damage\ \left[\frac{€}{a}\right] - Cost\ of\ Measure\ \left[\frac{€}{a}\right] \qquad (1)$$

2. the annual cost per % of non-monetary benefit, calculated with the formula shown in Figure 3.3.

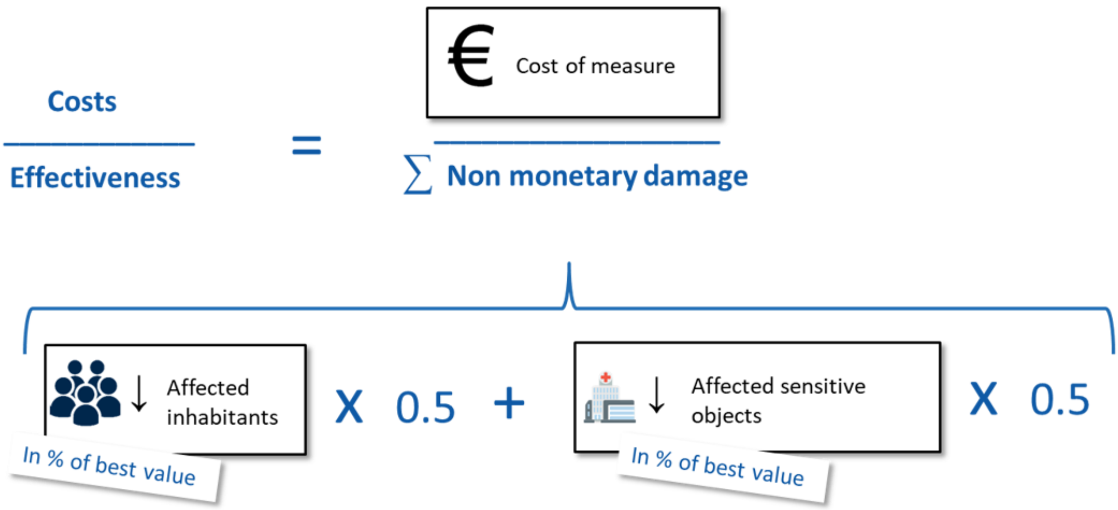


**Figure 3.3: Calculation of the cost per % of non-monetary benefit**

Positive values calculated by equation (1) indicate that the implementation of the respective measure is reasonable from an economic point of view. Thus it is in most cases advisable to implement the measure. However, it is possible that significant non-monetary justify a decision against the implementation of the measure. On the other side, the calculation of negative values indicates that there is no economic justification to implement the measure. However, here also significant non-monetary benefits of the measure might justify to implement the measure anyway.

The indicators for the non-monetary benefit of the adaptation measures were determined during a stakeholder workshop that took place at the Wupperverband on 4th of June, 2018. In that workshop, the stakeholders agreed on the following 9 potential indicators for the non-monetary benefit:

- the number of affected people
- the degree of constraint of rescue routes
- the number of monuments/memorials affected
- the effects on the urban development
- the effects on the cityscape
- the ecological effects
- the effects on the microclimate
- the effects on the image of the responsible stakeholders
- the number of sensitive objects affected (like hospitals, police stations, etc.)

In a subsequent stakeholder workshop (10.07.2018), a weighting of these indicators was conducted by the participants. Therefore each indicator was compared to all other indicators in pair-wise comparison, always answering the question which of the two compared indicators is rated as more important. If indicator A was rated to be more important than indicator B, indicator A got 2 points while indicator B got 0 points. In case of an equal rating of both indicators, each of them got 1 point. For this pair-wise comparison the template shown in Annex III was distributed to the stakeholders. The result of this scoring is shown in Figure 3.4.

| Indicator | *Effects on image* | *Number of sensitive objects affected* | *Number of affected people* | *Constraints on rescue routes* | *Monuments/memorials affected* | *Effects on urban development* | *Effects on cityscape* | *Effects on ecology* | *Effects on microclimate* | ***Sum of points*** | *Ranking* | ***Weighting Factor*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Effects on image | X | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | **2** | *9* | **2,78%** |
| Number of sensitive objects affected | 2 | X | 1 | 1 | 2 | 2 | 2 | 2 | 2 | **14** | *2* | **19,44%** |
| Number of affected people | 2 | 1 | X | 2 | 2 | 2 | 2 | 2 | 2 | **15** | *1* | **20,83%** |
| Constraints on rescue routes | 2 | 1 | 0 | X | 2 | 1 | 1 | 1 | 1 | **9** | *4* | **12,50%** |
| Monuments/memorials affected | 1 | 0 | 0 | 0 | X | 1 | 1 | 0 | 0 | **3** | *8* | **4,17%** |
| Effects on urban development | 2 | 0 | 0 | 1 | 1 | X | 1 | 0 | 1 | **6** | *6* | **8,33%** |
| Effects on cityscape | 1 | 0 | 0 | 1 | 1 | 1 | X | 0 | 0 | **4** | *7* | **5,56%** |
| Effects on ecology | 2 | 0 | 0 | 1 | 2 | 2 | 2 | X | 1 | **10** | *3* | **13,89%** |
| Effects on microclimate | 2 | 0 | 0 | 1 | 2 | 1 | 2 | 1 | x | **9** | *4* | **12,50%** |

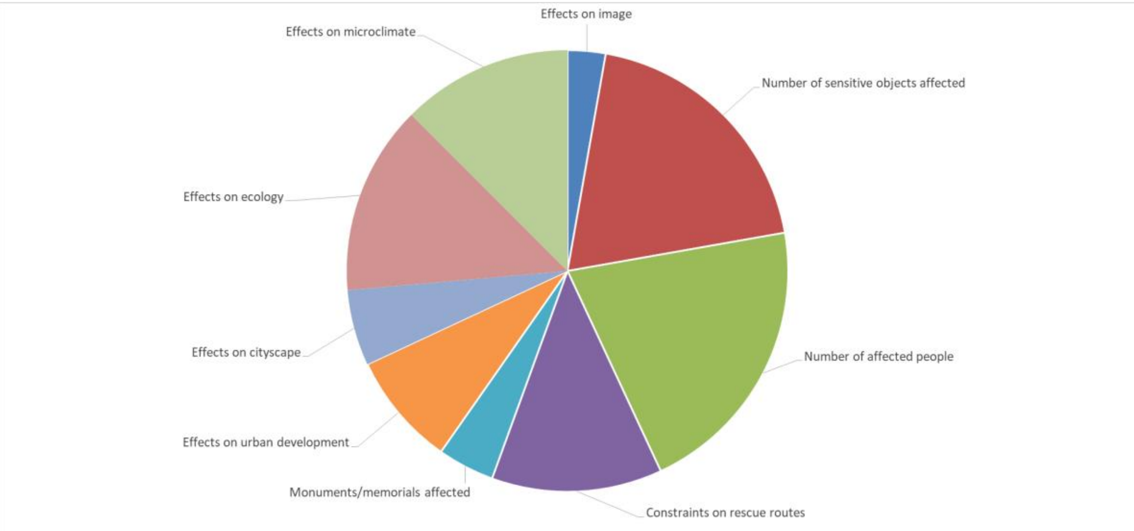


**Figure 3.4: Results of the stakeholder weighting of the 9 potential indicators for non-monetary benefits**

Although 9 indicators were determined and weighted, the subsequent data acquisition showed that a quantification for all these indicators is not feasible within the case study framework. Therefore, it was decided to concentrate on the two indicators that were weighted to be the most significant ones, namely the "number of affected people" and the "number of affected sensitive objects". In the economic analysis, both of these indicators will be weighted with 50 % as their weighting by the stakeholders was almost equal.

As most likely “the number of affected people” is significantly higher than the “number of affected sensitive objects”, the use of absolute values for these indicators would not be possible if an equal weighting shall be ensured. Thus, both indicators for the non-monetary benefits are considered as relative values in the equation in Figure 3.3. The measure that reduces the highest absolute number of affected people / affected sensitive objects is assigned to the value 100%, respectively. The value of the remaining two measures for the two indicators is determined in relative relation to this highest absolute value. An example with arbitrary numbers is given in Table 3.5.

**Table 3.5: Exemplary calculation of the relative values for the indicators of non-monetary benefits**

| Measure | Reduced number of affected people | Relative number of affected people [%] |
|---|---|---|
| Measure 1 | 150 | (150 / 400) * 100 = 37,5 |
| Measure 2 | 400 | 100 (as it is the highest absolute value of the investigated measures) |
| Measure 3 | 60 | (60 / 400) * 100 = 15 |

**Input data sets**

The investment costs and the yearly operational costs of the respective measures have been estimated by the engineering office Hydrotec GmbH (Hydrotec 2018-2019). From these two datasets the annual costs have been calculated by summing the yearly operational costs and the investment annuity. The latter has been calculated by applying equation (2), based on DWA (2012).

$$Invest\ annuity = C * \frac{i * (1+i)^n}{(1+i)^n - 1} \qquad (2)$$

In this equation, C marks the total investment costs of the measure, i marks the discount rate and n marks the expected lifetime of the respective measures. Table 3.6 gives an overview of the most important input data for the respective measure’s costs.

**Table 3.6: Input data for the cost estimation of the three adaptation measures**

| Measure | Investment costs [€] | Operational costs [€/a] | Expected lifetime of the measure [a] | Discount rate [%] |
|---|---|---|---|---|
| Line protection | 300,000[1] | 300[1] | 80[2] | 3[3] |
| Retention basin | 2,501,061[1] | 5,500[1] | 80[2] | 3[3] |
| Object protection | 70,000[1] | 350[1] | 50[4] | 3[3] |

The monetary damages have been determined by considering damages to buildings and vehicles in the flooded areas. The affected buildings have been determined by Hydrotec from flood maps for $HQ_{500}$, $HQ_{100}$ and $HQ_{10}$ events. Each of the affected buildings has been assigned to one of the economic sectors that are defined by the German Federal Statistical Office (Bundesamt 2008). The assignment to the economic sectors was realized inter alia by location inspections and investigations of the affected area in Google Maps. Based on information from the German Federal Statistical Office, different asset values have been assigned to the affected buildings by Hydrotec, following a common national classification for business classes (Statistisches-Bundesamt 2008). Thus, total monetary damages for each flood event ($HQ_{500}$, $HQ_{100}$, $HQ_{10}$) have been calculated by matching the usage category of the affected buildings with their asset values.

By intersecting the three different flood maps with census data, the number of affected people per flood event could be determined (Zensus 2011). Furthermore, it was assumed that one vehicle with a value of 10,000€ exists for every 3 inhabitants in the flooded area. For the flood events $HQ_{500}$, $HQ_{100}$ and $HQ_{10}$, a damage of 30%, 10% and 1% of the vehicle's value was assumed, respectively.

The number of affected sensitive objects was determined based on the economic sector that the affected buildings have been assigned to. In the case study area, the following categories that are defined as "sensitive objects" are relevant, based on a national statistical classification of business sectors, so called "WZ-codes" (Statistisches-Bundesamt 2008):

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[1] Hydrotec (2018-2019) Hydrologische Modellierung des Mirker Bachs, Hydrotec Ingenieurgesellschaft für Wasser und Umwelt mbH, Aachen.
[2] Values based on: DWA (2012) Leitlinien zur Durchführung dynamischer Kostenvergleichsrechnungen (KVR Leitlinien) (translation: Guidelines to conduct dynamic cost comparisons).
[3] Values based on: ibid.
[4] Assumption

- WZ 50: Automobile trade, maintenance and repair of motor vehicles & petrol stations
- WZ 80: Education and Lessons
- WZ 85: Health care, veterinary services & social services

The expected annual monetary damages, affected people and affected sensitive objects are calculated by equation (3) which is based on a methodology proposed by the German DVWK (DVWK 1985).

$$S_a = \sum_{i=1}^{k} S(i) * \Delta P_i \qquad (3)$$

In equation (3), $S_a$ marks the expected annual damage, S(i) marks the average expected damage between two probability values and $\Delta P_i$ marks the difference between these two probabilities, S(i) is calculated by equation (4) while $\Delta P_i$ is calculated by equation (5).

$$S(i) = \frac{S(P_{i-1}) + S(P_I)}{2} \qquad (4)$$

$$\Delta P_i = |P_i - P_{i-1}| \qquad (5)$$

The parameters in the equations (3) - (5) are visualized in Figure 3.5 for a better understanding. In this figure exemplary monetary values are used.

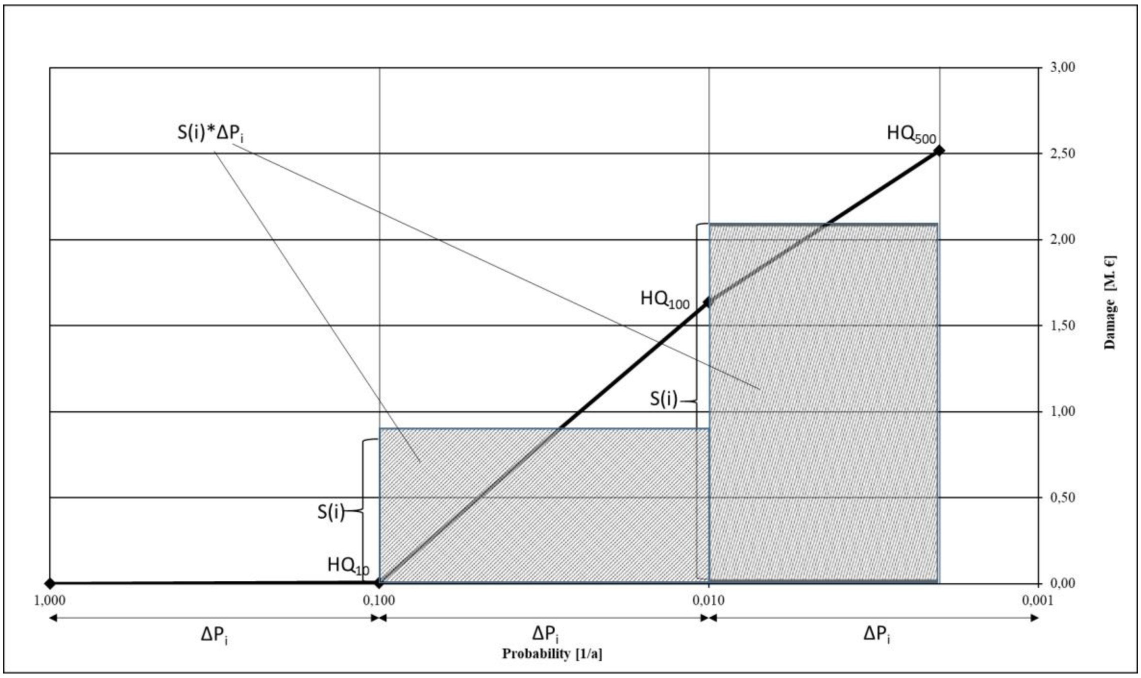


**Figure 3.5: Visualization of the calculation method for expected annual damages, based on (DVWK 1985)**

Different sets of climate change data have been considered in this case study. First of all, design rainfalls have been determined from KOSTRA data which is provided by the German Weather Service (DWD 2018). This data is based on rainfall series from 1951-2010. The design rainfalls have been determined for daily precipitation amounts as well as for 5-min rainfall periods. The chosen annuities were 10-yearly and 100-yearly events for daily precipitation and 10-yearly events for 5-min precipitation, 100-yearly events for 5-min precipitation have not been considered as no sufficient climate projection data exists for a reliable evaluation. Information on rainfall intensities is given as raster data with cells that cover an area of 67km$^2$. The case study area lies within the cells with the following coordinates as centres:

- Cell 1 → latitude: 51,291, longitude: 7,064 (Index 51011)
- Cell 2 → latitude: 51,307, longitude: 7,238 (Index 51012)

As approximately one half of the case study area lies in each of the cells, thus the arithmetic mean of the rainfall intensities in those two cell was assumed to be the design rainfall. The design rainfall intensities in the case study area are shown in Table 3.7.

**Table 3.7: Design rainfall events determined from KOSTRA data (DWD 2018)**

| Temporal resolution | Annuity | Rainfall intensity | | |
|---|---|---|---|---|
| | | Cell 1 | Cell 2 | Arithmetic Mean |
| Daily precipitation amount | 10-yearly | 62,4 mm/d | 61,8 mm/d | 62,1 mm/d |
| | 100-yearly | 86,1 mm/d | 81,9 mm/d | 84 mm/d |
| 5-min resolution | 10-yearly | 12,2 mm/5min | 11,7 mm/5min | 11,95 mm/5min |

For this case study, it is assumed that a 10-yearly precipitation event approximately causes an $HQ_{10}$ flood event and that a 100-yearly precipitation event approximately causes an $HQ_{100}$ flood event.

Three sets of climate projection data have been applied to assess the impact of climate change on flood event frequencies in the case study area. To evaluate the increase of daily precipitation events, data sets generated by the FU Berlin within the BINGO project (Work package No. 2) have been applied. These data sets are based on the IPCC RCP4,5 and RCP8,5 scenarios, respectively. The timeframe for these predictions of daily precipitation are the years 2006-2100, Furthermore, the geographical resolution of these predictions is similar to the ones from the KOSTRA data, thus the same raster cells have been applied and also the arithmetic mean has been calculated.

To evaluate the increase of 5-min heavy precipitation events, predictions of extremal episodes provided by FU Berlin within the BINGO project have been applied. These extremal episodes consist of predicted precipitation intensities in 5-min resolution for the months June-October in the years 2070-2100, respectively. Due to a lack of longer and more detailed predictions in 5-min resolution, the evaluation is based on the assumption that in the rest of the regarded years (months October-May), the threshold for 10-yearly 5-min precipitation events is not exceeded. The geographical resolution of the extremal episodes differs from the one in the KOSTRA data sets. From the predictions of extremal episodes two raster points have been chosen as representative for the case study area and the arithmetic mean of the predicted values at these raster point was calculated for the final assessment of climate change impact. The coordinates of the raster points chosen for the analysis are

- Point 1 → latitude: 51,250, longitude: 7,136 and
- Point 2 → latitude: 51,270, longitude: 7,136,

To determine the future expected annuities of 10-yearly and 100-yearly events based on the climate predictions, the amount of exceedances of the actual status quo threshold is counted and divided by the investigated timeframe. Afterwards the reciprocal of this value is calculated to determine the annuity, This was done by equation (6).

$$Predicted\ annuity = \frac{1}{\frac{No,of\ threshold\ exceedances}{Investigated\ timeframe}} \qquad (6)$$

Finally, also the social effects of the potential adaptation measures have been evaluated. This was realized by the provision of questionnaires for each measure to the respective responsible stakeholders. These questionnaires aimed to answer questions with regard to the distribution of costs or burdens and benefits for each measure so that a qualitative assessment of the social impacts was made possible. The original questionnaire used for each measure can be found in annex I.

### 3.2.4 Assessment results and discussion

**Socio-economic analysis**

As described in chapter 3.2.3, the socio-economic analysis was conducted under consideration of two different indicators, namely the annual monetary benefit gained by the implementation of the measure and the annual cost per % of gained non-monetary benefit. In Figure 3.6 the values of the indicators calculated for the three investigated adaptation measures are shown.

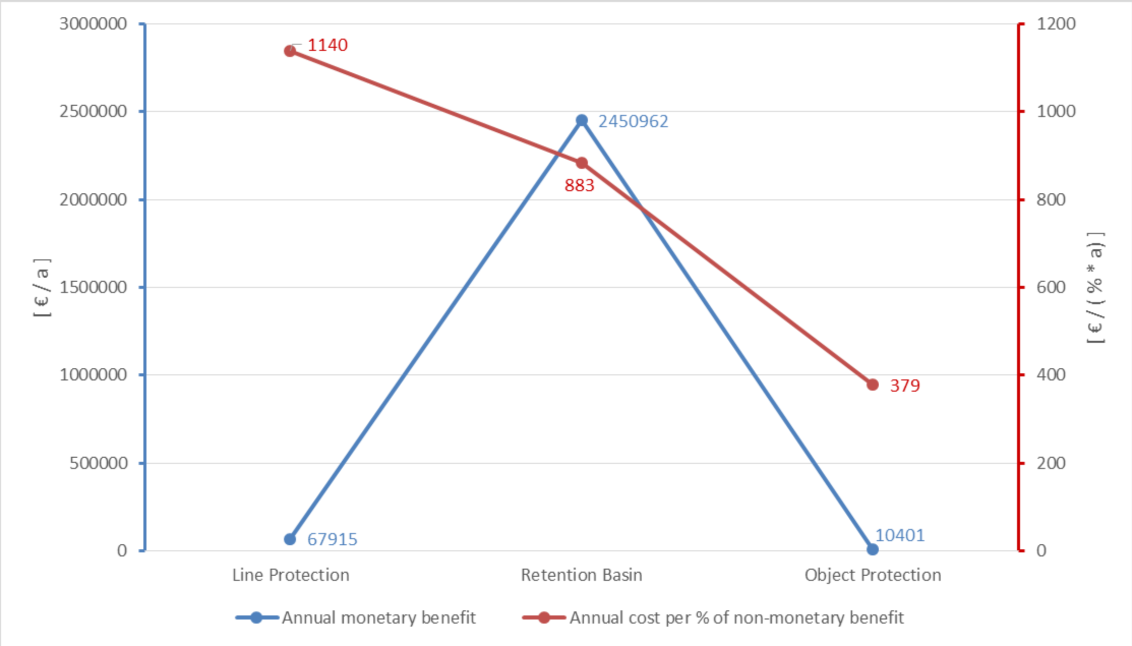


**Figure 3.6: Results of the calculations of the two indicators a) annual monetary benefit and b) annual cost per % of non-monetary benefit for the three investigated adaptation measures**

The retention basin shows to have by far the highest annual monetary benefit. With about 2,450,000 € of saved money each year, it turned out to be economically a very profitable measure. This is remarkable especially because the retention basin is also by far the most expensive one of the investigated adaptation measures (cf, table 3.2). However, the calculated high profitability is caused by its effectiveness on a multitude of hotspots (MI2-5, MI12) that are located downstream of the retention basin. This is the most significant difference of the measure “retention basin” in comparison to the other two adaptation measures, whose effectiveness is exclusively limited to the hotspot where they are implemented.

Although the other two measures are expected to gain significantly less economical profit (2,7% and 0,42% compared to retention basin for line protection and object protection, respectively), they still turned out to be economically advisable too as the expected avoided monetary damage per year is higher than the annual costs of the measure. Thus, for a final decision which measure(s) should be implemented, the relevant decision makers have to balance between the high monetary benefits of measure 1 and the lower costs of the measures 2 and 3.

The analysis of the calculations for the costs per % of non-monetary benefit resulted in a different measure that showed the best value for this indicator. Here the object protection is the adaptation measure that promises the highest amount of non-monetary benefits per euro spent for the measure. The object protection's annual costs of 379€ per % of non-monetary benefits lie significantly under the 883 / 1140 € / (%*a) of the other two measures.

The results of both indicators, the one for the monetary benefits as well the one for the costs of non-monetary benefits, have to be interpreted from a holistic point of view. Neither single decision makers like water associations, governments or similar get information on their individual advantages from implementing the measure, nor do the stakeholders affected by the floods receive information on the amount of their personal gains. The indicators rather allow a holistic evaluation of the economic and social benefits that a community can gain from the implementation of different adaptation measures, without specifying who exactly will predominantly profit from the measures' advantages and who will rather suffer from their negative side effects. However, this limitation does not devalue the important information that can be gained from the calculated indicators. They got the potential to serve as important pillars in the decision processes for or against different adaptation measures as the decision should always be based on a maximum gain of public welfare.

However, one important limitation has to be kept in mind for the second indicator. This limitation shall be explained based on the values of non-monetary benefits and costs for the investigated adaptation measures given in Table 3.8.

**Table 3.8: Calculated values for the determination of the annual costs per % of non-monetary benefit**

| Adaptation Measure | Relative reduction of no, of affected people [ % ] | Relative reduction of no, of affected sensitive objects [ % ] | Annual cost of measure [ € / a ] | Annual cost per % of non-monetary benefit [ € / ( % * a ) ] |
|---|---|---|---|---|
| Line protection | 3,4 | 14,5 | 10,234 | 1,140 |
| Retention basin | 100 | 100 | 88,316 | 883 |

| | | | | |
|---|---|---|---|---|
| Object protection | 6,62 | 9,6 | 3,071 | 379 |

Table 3.8 shows that the retention basin has got by far the most non-monetary benefits which are at rough estimate ten to twenty times higher than the ones gained by the other two measures. Nevertheless, the indicator indicates that e.g. the object protection is more advisable to implement as the costs per % of non-monetary benefit are lower. This example illustrates that the indicator just gives information on the costs per percent of non-monetary benefit gained, neglecting the amount of increase of non-monetary benefits. It may not be forgotten that the significantly lower amount of non-monetary benefits gained by the object protection cannot simply be compensated e.g. by spending the double amount of money to get the non-monetary benefits doubled. The costs per % of non-monetary benefits with this indicator are calculated for one specific scenario.

The calculated results for the two indicators do not deliver a final decision which adaptation measure from a set of different measures should be implemented. They rather represent sound pillars that the final decision should be based on. The final decision will strongly depend on the stakeholder who has to take the decision as the interpretation of the calculated results might differ significantly from stakeholder to stakeholder. The answers to the following questions might have a strong impact on the final decision which adaptation measures will be implemented:

- Is the stakeholder that takes the decision for or against adaptation measures the same as the one who pays the measure?
- Will the stakeholder that pays the measure also be the one that profits from the reduction of the monetary damages?
- In how far does the stakeholder that pays for the measure also profit from the non-monetary benefits?

The results of the calculations conducted in this case study may not be transferred to other cases without any limitations. The results may look very different for line protections, retention basins and object protections at other locations and research sites, Despite of this limitation, the methodology that was developed and presented itself is transferable. Both indicators are promising to support decision makers also at other locations and research sites in their work.

**Expected climate change impacts**

Expected changes in the global climate may also affect the region of Wuppertal, Therefore overall three future scenarios have been evaluated with regard to their effects on heavy precipitation frequencies in the region. These three scenarios are described in detail in chapter 3.2.3. The changes in precipitation annuities are shown in Table 3.9.

**Table 3.9: Climate change prediction for mean daily precipitation and for 5-min heavy precipitation events**

| Climate change scenario | Precipitation Intensity | Annuity in status quo | Expected future annuity |
|---|---|---|---|
| RCP 4,5 | 62,2 mm/d | 1/10a | 1/31,3a |
| RCP 4,5 | 84 mm/d | 1/100a | No event predicted |
| RCP 8,5 | 62,2 mm/d | 1/10a | 1/13,4a |
| RCP 8,5 | 84 mm/d | 1/100a | No event predicted |
| Extremal episodes | 11,95 mm/5min | 1/10a | 1/0,04a |

The results for daily precipitation and the results for 5-min heavy precipitation show different future trends. For both scenarios investigating daily precipitation (RCP 4.5 & RCP 8.5) the frequencies of rainfall 10-yearly rainfall events decrease. Here the RCP 4.5 scenario turned out to be a drier scenario than the RCP 8.5. Rainfall events that are marked as 100-yearly events in status quo have not been predicted at all in the period from 2006-2100, neither in the RCP 4.5 nor in the RCP 8.5 scenario. These investigations confirm the expected drier future scenarios. However, the results look significant different for the 5-min lasting heavy precipitation events from the extremal episodes. Here a very strong increase of heavy precipitation event frequencies from once in 10 years to 25 times per year can be expected. In other words, the precipitation amounts in the future are expected to decrease, however the remaining amounts of precipitation might fall in shorter and concentrated timeframes. This might especially lead to an increase of urban floods by exceeding the drainage capacity along the Mirke Creek, illustrating the need to take action and to implement efficient adaptation measures.

However, one should keep in mind the limitations of the calculated values' validity. The daily precipitation intensities do not give much information on the hazard of urban flooding the rainfall might be very distributed during the day. Thus, these predictions have only limited validity with respect to short heavy rainfall events.

Furthermore, it has to be kept in mind that the extremal episodes have been applied as “best case” scenario. As already described in chapter 3.2.3. Predictions have only been available for the months June-October for the years 2070-2100. For the rest of these years it has been assumed that the threshold for status quo 10-yearly precipitation is not exceeded. Thus the predicted value is most likely more optimistic than it can be expected considering potential rainfall events in the time period from October-May in the investigated years.

Summing up it can be stated that, although the overall precipitation amounts are expected to decrease in the future in Wuppertal, the occurrence of short heavy rainfall events leading to urban flooding will increase significantly emphasizing the need to adapt to these aggravations of precipitation patterns.

**Results derived from the social justice questionnaires**

In the following, the results from the answered questionnaires are described in a qualitative way. These evaluations shall support the responsible stakeholders in their process of decision making which of the potential adaptation measures should be implemented, In combination with the indicators, these social justice evaluations ensure that the decision makers get a holistic view of the adaptation measures’ impacts.

*Retention basin*

For the impacts of the retention basin the solidarity principle applies, because property owners downstream of the retention basin benefit from the measure while property owners above the endangered areas have the rainwater basin built on their properties or in its direct environment. Accordingly the measure is not helping the general public, but rather direct people with a great exposure to urban floods caused by heavy precipitation events.

Apart from the measure’s main aim, which is the minimization of the negative effects accompanying urban floods, a retention basin has several side-effects.

One benefit for the endangered property owners may could be a better insurability of buildings and belongings on the property due to a better protection of the latter. This might be a significant monetary relief.

The direct monetary burden in this case lies just at the Wupper Association which would be responsible for the costs of implementing and operating the retention basin. An indirect monetary burden might be expected for the property owners in the surroundings of the basin due to its potential negative environmental impacts and a decrease of the environment’s aesthetics. Thus the value of their properties maybe decreasing. To minimize this effect an appealing design of the basin and an environmentally friendly construction of the basin (“green engineering”) should be considered.

For the Wupper Association also the water quality of the rivers and lakes plays an important role. With the measure of a retention basin the quality maybe can enhanced, because the amount of direct runoffs into the natural streams after a rainfall is reduced.

*Object protection*

Here the deontological principle applies, due to the fact that not the general public benefits from the measure, Instead the property and house owners who are living in the hot spot areas (area with potential flooding risk) are paying for and benefiting from the technical protections,

Hence the property owners are mainly influenced by the negative side-effects. Besides the fact that the costs for the measures are not jet clearly allocated, potentially one part of the costs has to be beard by property owners and other parts by funding or subsidies. Also the property's value can decrease due to decreased aesthetics and the implication of an obvious flood risk. For the protection of public places and public buildings, most likely the municipality has to pay. However, the social perception (trust) in the municipality's efficiency could increase with this measure, depending on the broad public perception. To minimize the negative effects, the technical protection should have an appealing design to embellish public places.

With the measure the local, private construction companies can benefit from a stable order situation and can co-determine the image of the municipality.

*Line protection*

For the line protection the equity principle relies on who takes over the costs for the measure in the end. The solidarity principle applies if the Wupper Association is paying, because then it is focused on enhancing the situation for all flood affected people. Instead the principle changes to the deontological principle if the property owners are paying (which is less likely). In this case the property owner would be responsible and the high costs which have to be paid for the implementation can even lead to an increase in social inequalities.

A mitigation of the negative effects, due to the decrease of landscape aesthetics, can be done by an appealing design of the line protection.

### 3.2.5 Conclusions and outlook

In the case study "DE2 – Too much water" a solid concept to support the prioritization of adaptation measures was developed. By using a customized method and set of quantified indicators as well as with an additional social justice analysis, the responsible stakeholders are provided with tools supporting the decision for or against certain measures. The methodology is transferable to different case studies in different countries and thus not limited to an application in the Wupper basin.

From the three investigated adaptation measures, all of them turned out to be economically valuable. However, the final decision should also take into account the amount and distribution of non-monetary benefits. Thus, the decision is always case specific and cannot be taken generally. For this case study, the retention basin turned out to promise by far the most benefits after its implementation. However, due to the significantly higher costs, the decision for this measure should be checked beforehand to ensure sufficient financial resources. In case of limited financial resources, the object protection promises the lowest costs per % of non-monetary benefits and thus an efficient alternative.

The climate change projections predicted an overall decrease of rainfall amounts with a significant increase of short heavy precipitation events that might lead to a similar increase of urban flood events. This finding emphasized the need to act and to implement effective adaptation measures.

In future work the indicators for non-monetary benefits could be expanded, e.g. by quantifying and integrating those indicators that have been proposed by the stakeholders but neglected in the present analysis due to a lack of reliable data. Furthermore, the methodology should be applied to other hotspots and creeks in the city of Wuppertal to ensure a holistic concept for flood protection and climate adaptation covering the whole city.

# 4 ADAPTATION MEASURES AT VELUWE RESEARCH SITE

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## 4.1. Introduction

### *4.1.1 Setting the Economic and Social Analysis into the BINGO and the WP 5 context*

In the BINGO Project, under Work Package 5, risk treatment and adaptation strategies for extreme weather events are developed and analysed, at each of the six research sites. Task 5.2 proceeds from task 5.1, i.e. from the development of such strategies, aiming at an economic and social analysis of the impacts of such measures/strategies. It includes three main activities:

- The definition of the goal of the economic and social analysis related to the topic and of the specific goals of the analysis per research site, as well as decision on the methodologies to be used (e.g. the definition of the minimum requirements and conceptual basic design for the economic analyses to be conducted at the research sites etc.).
- The composition of the approach for the analysis and the determination of the data sets to be analysed (e.g. setting the system boundaries for the economic evaluation, determining where an in-depth analysis is feasible etc.).
- The realisation of the economic and social analysis at the each research site (including defining/selecting the set of measures and activities to be evaluated), including an assessment of issues related to social justice, equality and distributional effects.

This task is linked to other BINGO Work Packages, namely WP3 and WP4, and assimilates the outcomes of the workshops in task 5.1 related to the local challenges at the research sites.

Seven socio-economic analyses of possible adaptation measures/strategies are conducted within BINGO. Three of them, Bergen, Badalona and Wuppertal (first case) will follow special case-dependent in-depth methodologies. The remaining cases, namely Wuppertal (second case), Cyprus, Netherlands and Portugal will follow a common methodology for the socio-economic analyses in order to assess suitable adaption measures/strategies to face climate change impacts and be able to choose the most fitting one.

The case study discussed in the report, at the Veluwe research site (see chapter 1.2), uses the common methodology following a customized Multi-Criteria-Analysis (MCA), which is described in chapter 2. The measures selected are presented in chapter 3, and the results of the analysis in chapter 4. Chapter 5 presents a short discussion and analysis of the results.

### 4.1.2 Description of the Case Study area

The Veluwe research site (ca. 1.250 km²), located in the north of Arnheim in the centre of the Netherlands (Figure 4.1), consists of ice-pushed moraine and fluvio-glacial complexes. Since groundwater levels are deep and soils infertile by nature, agricultural and occupation were sparse and extensive in historical times. Nowadays, the area consists of forests, heathlands and drift-sands.

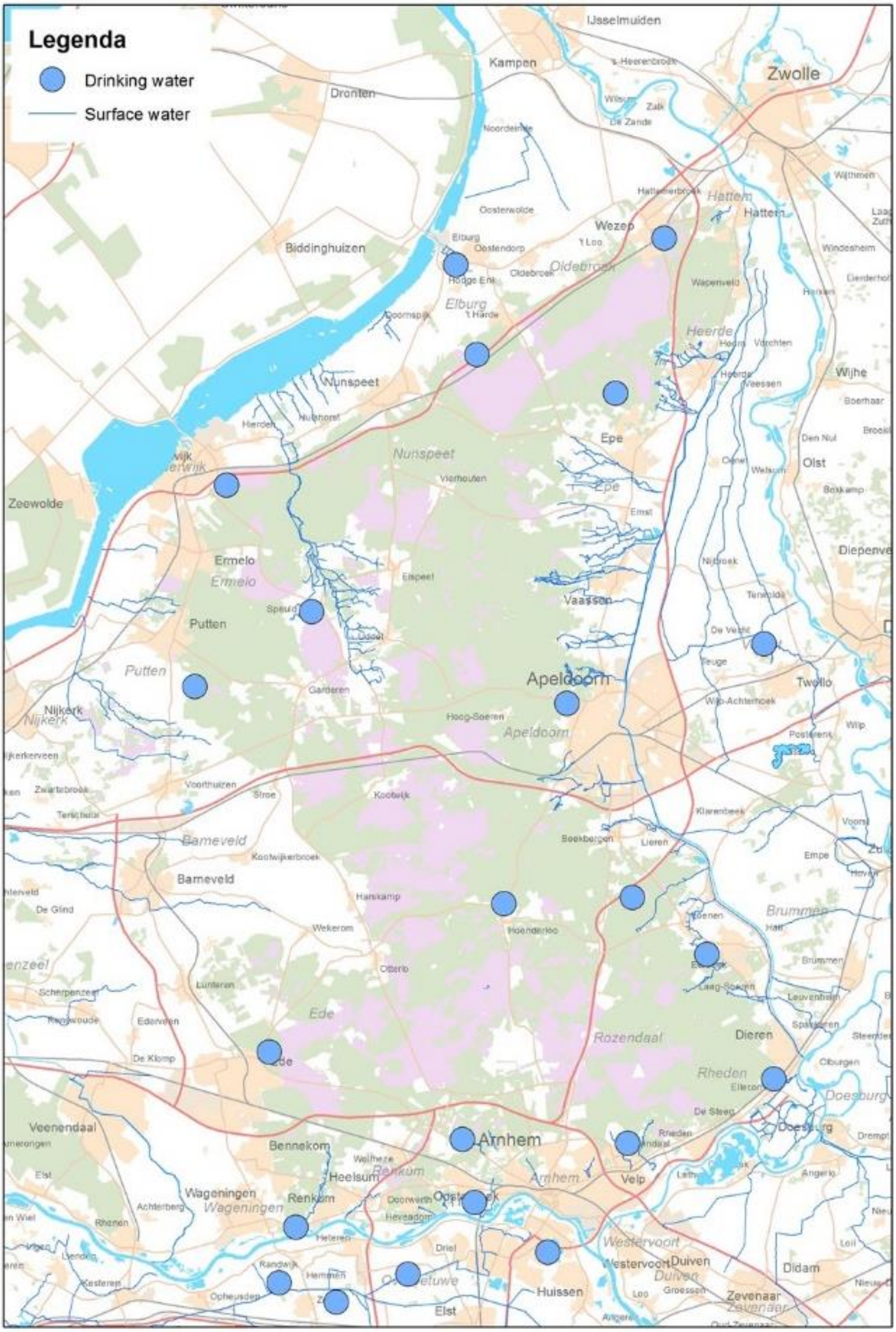



**Figure 4.1: Research site location (green-grey area on the map)**

Current (1981-2010) precipitation is on average approximately 950 mm/y, with an actual evapotranspiration of 575 mm/a, resulting (in the absence of surface waters) in a daily groundwater recharge of ca. 1 mm per day (Verhagen et al. 2014).

Villages and small cities have mainly developed at the fringe of the Veluwe, in the neighborhood of fertile soils, shallow groundwater and streams that drain the elevated central discharge area. The historical land-use is described by Bieleman (2000): as a result of large-scale commercial sheep farming, combined with the so-called "sod-cutting - manuring" system (mixture of animal manure and forest litter or heathland sods), the semi-natural landscape of the Veluwe was confronted with an ever increasing human pressure in the 17th - 19th centuries. Fanta en Siepel (2010) and Koster (1978) show how this lead to a large-scale replacement of semi-natural deciduous woodlands by heathlands, as well as a strong increase of drift sands, ending in an extremely open landscape in the second half of the 19th century. These land-use changes have significant effect on the groundwater recharge of the Veluwe system.

After the abolition of the commons in 1834, large parts of the heathlands and drift sands have been bought by the owners of large estates and by the Dutch national state, which started a large-scale afforestation, mainly consisting of scots pine and other conifer species. This development of afforestation increased the evapotranspiration significantly. Also the surrounding discharge area underwent considerable changes, starting with the excavation of bog peat and the first canalizations, as was demonstrated e.g. by Stol (1992) and by Van Beusekom et al. (2009), and ending with large scale drainage, land reclamation and groundwater abstractions in the 20th century.

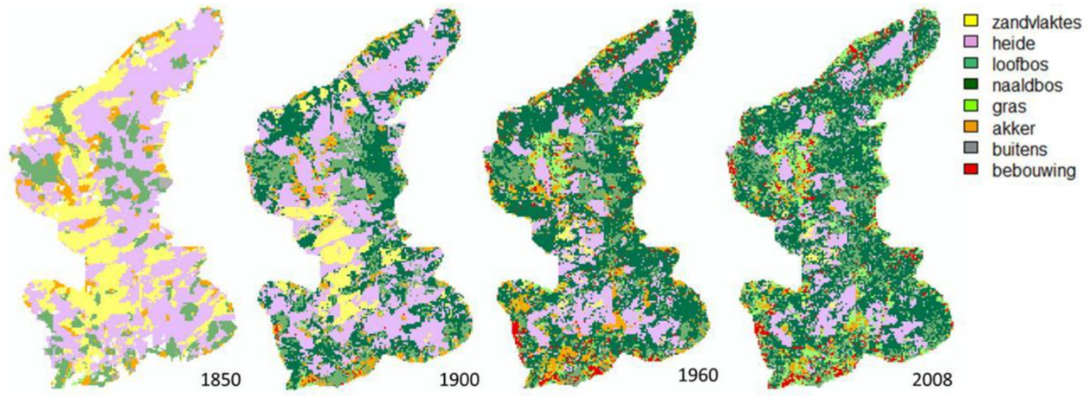



**Figure 4.2: Land use change Veluwe trough time (1850 -2008)**

Nowadays, the Veluwe serves as an important area for nature and recreation. Groundwater dependent nature reserves and streams of high ecological and cultural heritage value are important. Moreover, its subsoil contains a large reservoir of fresh groundwater that is exploited for the production of drinking water (official capacity 110 $Mm^3$ per year, equivalent to the consumption need of two million people; actual annual use is 74 $Mm^3$ drinking water, 30 $Mm^3$ industrial use, 6 $Mm^3$ agricultural use).

Nijssen et al. (2011) postulate that if current succession rates continue, drift sand landscapes in the Netherlands will have completely disappeared in 2050 – 2077. This will reduce water availability considerably, since evapotranspiration in drift sand landscapes is much smaller than evapotranspiration in forests.

The Dutch government states in the 2014 policy paper “Schoon drinkwater voor nu en later” that great attention should be given to the protection of groundwater for drinking water. Increasing pressures and climate change are important reasons for the Dutch government to implement a new long-term protection policy for groundwater. Present groundwater abstractions are protected by national and provincial law. The new policy seeks also protection for future use of groundwater for drinking water.

The research site Veluwe is the biggest land-based nature reserve in the Netherlands. The national government has decided that the Veluwe is part of the Dutch Natura 2000 network. The Veluwe is also one of the biggest tourist attractions in the Netherlands.

Climate change scenarios if translated to hydrological models learn that the average groundwater availability will increase, however the Veluwe system has a long-term variability with high and low groundwater levels.

The main challenges are

a) Long-term drought (e.g., a series of three dry years), which:
- may reduce groundwater recharge, seepage fluxes and levels,
- increases the demand for fresh water in the agricultural sector for irrigation,
- increases the demand for fresh water in nature management to combat low stream flow and sustain ecological values in these waters,
- reduces the availability and quality of groundwater resources in other parts of the Netherlands, increasing the demand on the Veluwe's groundwater resource.

b) Warming and heat stress, which:
- increases the growth of algae and bacteria, affecting the quality of groundwater and all (surface) water systems dependent on that (streams, springs, recreational water),
- in natural and rural areas, increases evaporation while extending the growth season, which increases the demand for water in the agricultural and nature management sectors,
- in urbanized environments, increasing the demand for drinking water and (public and private) recreational water facilities,
- increases the demand for industrial cooling water,
- increases the attractiveness of the Veluwe as a recreational area and the water demand from the tourism sector accordingly.

An extra challenge is the expected increase in demand for drinking water in a high economic development scenario. The main question is: Can we meet extra demands and protect and develop existing values under a high impact climate and economic scenario?

## 4.2. General Approach and Methodology

### *4.2.1 General approach used in all Case Studies*

The general approach in all case studies is depicted in Figure 4.3 below - a three-step approach was employed, starting with the formulation of the problem/challenges and a long list of risk reduction measures to address these. In the second step, in a pre-assessment, this long list of measures was reduced to a short list, and the final selection of the "most promising" (i.e. the most effective with regard to risk reduction) measures was done. The third and final step encompassed the cost assessment and the setting of the scope for the economic and social analysis.

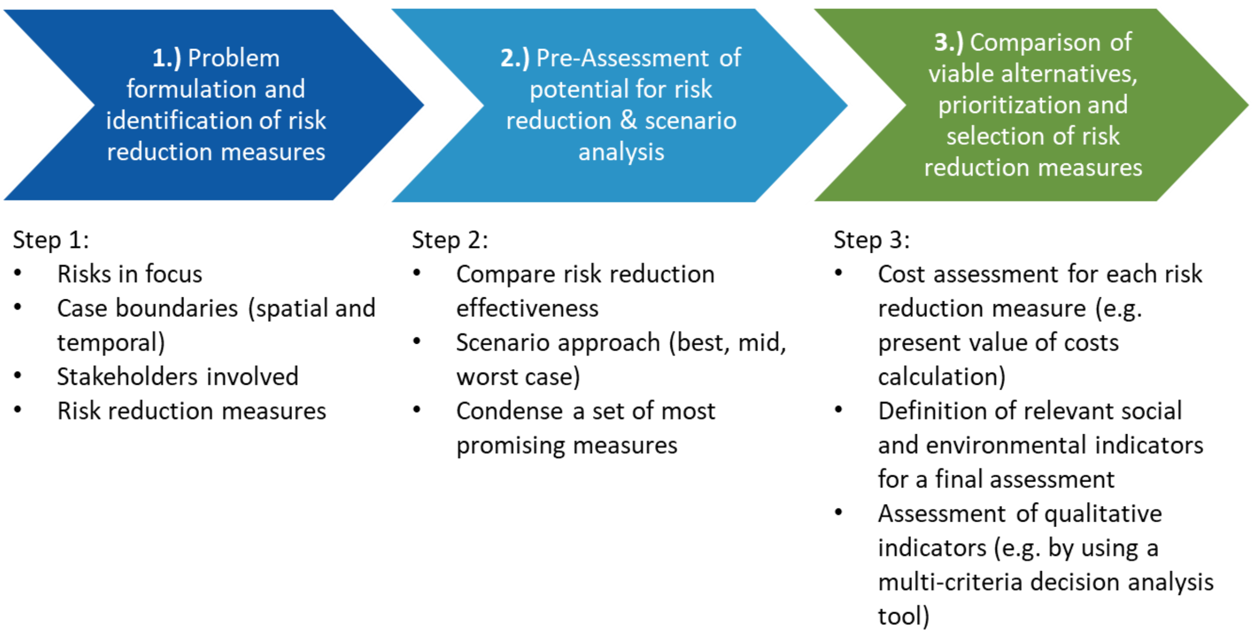



**Figure 4.3: General approach in all case studies**

### *4.2.2 Methodology applied in the Veluwe Case Study*

Measure selection

In the Veluwe case study area, the preparation of the long list of risk reduction measures, and the final selection of the measures to be analysed in the economic and social analysis, was done over the course of several stakeholder workshops in the framework of the BINGO

Community of Practice (CoP). The final selection of measures (presented in chapter 3 below) took place at the fifth BINGO stakeholder workshop on climate change in the Veluwe, held in Arnheim on the 19th of June 2018.

Cost assessment and case study template

More detailed information on the case study area, as well as the selected measures, was thereafter elicited via a template, prepared by InterSus and IWW. The "case study template" set the basis for the economic and social analysis, aiming at gathering the relevant information necessary for conducting the economic and social analysis. First, it provided a detailed description of the research site, summarizing the research problem in terms of describing the site specific climate change effects, both spatially and from a user perspective (e.g. economic activities), drawing on results of the BINGO WPs 3 and 4. Second, it provided the data relevant for the case specific economic and social analysis (e.g. spatial and land use-related information, such as agricultural data, data on geology and hydrogeology). Third, it obtained detailed information on the selected measures to reduce climate change induced risks at the site, such as the expected effects of these measures, the challenges in implementing them (e.g. key sectors/economic used, water quantity/quality, stakeholder affected, etc.), and any quantitative figures, specifying the risk reduction measure's implementation, costs and expected effects.

Selection of criteria for the Multi-Criteria-Analysis

In the framework of the BINGO Community of Practice, i.e. the stakeholder workshops, also criteria for the analysis of the measures were selected, similarly to the measures in two steps: from a "long list" to a "short list", which was finalized also at the fifth BINGO workshop at the Veluwe, on the basis of the criteria from the previous workshops.

It was decided that criteria on cost and effectiveness are calculated quantitatively and are hence taken into account not via the scoring. InterSus proposed to differentiate between the criteria:

- Impact-related criteria: Environmental and socio-economic criteria.
- Characteristics of the measures: these criteria belong to the measure and are therefore difficult to compare with the other two categories.

The proposed criteria and the need for additional criteria were discussed in 3 groups. The results of the three groups were then compiled into one final proposal for criteria. No criteria were dropped, but some have been further disaggregated or added, such as the effects on the different functions in the Veluwe. A total of 19 criteria have been finally identified. The stakeholders then gave each criterion a score from 0 (not important) to 10 (very important).

This resulted in the list of criteria presented below (Table 1), with the corresponding score and order.

Weighting of the criteria for the MCA

The challenge was that this ranking or "weighting" did result not in “factors” which increase the weight/importance relative to the other indicators, but in a ranking according to importance. It was now necessary to “translate” the rank of the criteria into “factors” for the Multi-Criteria-Analysis. The difficulty was in "translating" a ranking into factors that influence the scoring, i.e. that give different "weight" (importance) to the points scored during the MCA. Hence, the order/ranking needed to be translated into a "weighting" - "weighting" of the criteria/indicators meaning to assign importance, or "weight", to the criteria/indicators, relative to the importance/weight of the other indicators.

The solution found was to assign such factors in the form of multipliers to the different criteria/indicators according to their rank, starting by assuming that the median criteria (position no 10 “Public health (fine dust, bugs) incl. perception of the environment”) scores neutrally, i.e. the factor for the MCA is “1” (meaning: the result of the assessment for the measure will be multiplied by 1); then, we increase/decrease this factor in increments of 0.2, going up and down the “ladder”. That means the criteria one position up score with a factor of 1.2 (increasing their importance), the criterion one position down 0.8 (decreasing their importance). The factors were finally being adapted by the stakeholders. The final ranking of the criteria, and the resulting MCA factors are depicted in Table 4.1 below.

**Table 4.1: Final ranking of the criteria, and the resulting MCA factors**

| Criteria (ranked according to the score) | | Stakeholder Score | Factor for MCA |
|---|---|---|---|
| No 1 | Effects on groundwater dependant terrestrial nature | 128 | **1.6** |
| No 2 | Effects on aquatic nature | 124 | **1.6** |
| No 3 | Effects on drinking water | 118 | **1.6** |
| No 4 | Social acceptability and conflicting interests | 96 | **1.4** |
| No 5 | Effects on agriculture | 91 | **1.2** |
| No 6 | Effect on risk on forest fires and erosion | 91 | **1.2** |
| No 7 | Cultural history | 89 | **1.2** |
| No 8 | Tourism and recreation | 85 | **1** |
| No 9 | Effect on CO2 emissions and storage | 84 | **1** |
| No 10 | Effect onm public health (fine dust, bugs) incl. perception of the environment | 84 | **1** |
| No 11 | New economic potential on agriculture and forestry | 83 | 1 |
| No 12 | Effect on ecosystem services provision | 82 | **1** |
| No 13 | Effect on urban areas | 81 | **1** |
| No 14 | Judicial implementation hurdles, incl. N2000 and WFD | 78 | **0.8** |
| No 15 | Technical feasibility/knowledge requirement | 77 | **0.8** |
| No 16 | Justice and ethics (fair allocation and pricing of water/affordability) | 72 | **0.8** |

| | | | |
|---|---|---|---|
| No 17 | Flexibility of the measure | 71 | **0.8** |
| No 18 | Effects on labor | 68 | **0.6** |
| No 19 | Time horizon (short or long term) | 60 | **0.6** |

Green: environmental impact, Red: socio-economic impact, Blue: measure-specific

<u>Scoring and development of a ranking of the selected measures</u>

Via expert meetings and focus groups, held in October and November 2018, the selected measures were then scored against each of the 19 criteria, using a scale ranging from 1 (low/negative effect) to 5 (high/positive effect). Multiplied with the MCA factor according to the weighting of the criteria, each measure was assigned a final "MCA score", resulting in a new ranking.

Besides, the quantitative information on costs and effectiveness of the measures was evaluated, and a cost-effectiveness ratio calculated (initially, figures for "Euro per saved m³ of water" were aimed for, but such figures could not be generated in the Veluwe case study, due to the nature of the modeling results). Combined with the final MCA score, a broad information base on each measure was available, resulting in a qualitative analysis and evaluation of them (see chapter 5).

### 4.2.3 Acquisition of data and information: stakeholder meetings and expert opinion

The selection of risk reduction measures to be analyzed, and the acquisition of the necessary data and information to be able to select and analyze the measures, was done by the Veluwe case study partner, the Provincie Gelderland, over the course of three major stakeholder workshops in the frame of the BINGO CoP. Additionally, experts and other stakeholders were met and interviewed individually, to solicit expert knowledge on specific questions.

Quantitative impacts of measures were calculated via hydrological modelling (see BINGO Deliverable 4.3 for details). This modeling could not generate concrete, spatially explicit information on water saving potential of each measure; instead, the modeling results were evaluated by experts from the Provincie Gelderland, and savings per measure were estimated.

The stakeholders and experts participating and providing expert knowledge were from the following organisations:

- Stichting Sprengen en Beken (cultural heritage and ecology of streams)
- Gelders particulier Grondbezit (forestry and estate management)
- Waterboard Vallei en Veluwe (water management)
- Staatsbosbeheer (forestry and ecology, nature management)
- Provincie Gelderland
- KWR (research)
- Bosgroep Midden Nederland
- Hogeschool Van Hall Larenstein (research)
- Vitens (water provision)
- Stichting Natuur- en Milieuzorg NW-Veluwe
- Gelders Particulier Grondbezit

## 4.3. Presentation of the measures selected

### 4.3.1 Description of the selected measures, their costs and effects

In the Veluwe case study, three measures have been selected for being assessed in the economic and social analysis:

- The reduction of the area covered by pine trees (land-use change).
- Surface water infiltration.
- Limit sprinkler irrigation.

In Figure 4.4 the locations of the three measures under study are provided. The measure “limit sprinkler irrigation” is located just outside of the main study area, but affecting Veluwe groundwater levels.

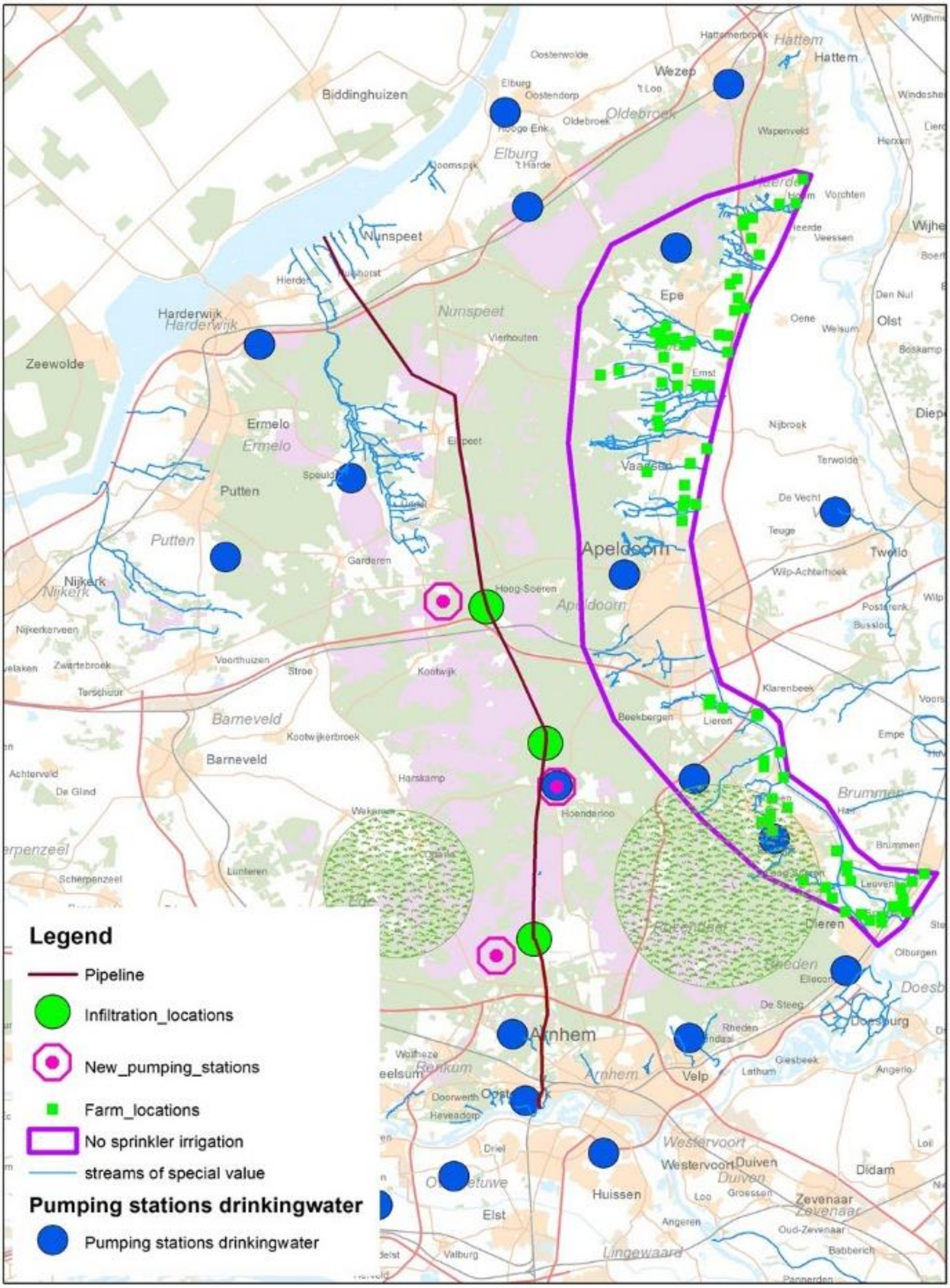



**Figure 4.4: Location of water system measures (land-use change in greenish circles)**

### 4.3.2 Measure 1: The reduction of the area covered by pine trees

Description of the measure: Changing pine tree forests (evapotranspiration 500-600 mm/y/m$^2$) into heather/grassland (evapotranspiration 200-300 mm/y/m$^2$) or broadleaf forests (evapotranspiration 400-500 mm/y/m$^2$) will reduce evapotranspiration and increases groundwater recharge. This will counteract the possible reduction of groundwater recharge and the increase in groundwater demand for drinking water.

Two possibilities are discussed: reducing the pine forest by 2,000 hectares, and replanting the area with broadleaf forest ("Sustainability Eventually") or clearing the area of all pine forest (10,000 hectares), planting some broadleaf forest (2,000 hectares), and leaving the rest as heather/grasslands (6,000 hectares) and open sand (2,000 hectares) ("Economy First"; see Table 4.2).

**Table 4.2 : Options for land-use change**

| Option | Pine forest | Broadleaf | Grass/Heather | Open sand |
|---|---|---|---|---|
| Sustainability Eventually | -2,000 ha | +2,000 ha | - | - |
| Economy First | -10,000 ha | +2,000 ha | +6,000 ha | +2,000 ha |

Changing forests is an emotional step, and resistance to this change will be strong. As such, 3-4 years process and procedures are foreseen, followed by 5 years of implementation (400 hectares per year for “Sustainability Eventually”;2,000 hectares per year for “Economy First”).

Costs of the measure: To assess the costs of the measures to reduce pine tree cover, income through the expected harvest will be contrasted with the expected costs.

The costs for the harvest amount to 23 €/m$^3$, with an expected income of 60 €/m$^3$, leading to a net result of +37 €/m$^3$. Per hectare, 150-230 m$^3$ of harvest can be expected, meaning a range of 5,550 € –8,510 € of income per hectare (average: 7,030 €/ha).

Planting costs amount to around 7,600 € per hectare, including the costs of 6,000 siblings (2-year old) per hectare (De Jong/Van Raffe, 2016). As the principal objective of the newly planted broadleaf forest is nature protection/conservancy, no forestry products are extracted, and there will be no income from the forest over time (small revenues through nature subsidies and possibly recreation are excluded from this analysis, as well as the costs of the loss of future production). At the same time, there will be no (or only very little) maintenance costs over time. In the “Economy First” option, litter/forestry revenue and wood stumps have to be removed from the cleared area to create grasslands/heath and open sandy areas (25,500 €/ha).

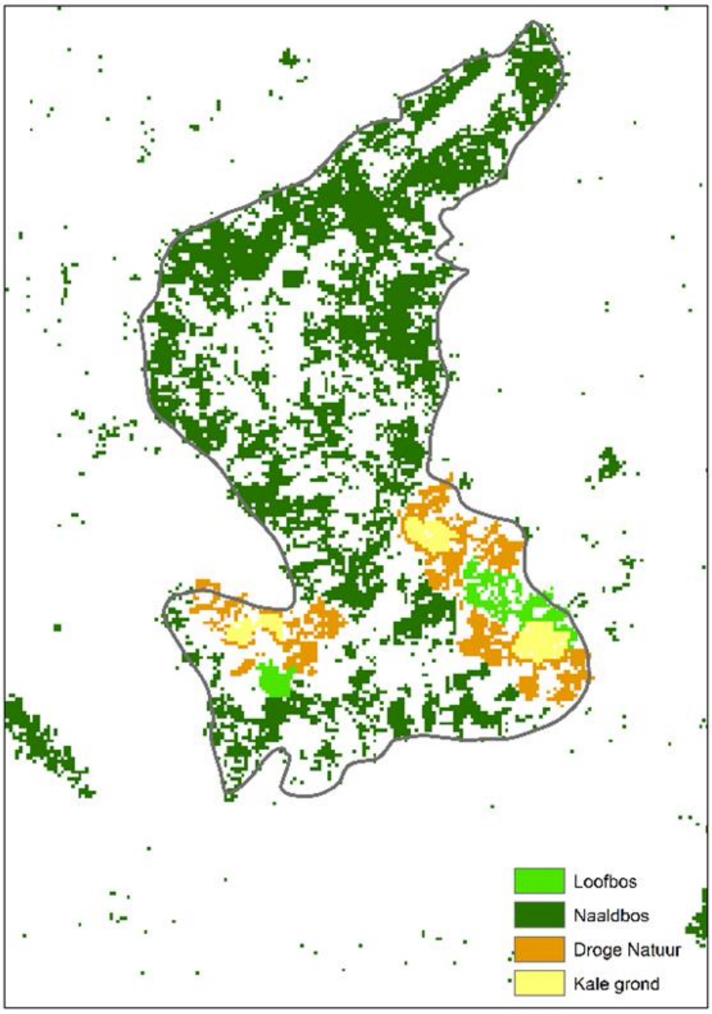



**Figure 4.5: Option "Economy First"**

The overall costs for the two options are depicted in the following table:

**Table 4.3: Cost of options for land-use change**

| Option | Removal of forest | Removal of litter/stumps | Planting | SUM/ha (costs) | Hectares | SUM (costs) |
|---|---|---|---|---|---|---|
| Sustainability Eventually | Income 7,030 €/ha | - | 7,600 €/ha | 570 € | 2,000 | 1.14 M€ |
| Economy First | Income 7,030 €/ha | -<br>25,500 €/ha | 7,600 €/ha | 570 €<br>18,470 €<br>18,470 € | 2,000<br>2,000<br>6,000 | 1.14 M€<br>36.94 M€<br>110.82 M€ |

Risk/challenge targeted: Low flow conditions in ecological streams in dry periods through increasing groundwater input in the Veluwe system. Also, the risk of forest fires close to tourism parks is addressed (reduced).

Quantitative effects/impacts:

The expected results are a rise in the groundwater table and increased stream flow. In BINGO Deliverable 3.4 is was demonstrated that the different 10-year ensembles are within the variability of the historical Veluwe system. In figure 6 below the results of the land-use scenarios are presented. The land-use change in the "Sustainability Eventually" scenario has only a local and very small effect on groundwater heads (picture f in Figure 4.6).

The scenario "Economy First" with major land-use change has in all climate ensembles significant effect on groundwater heads (pictures g, h and I in Figure 4.6).

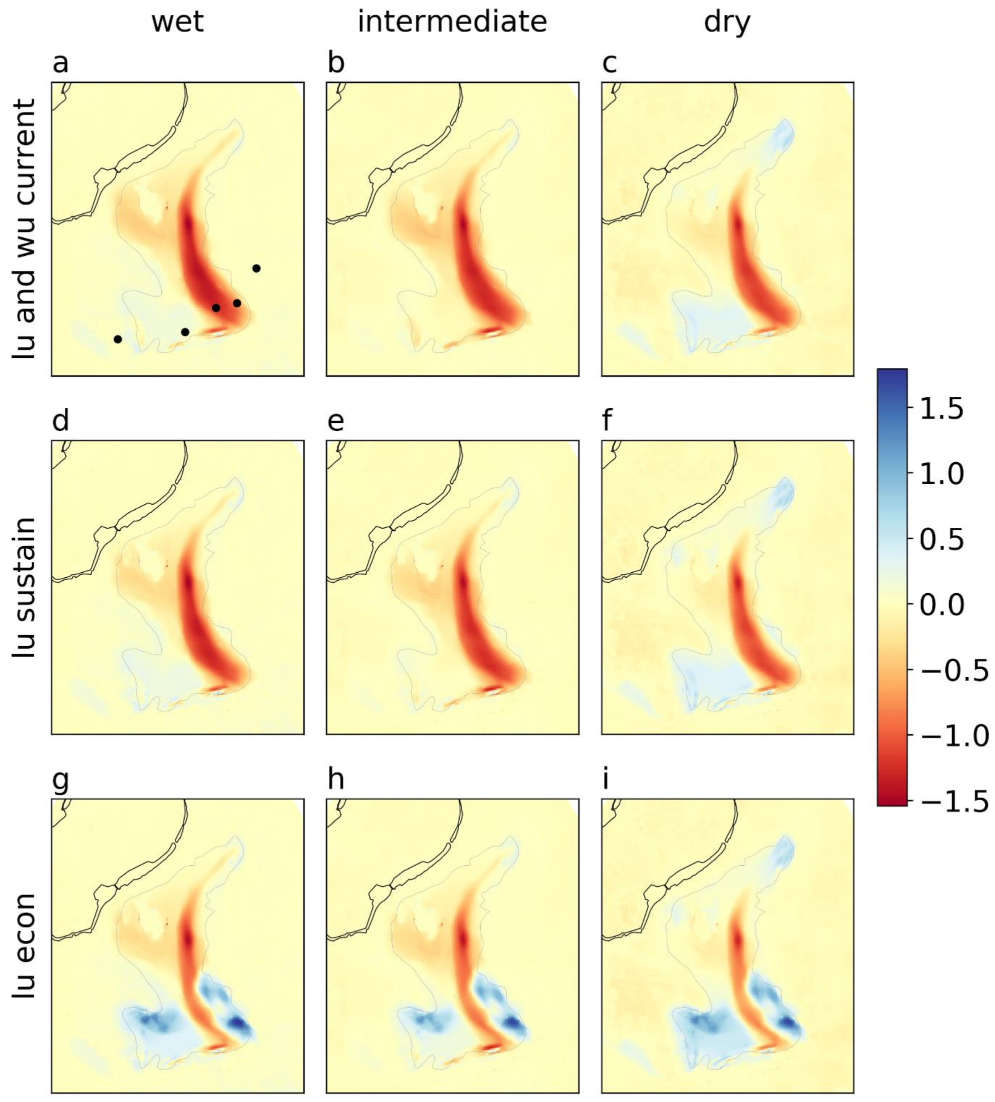



**Figure 4.6: The effect on groundwater levels in meters due to the land-use change scenarios on the Veluwe system under the different climate ensembles (measure 1)**

In quantitative numbers, the "Sustainability Eventually" scenario leads to additional groundwater recharge of around 1-2 million m³/year (medium effect for the case study area - on a regional scale, the effect is very low), while the "Economy First" scenario will generate 15-20 million m³/year in additional groundwater recharge (a high effect for the case study area - at the regional scale, the effect is low-medium).

### 4.3.3 Measure 2: Surface water infiltration

Short description of the measure: From the river Nederrijn and from a lake north of the Veluwe, surface water will be pumped into the area. With this water, an additional infiltration of 30 Mm³/year will be realized and used to compensate groundwater extractions for drinking water. This is a major infrastructure project, as it includes two intake structures at the lake, 40 km of pipelines, 40-50 hectares of infiltration ponds, treatment installations and three new groundwater pumping stations. The preparation time will be long for studies, procedures and decision making: approx. 5 years for environmental impact assessment, Natura 2000 allowance procedure, political decision, then 3 years for building the infrastructure, and 2 more for bringing the system up to full capacity - i.e. it will take 10 years to realize the project.

Costs of the measure: The estimation of the cost of the different components of the project are estimated based on similar projects/infrastructures in the Netherlands, the "Epe" project (6 Mm³ infiltration water transported over 10 km, with a total investment of 6 M€) and the "Schalterberg" project (2 Mm³ infiltration water transported over 5 km, with a total investment of 3.3 M€). The operation and maintenance costs (O&M) of the two projects are 10,000 € per 1 million m³ infiltrated water per year. These costs are mostly energy costs.

In the planned project, 30 Mm³ infiltration water will be transported over 40 km, and because of the large quantity of water transported, a double pipe system is needed, at an estimated installation cost of 80 M€ (2 * 40 km * 1000 €/m). For the infiltration, ponds with an area of 50 hectares are to be created, at a cost of 10 M€, plus two necessary treatment plants (capacity 15 Mm³/y, costing 60 M€). The pumping stations to be built will amount to 75 M€.

Total investment, hence, will be 225 M€.

The operational costs are estimated to be 4 M€/y for the purification and transport of 30 Mm³ water, 100,000 €/y for the maintenance of the pipes, 600,000 €/y for the operation and maintenance of the pumping stations and 300,000 €/y for the maintenance of the infiltration locations. Total O&M costs amount to 5 M€/y.

Risk/challenge targeted: Compensation for extra extraction of groundwater for drinking water purposes from the Veluwe groundwater system, amounting to a saving of 30 Mm³ of extra groundwater demand, because surface water is used instead of groundwater. The surface water is extra input in the groundwater system. To prevent changes in the groundwater system quality, all the infiltrated water will be extracted again.

Quantitative effects/impacts:

In this analysis only the effects of the infiltration are presented. If also the extra extraction would be modeled than the effects would be zero. The expected results are a rise in the groundwater levels and more stream flow. Figure 4.7 shows the change in groundwater heads due to increased infiltration of surface water. Directly under the infiltration sites the increase is the highest. Looking at the Veluwe system as a whole, the measure is comparable to the land-use change "Economy First" (additional groundwater recharge of around 30 million m³/year is expected, a locally high and regionally medium effect). However, the locations are different, so local differences in effects are to be expected.

Additionally, streamflow will be positively affected.

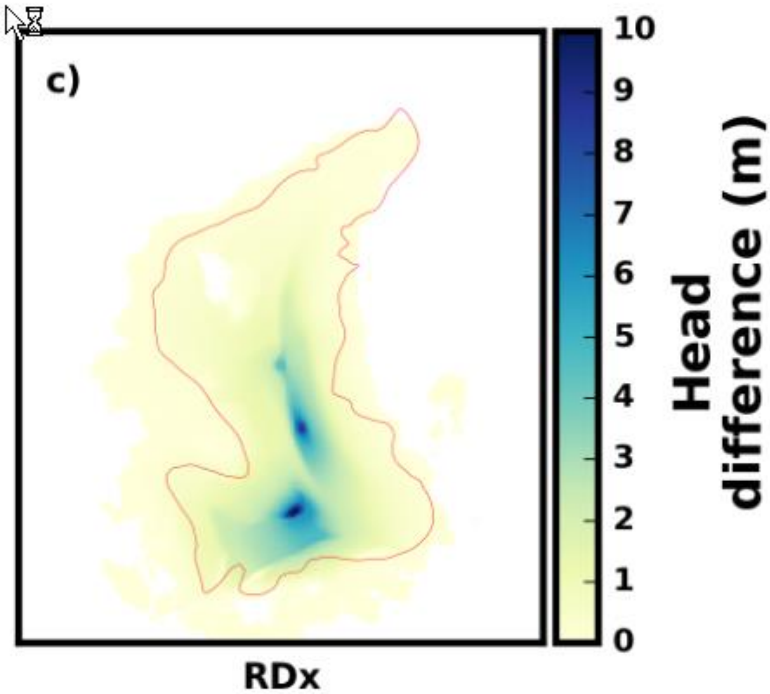



**Figure 4.7: Change in groundwater heads caused by infiltration of surface water**

### *4.3.4 Measure 3: Limit sprinkler irrigation*

Short description of the measure: The measure “limit sprinkler irrigation” will take place outside of the main study area, because the agricultural activity at which the measure is aimed is located here. Sprinkler irrigation using water from the small creeks and streams originating from the Veluwe indirectly affects the Veluwe groundwater levels, as the streams feed into the groundwater through infiltration. In the area East-Veluwe, were the many streams are situated, sprinkler irrigation will be banned completely. About 60- 80 farmers will be involved in and impacted by this measure. Investment in farming development in the region will be necessary to compensate for the effects of this measure.

In order to implement this measure, a four year period of running a land exchange project is foreseen, with parallel decision making, followed by a one year implementation, and a five year transition period, i.e. it will take 10 years to realize the project.

Costs of the measure: Land exchange, changing farming practices and farm development are estimated to amount to: the land exchange project costs 100,000 € per year, and will run for 4 years at a total cost of 400,000 €; the transition of 20 farms into soil oriented farming costs 40,000 € per year per farm for 5 years including monitoring (total costs: 20 * 40,000 * 5 = 4 M€). The loss of value on 4 farm locations is estimated to amount to 400,000 € per location, totaling 1.6 M€. Hence, total costs over a period of 10 years are 6 M€.

Risk/challenge targeted: Low flow conditions in ecological streams in dry periods through direct measures in dry periods close to the ecological streams.

Quantitative effects/impacts: The measure was included to get an idea of whether local measures close to the ecological streams will have significant effects. Figure 8 shows the sites of sprinkler irrigation which are included in the model.

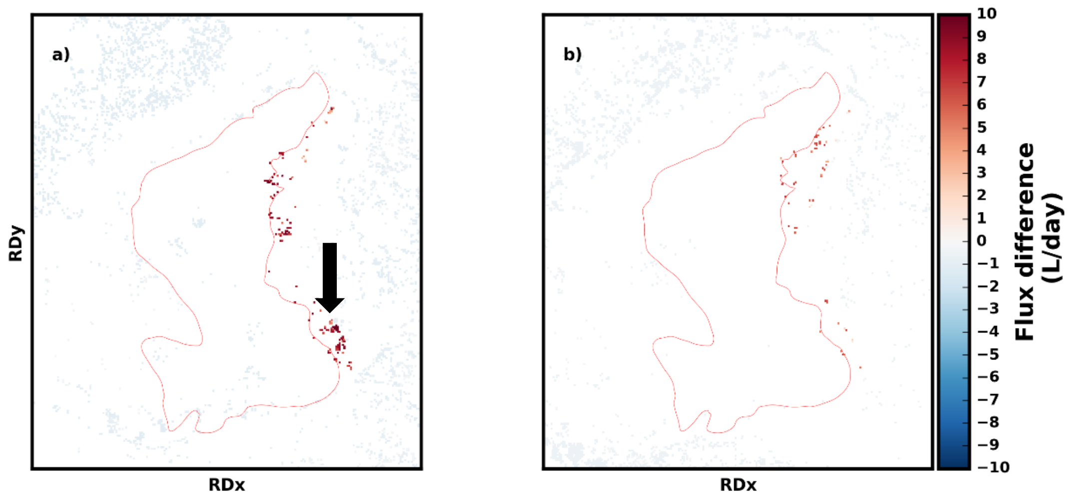



**Figure 4.8: Sprinkler irrigation as calculated by the model. Picture a) depicts groundwater, picture b) surface water. The arrow marks the spot for the groundwater head calculation.**

Only groundwater is analyzed because in the dry period sprinkler irrigation from streams is prohibited. Picture a) in figure 8 shows an uneven distribution of the irrigation. In figure 9 the effect on groundwater levels is presented.

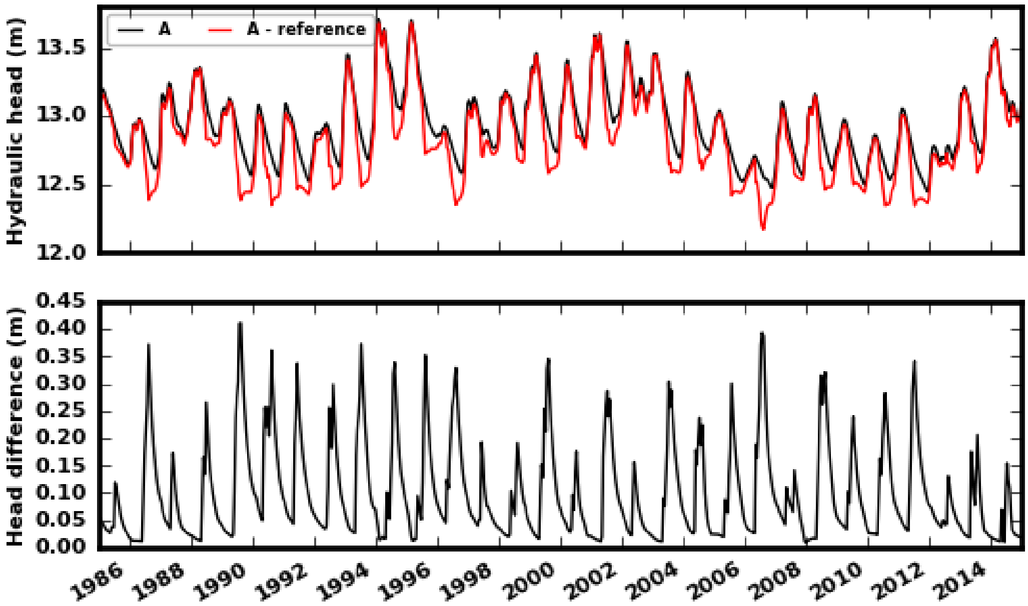



Figure 9: Groundwater levels for A - reference (with sprinkler irrigation) and A (no sprinkler irrigation).

The effects of prohibiting sprinkler irrigation are very small, and only 0.2 - 0.3 million m³/year of groundwater would be saved. This is a very low local effect, which is on the regional scale negligible.

## 4.4. The Multi-Criteria-Analysis

### *4.4.1 Scoring of the measures*

As explained above, the selected measures were then scored against each of the 19 criteria, using a scale ranging from 1 (low/negative effect) to 5 (high/positive effect). Multiplied with the MCA factor according to the weighting of the criteria, each measure was assigned a final "MCA score", resulting in a new ranking. The scoring and new ranking is depicted in Table 4.4 below:

**Table 4.4: Final scoring of the measures against each criterion**

| Criteria | Factor for MCA | Measure 1: Original score | Measure 1: Adapted score | Measure 2: Original score | Measure 2: Adapted score | Measure 3: Original score | Measure 3: Adapted score |
|---|---|---|---|---|---|---|---|
| Effects on groundwater dependant terrestrial nature in the Veluwe | 1.6 | 4 | 6.4 | 2 | 3.2 | 2 | 3.2 |
| Effects on aquatic nature | 1.6 | 5 | 8 | 2 | 3.2 | 4 | 6.4 |
| Effects on drinking water | 1.6 | 2 | 3.2 | 5 | 8 | 2 | 3.2 |
| Social acceptability and conflicting interests | 1.4 | 1 | 1.4 | 2 | 2.8 | 2 | 2.8 |
| Effects on agriculture | 1.2 | 2 | 2.4 | 2 | 2.4 | 1 | 1.2 |
| Effect on risk on fires and erosion | 1.2 | 1* | 1.2* | 4 | 4.8 | 2 | 2.4 |
| Cultural history | 1.2 | 4 | 4.8 | 2 | 2.4 | 2 | 2.4 |
| Tourism and recreation | 1 | 4 | 4 | 4 | 4 | 2 | 2 |
| Effect on CO2 emissions and storage | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| Effect on public health (fine dust, bugs) | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| New economic potential on agriculture and forestry | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| Effect on ecosystem services provision | 1 | 4 | 4 | 5 | 5 | 2 | 2 |
| Effect on urban areas | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| Judicial implementation hurdles, incl. N2000 and WFD | 0.8 | 1 | 0.8 | 1 | 0.8 | 5 | 4 |
| Technical feasibility/knowledge requirement | 0.8 | 4 | 3.2 | 1 | 0.8 | 4 | 3.2 |
| Justice and ethics (fair allocation and pricing of water/affordability) | 0.8 | 1 | 0.8 | 2 | 1.6 | 3 | 2.4 |
| Flexibility of the measure | 0.8 | 3 | 2.4 | 1 | 0.8 | 5 | 4 |
| Effects on labor | 0.6 | 3 | 1.8 | 3 | 1.8 | 2 | 1.2 |
| Time horizon (short or long term) | 0.6 | 5 | 3 | 5 | 3 | 5 | 3 |
| **TOTAL** | | | 52.4 | | 50.6 | | 51.4 |

*Negative because heather vegetation is more prone to starting fires.

All three measures score relatively similar, with Measure 1 (reduced pine tree area) leading with 52.4 scoring points, Measure 3 (limit sprinkler irrigation) as second with 51.4 scoring points and last being Measure 2 (surface water infiltration) with 50.6 scoring points.

- Looking at the environmental impact criteria (green), Measures 1 and 2 score at 32 points, and Measure 3 at 24.8 points.
- Looking at the societal impact criteria (red), Measure 1 scores at 11 points, Measure 2 scores at 13.2 points, and Measure 3 at 12.4 points.
- On the technical side (blue), Measure 1 scores at 9.4 points, Measure 2 scores at 5.4 points, and Measure 3 at 14.2 points.

In the following chapter, these scores will be contrasted with the quantitative results on effect/impact.

NOTE to the legal implementation of the measures: Land-use change will be under Natura 2000 legislation very difficult. The Natura 2000 status of the Veluwe is targeted on maintaining and improving the existing values. Major land-use change will affect the whole system. Some species will increase in number and some will strongly decrease. Land-use change of this magnitude is not possible within the existing framework. For infiltration the changes are less severe but implementation will still be difficult within the existing framework. Stopping sprinkler irrigation without compensation will be legally possible, but politically not feasible. A transition project to implement this measure will be needed.

### 4.4.2 Cost effectiveness - discussion and ranking

Measure 1: Over a period of 10 years (at least 4 years of process and procedures are foreseen, followed by 5 years of implementation), the scenario "Sustainability Eventually" will incur costs of 1,14 million €, resulting in additional groundwater recharge of 2-3 million $m^3$/year. The scenario "Economy First", while generating much bigger groundwater recharge (15-20 million $m^3$/year), is also much more expensive (148,9 million € over a period of 10 years).

Thus, the scenario "Sustainability Eventually" provides additional groundwater recharge of 17,5-26,3 $m^3$ per Euro invested (in 10 years), while "Economy First" only provides around 1-1,3 $m^3$ over 10 years per Euro invested.

Measure 2: The transport and infiltration of water incurs investment costs of 225 million €, and 5 million € operation and maintenance costs per year. Assuming a ten year period for better comparison with the other measures, the costs are approximately 275 million €, or 27,5 million €/year. An additional groundwater recharge of around 30 million $m^3$/year is expected, a locally high and regionally medium effect. Hence, around 1,1 $m^3$ of additional groundwater recharge/infiltrated water is created for every Euro invested.

Measure 3: The limiting of sprinkler irrigation and flanking measures cost 6 million € over a period of ten years, with a small effect of saving 0.2 - 0.3 million m³ groundwater per year, corresponding to 0,3 -0,5 m³ per Euro invested.

Comparing the costs per saved/newly gained $m^3$ of groundwater, a significant range between the three measures can be determined:

- Measure 1, scenario "Sustainability Eventually": 17,5-26,3 $m^3$ additional groundwater recharge per year is created per Euro invested into land use change/changing forest cover over a period of ten years.
- Measure 1, scenario "Economy First": 1-1,3 $m^3$ additional groundwater recharge per year is created per Euro invested into land use change/changing forest cover over a period of ten years.
- Measure 2: 1,1 $m^3$ additional groundwater recharge/infiltrated water per year created for every Euro invested, also over a period of ten years.
- Measure 3: 0,3-0,5 $m^3$ groundwater is saved per year for every Euro invested, over a period of ten years.

Hence, the land use change scenario "Sustainability Eventually" is by far the most cost effective of the three measures in terms of "water saved/water resource gained" per Euro invested, while the land use scenario "Economy First" and the transport and infiltration of water into groundwater aquifers are similar in their efficiency. The limiting of sprinkler irrigation is only half as efficient, due to the high costs of flanking measures.

### 4.4.3 Ranking according to the scores and the costs/effects

The land use change scenarios scored highest in the Multi-Criteria Analysis. Stakeholders seemed to perceive land use as the most feasible solution for increasing groundwater resources, except in terms of societal impact criteria, where it scored lowest. Stakeholders' perception is only partly in accordance with the results of the cost-effectiveness analysis, where only the scenario "Sustainability Eventually" is by far the most cost-effective measure in terms of "groundwater resource gained".

However, the second scenario is the second most efficient, sharing this rank with the measure to transport and infiltrate water from afar, which only scored third in the Multi-Criteria Analysis. Strangely, this measure scored high in terms of environmental impact, in spite of the infrastructure needed for it.

Finally, the third measure (limiting sprinkler irrigation) scored both low in the Multi-Criteria Analysis as well as the cost-effectiveness analysis. In both cases, it received the lowest score. Interesting also here the low score in terms of environmental impact, although the measure has the least effect in terms of disturbances in the water balance or land use/plant coverage.

## 4.5. Summary and discussion

### *4.5.1 Analysis and discussion of the results*

Land use change in the “Economy First" scenario and the transport and infiltration of surface water have effects in a similar magnitude and show the expected positive results for groundwater levels.

However, the measures are specific to the location and the geohydrological system. By choosing the measure location and the geohydrological system, the extent and location of the effects vary.

Minor land use change and banning sprinkler irrigation do not show significant results, although the efficiency of "Sustainability Eventually" land use changes is the highest of all measures. Because of the magnitude of the Veluwe system only measures with high areas of land use change or high volumes of water are effective on a broader scale. All measures need high investment in money and social acceptance.

The MCA showed slightly indifferent results, the measures being pretty close in terms of their scoring. Unexpectedly, the measure involving transport and infiltration of water from afar (using costly infrastructure) scores high on the environmental side, while a regulatory-only measure (limiting sprinkler irrigation) scores low in this regard. This hints at some form of misinterpretation on the stakeholder´s side, and should not be over-interpreted.

### *4.5.2 Social justice and distributional effects*

Within WP 5, adaptation measures have been identified at each research site, which have been assessed by the WP5-team in terms of their governance needs and socio-economic effects. As a last step in the assessment of selected adaptation measures, an analysis of the impact of these measures on social justice was done.

Social justice in this case refers to "how the basic structure of a society distributes advantages and disadvantages to its members" (Miller, 1999). These distributions are often based on, and legitimized through, "distributive" or "equity" principles (Cook ,1987; Caney, 2005). Equity principles appeal to general conceptions of what is good and what is bad. Besides notions about fair distributions, they are closely related to considerations of vulnerability (Adger, 2006). Generally, the political-philosophical literature distinguishes between three general equity principles (Shue, 1999; Low and Gleeson, 1998):

- The deontological principle is based on Kant’s notion that people are rational and act intentional, and can therefore be held responsible for their choices and actions. The "polluter pays" principle is an example of this principle.

- The <u>solidarity</u> principle aims to neutralize "involuntarily inequalities" between people. Distributions follow Rawls' "maximin" principle which involves maximizing the well-being of those who are worst-off.
- The <u>egalitarian</u> principle is based on Mill's and Benthams' utilitarian "greatest happiness principle". Distributions aim to maximize the positive effects and minimize the negative effects for society as a whole.

The analysis on social justice, equality and distributional effects is based on a questionnaire sent to the Case Study partners in Veluwe in December 2018, and which can be found in Annex 1 to this document.

**For Measure 1 (Land-use change),** the costs for the measure ("removal and reforestation ") are borne by the pine forest owners who therefore need to be compensated by either the province or by water users (e.g. being paid for the amount of water infiltrated above the current rates). The direct benefits of the measure, the enhancement of public goods ("sustainable drinking water supply"; "preservation of the groundwater system") are allocated equably among water users and the general public throughout the region. Positive side effects of the measure ("a more diverse and robust landscape"; "enhanced soil condition"; "increased biodiversity") are also public goods and equably shared by the general public.

Negative side effects are the loss of wildlife and plants specific for pine forests which may be indirectly mitigated by an increase in biodiversity after the land-use change. The loss of pine forest landscape which may negatively affect inhabitants and tourists in favour of it as well as it may affect tourism entrepreneurs, may be to a certain extent be mitigated through time (development of a more diverse landscape). Informing the public on the background of the measure may help reduce opposition. During the transition period, financial losses of tourism entrepreneurs due to intensified foresting activities are possible.

**Measure 2 (Surface water infiltration)** will be paid for by an increase in the drinking water price for water customers. The water supply company as well as the general public directly benefit from the measure. The benefits ("sustainable drinking water supply"; "preservation of the groundwater system") are allocated equably among water users throughout the region. This also applies to the positive side-effect which benefit the general public ("possibility to connect measure to forest fire mitigation/prevention").

Negative side-effects are decline of local spatial quality due to new water supply infrastructure, additional energy demand and probably ensuing additional energy infrastructure. Additional wind turbines would among others, affect general landscape attractiveness. These effects are mostly borne by residents living nearby the infrastructure. Mitigation activities include minimization of visibility and ecological effects.

**With Measure 3 (Limit sprinkler irrigation)** farmers affected by the measure would carry the major burden but would be compensated for by the regional or national government in order to compensate farmers for loss of production capacity, hence by the general public in the form of tax payers. The local groundwater supply and natural environment are positively affected which directly benefits land owners, local inhabitants and tourists.

Summarizing, all measures serve the egalitarian principle by securing general public goods (“sustainable drinking water supply”; ”preservation of the groundwater system”; “water supply for the natural environment”). With Measures 1 and 2 users throughout the region benefit equably from the securitization of drinking water supply. Hence, with regard to drinking water quality the solidarity principle is served well. The same applies to the positive side effects these measures. However, it does not hold true for the negative side effects of Measures 1 and 2: The negative side effects are borne by specific groups only, with Measure 1 having most negative side-effects. But mitigation activities are possible, of which compensation efforts may re-enforce the solidarity principle. With Measure 3, direct benefits are only distributed to certain groups of people. Hence, this negatively affects the solidarity principle, especially under the condition that the general public pays for the measure. Compensation paid for the farmers, who would otherwise have to bear negative side-effects, re-enforces the solidarity principle. The deontological principle is served best by Measure 2, because water users, the direct beneficiaries, actually pay for the measure. Measure 3 does not meet the deontological principle since beneficiaries are not congruent with the group who pays for the measure. Measure 1 would only meet it if it were paid for by the beneficiaries.

# 5 ADAPTATION MEASURES AT TAGUS RESEARCH SITE

*Authors:* Fernanda Rocha; Pedro Brito; Alberto Freitas

## 5.1. From risk analysis to adaptation

### 5.1.1 Brief introduction to the case study

The Portuguese research site is located in the lower Tagus river basin. It addresses climate change adaptation of two key sectors, one concerning an important public service, public water supply, and the other concerning agriculture, one of the most relevant economic activities in the region. The climate change adaptation concerns how changes in water resources availability compromises both sectors and how they should prepare themselves to deal with these changes, being water resources deficit the potential threatening hazard.

The agriculture Portuguese case study of Sorraia Valley Public Irrigation Perimeter (Sorraia PIP) has as main feature to dispose of private storage capacity for irrigation, able to endure at least one year of reduced precipitation while assuring agricultural campaigns. Hydroelectricity is also produced in this irrigation scheme that is sold to the public electric network. Work package 4 put in evidence that present conditions of the irrigation scheme infrastructures are the main internal vulnerability, therefore reduction of water resources deficit by means of improvement of **efficiency of water conveyance and use** is the main regional concern.

Work package 4 also put in evidence that water resources management is a key cross-cutting factor is a major concern in the region, when water bodies are shared for multiple purposes. The public water supply utility, EPAL, has already embedded a risk culture in its operational management and climate change preparedness. As EPAL does not have private water sources, water resources management dependency is considered to be the main external vulnerability, a key concern that is shared with one of the agriculture Portuguese case studies, LGVFX public irrigation scheme, as they share Tagus River's water resources. Being a generalized regional and national concern, **water resources management (WRM) improvement** is identified as being an important issue, mainly under conflicting periods.

These conclusions justify the selection of measures presented in Chapter 5.3.

### 5.1.2 Sorraia PIP case context for efficiency of water conveyance and use

The hydro-agricultural project of the Sorraia valley Public Irrigation Perimeter (Sorraia PIP) was built between 1951 and 1959, by the Portuguese government, with the main objective of assuring irrigation to 15365 hectares. This benefited agricultural land occupies a longitudinal strip of almost 75 km length, in the E-W direction (Figure 5.1), along the Sorraia River and two of its tributaries: the Sôr river and the Raia river (also known as Seda river), distributed along the municipalities of Ponte de Sôr and Avis, in the district of Portalegre, Mora, in the district of Évora, Coruche, Salvaterra de Magos and Benavente, in the district of Santarém. Beneficiary farmers have rights and duties.

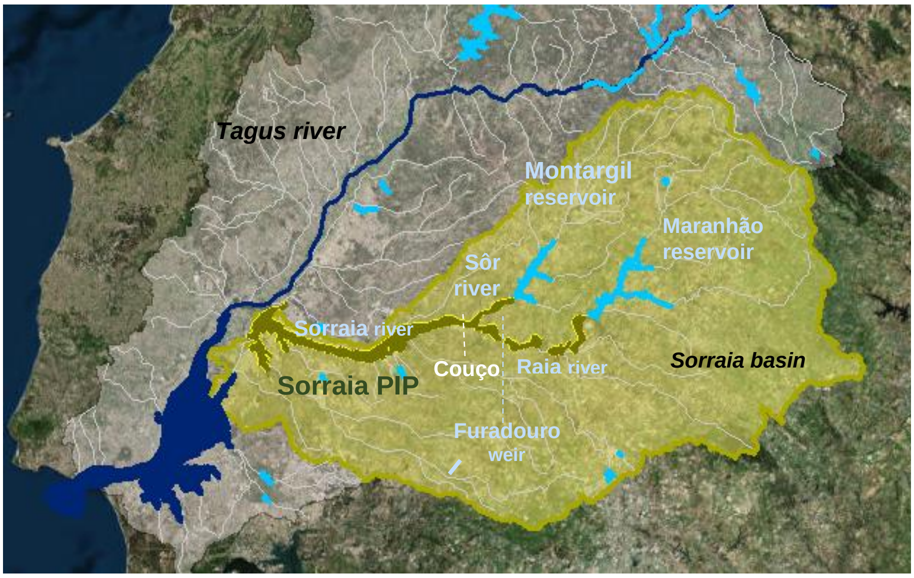



**Figure 5.1: Location of Sorraia Public Irrigation Perimeter (Sorraia PIP)**

The most important water sources of this irrigation scheme are the dammed reservoirs of Maranhão and Montargil, located in the streams of, respectively, Raia (Seda) and Sôr, whose combined total storage capacity is 369 cubic hectometres (utile volume of respectively 180.9 and 142.7 $hm^3$). Both dams also produce hydro-electric power.

According to the original project the downstream maximum areas watered by these reservoirs are:

- 3 228 ha only possible of being irrigated from Maranhão reservoir;
- 870 ha only possible of being irrigated from Montargil reservoir;
- 11 267 ha being irrigated by one or other of the reservoirs.

Two large weirs were also built on the Raia river: Gameiro and Furadouro weirs. The first one raises the river's water plan for the production of energy (Gameiro's central station) and the feeding of two pumping stations. Furadouro weir function is to raise the water level in the Raia river, to make the diversion to a local distributor (Franzina) and to the Furadouro-Couço canal (first stretch of the main canal), one of the main feeding equipment's of the Perimeter, that downstream from the village of Couço, also receives water from the Montargil reservoir and gives rise to the Couço-Divor canal. Some other small contributions exist (D4.1).

The entire irrigation scheme was originally conceived and equipped in a perspective of transport (primary network), distribution (secondary network) and water delivering for irrigation by gravity. This mode of operation implied high water losses in some daily periods and water deficits in other periods, which required complicated management of water and of all infrastructures. Since 1959 the network expanded, some rehabilitation and modernization works were carried out and some pumping stations were introduced in the scheme. Presently, the primary transport network, crosses a territory of over 95 km, and includes the intakes at Montargil and Maranhão dams, several flow diversion structures; a stretch of Raia River till Furadouro weir, then followed by long concrete canals. The distribution network composed of smaller canals which spreads along the alluvial plains (irrigated area), ramifies from the primary network and feeds low pressure pipes that deliver water to each irrigated plot. Since water is provided with no pressure, most of non-rice fields have installed individual pumping systems to operate their sprinkler and drip irrigation systems. At an intermediate position Peso reservoir assure storage of exceeding volumes from canals operation, to allow further allocation downstream, in opportune time.

The management and exploitation of dams and reservoirs, water transport, distribution and delivery for irrigation as well as electricity production was committed to the Sorraia PIP Irrigator's Association - ARBVS.

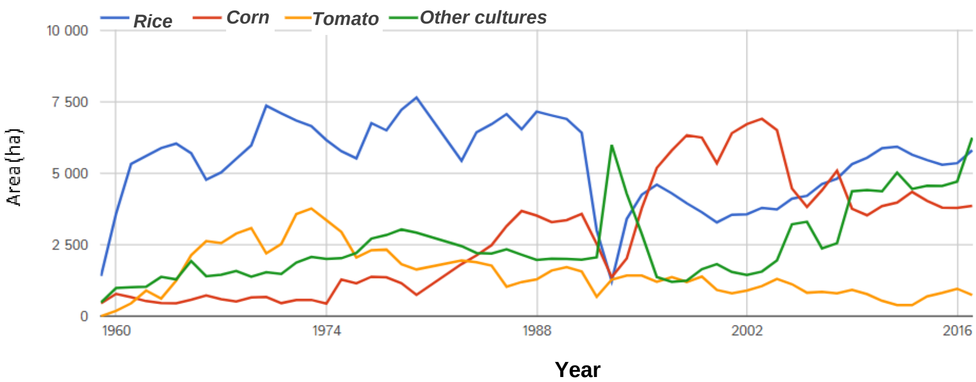
The area of the irrigation perimeter is divided into territorial units, the irrigation blocks that are the fundamental units of management at various levels: hydraulic regulation; surveillance and control services; maintenance; administrative services; etc. 9 blocks correspond to the original project. Later on 2 other blocks, fed by Magos reservoir, integrated the Sorraia irrigation scheme, reaching 16327 hectares.

Due to increasing water use efficiency it has been possible to further expand the irrigated areas. For the last few years the Irrigators association (ARBVS) has guaranteed the supply of water for irrigation in surrounding areas (not foreseen in the original project), around the main reservoirs and along the canals, especially the most important ones.

Soils are of very good quality, but in the lower Sorraia downstream basin the soils present high salt content due to tidal influence. The main annual cultures are rice and maize. Tomato and other crops are also produced. Tomato canning processing is quite relevant in the region. Portugal is placed among the 10 major world processed tomato exporters (varying between 5$^{th}$ and 8$^{th}$ position). Droughts affecting tomato production affect a whole chain of post-production with national economic impact. Some permanent cultures also exist, as olive and fruit orchards (Figure 5.2).

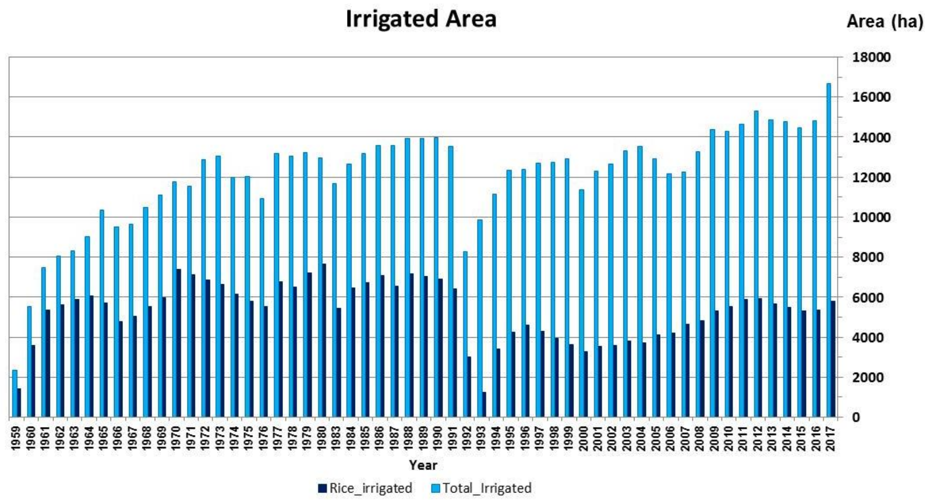

**Figure 5.2: General view of the irrigated crops of Sorraia Valley scheme on 2017 campaign; blue parcels stands for rice pads, green for maize fields, bright red for tomato fields, dark red for olive trees recent plantations and yellow are uncultivated land**

The market and the European Common Agricultural Policy (CAP) have influenced along the years the percentage of area being cultivated and the type of crops being produced. Figure 5.3 shows the evolution of irrigated areas of the three main types of cultures in the Valley since the beginning of operation of the irrigation scheme. Figure 5.4 shows the evolution of the total irrigated area and the representativeness of rice for the local agriculture. As agriculture become much more efficient in the region over the last two decades, the average annual storage surplus allowed to expand the irrigated area. In 2018 almost 19.000 hectares were irrigated. Figure 5.5 shows the water supplied by the ARBVS in the last two decades.



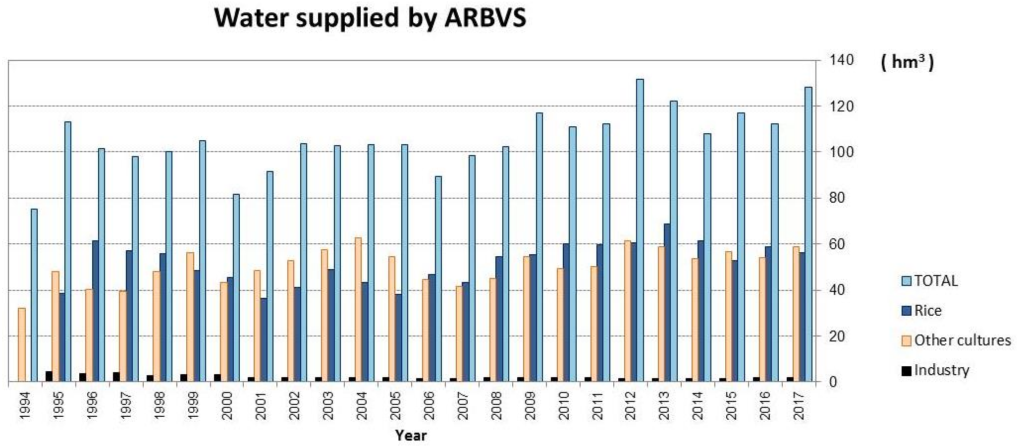
*Source: http://www.arbvs.pt/arearegada#.XIkZiSL7SHs*

**Figure 5.3: Evolution of irrigated areas per main types of cultures**




*Data source: http://www.arbvs.pt/arearegada#.XIkZiSL7SHs*

**Figure 5.4: Evolution of total and rice irrigated areas**




*Data source: http://www.arbvs.pt/volumesagua*

**Figure 5.5: Evolution of water supplied by ARBVS**

In *Sorraia Valley,* rice crop occupies most of the lower plain at downstream area (with high salt content), but is also growing at the middle part of the irrigated valley - about 5 800 ha of the total 16 600 ha irrigated area (in 2017). Rice use of water represent 67.5 $hm^3$ of the 128.3 $hm^3$ in 2017 (52.6%), accounting for about half of the total annual mean supply.

Since rice is the most water demanding crop, using about 12000 cubic meters per hectare, where maize or tomato crops requires less than 6 000 $m^3$/ha, it is obvious the importance of accessing the question of future social-economic consequences of the expected increase of water deficit due to climate change scenarios.

The construction of the public irrigation perimeter provided large competitiveness to the farmers benefiting from it. As described in the context (D4.1), presently farming in this region is skilled, highly evolved and very much adapted to the economic environment. Irrigation methods on parcels are generally very well adjusted to the crops and very efficient. In fact, in the last two decades, farmer's water use efficiency improved greatly.

From the 60$^{th}$ to the 80$^{th}$ irrigation was not efficient and around 200 hm$^3$ were used every year. Since then, the irrigated area increased in the valley but the water use efficiency increased as well. As Maranhão and Montargil together has more than 300 hm$^3$ storage capacity, presently it can assure 2 consecutive years campaigns, if precipitation allows for sufficient inflows to the reservoirs.

In average years, the water allocation is processed peacefully. During droughts, an apportionment strategy, if necessary, is peacefully put in place. The last time that water partitioning was put in place was in 1991/92, although the region experienced drought periods afterwards. In the years 70$^{th}$ and 80$^{th}$ partitioning was necessary with higher frequency, when irrigation was still very inefficient.

Maranhão and Montargil reservoirs, as part of the Sorraia irrigation scheme, provided inter annual regulation capacity, reducing exposure to the hazards associated with regional Mediterranean climatic variability. Presently they are quite important in providing resilience to climate changes.

### *Risk associated with climatic scenarios for the next decade*

Figure 5.6 depicts the flow duration curves coming from the 10 rainfall-replicas' input (from WP2) and, by comparison with the historical curve for the 1999-2008 period, 50% of the replicas for the Sorraia basin headwaters present shorter durations for the same magnitude of flows (D3.4). This means that the average annual precipitation tends to decrease in the Sorraia basin and, as a result, the inflows to Maranhão and Montargil tend to decrease.

Although a hydrologic hazard increase is expected for the next decade (WP2), it does not seem to increase substantially the existing water resources deficit risk (D4.3 and D4.4), as inflows tend to surplus demand. Nevertheless, some exceptionally dry years can cause problems. A sequence of 4 years in a row of very dry years is quite unlikely. With the replicas provided, even 3 years in a row were inflows are not enough to satisfy demand have very low chance of happening. The scenarios designed for this analysis are based on the worst scenarios presented in Table 5.10 of D4.3, but worsened, by assuming an initial storage of zero m$^3$, to indirectly simulate an increase in demand (due to acquisition of new beneficiary) or a decrease of inflows to Maranhão.

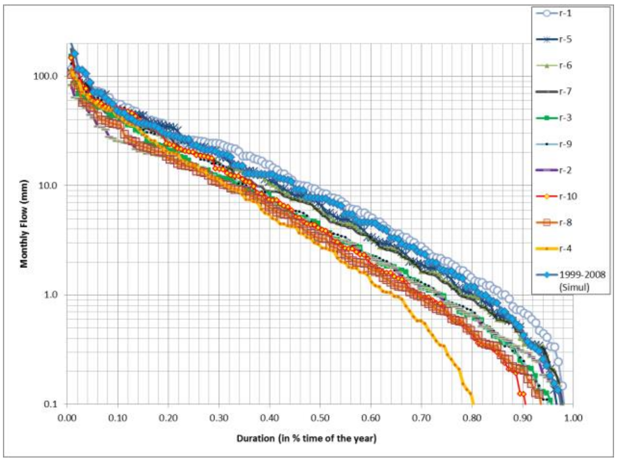



**Figure 5.6: Duration curves for the 10 rainfall-replicas' input to the model and comparison with the last monitored decade data in the headwaters of the Sorraia basin (D3.4).**

**Table 5.1: Scenarios**

| EVENTS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Water Resources AVAILABILITY** (Potential Hydrologic hazardous events) | | | | | **Water DEMAND** | **HAZARD Water Resources DEFICIT** (Imbalance between Availability and Demand) | |
| | **CAUSES** | | **HAZARD pathway** | | | | | |
| | **Climatic event** | **Initial Storage** (@ beginning of hydrol. year) **(hm³)** | **Reservoirs inflow** for the **period (hm³)** | **Replica Nº** | **Hydrologic Year(s)** | (hm³) | **Imbalance** | **Likelihood** (hydrologic episode) |
| a | Low precipitation during **ONE** hydrologic -Year | 0 | 70 | 4 | 2015/ 16 | 150 | Supply/ demand = 47% | Low |
| b | Abnormal low precipitation during **TWO** consecutive hydrologic -Y | 0 | 233 | 4 | 2015/ 17 | 300 | Supply/ demand = 78% | Very Low |

Due to the increase of farmers' efficiency during last decade, the Irrigators Association decided to spread the irrigation area, supplying new farmers. In the past, temporary deficit was already experienced. Although none of the scenarios produced in WP2 conduct to an extremely unfavourable climatic episode, it is known to be possible of happening and, the supply of more farmers, increase the Irrigators Association responsibility.

Being Sorraia's agriculture dependent on climate variability, climate changes create a feeling of financial uncertainty, specially, considering future scenarios of precipitation reduction. The recent expansion of irrigated area also increases demand, although new irrigated areas are olive orchards, with low water requirements.

***Other risk influencing factors contributing to increase the risk of water resources deficit***

Presently, the construction of a reservoir upstream of Maranhão seems to be plausible. If it is built it will reduce the inflows to Maranhão in a more significant way that climate changes.

Other factors contributing to increase the water resources deficit are related to water losses and operational wastes in Sorraia irrigation scheme. Maranhão and Montargil reservoirs were planned to assure irrigation needs of Sorraia Valley. Aged sixty years, the transportation/ distribution Sorraia scheme has degraded over time and leakage occurs. Designed by the standards of the mid XX century, mainly gravity based, favours operational water loss, and requires upgrading to allow for better operational performance.

Each year, in the beginning of summer campaign (March), the estimated water irrigation needs are compared with the storage available in reservoirs. If a water resources deficit exists, apportionment is put in place. Permanent cultures are priority, in order to avoid losing initial significant investment. Afterword's, water is allocated to each farmer producing seasonal crops, proportionally to the area being irrigated. This apportionment strategy, based on the area, has two main features:

- The water lost in the common irrigation scheme either through leakage or due to inefficient operational practices affects all the farmers (proportionally to the area). Any savings introduced in the system will be shared among all the farmers;
- Once a certain volume is allocated to a farmer, its own efficiency will determine its revenue in a year of water shortage.

As previously referred, the last time it happened was in 1992, although in recent 2017 the volume stored by the end of February was so low that it would not even fulfil permanent culture's needs. Happily, in March, precipitation was so intense that the summer campaign could be performed without constraints and a surplus assured part of 2018 campaign.

Although the main canals (primary distribution) have been improved, including lining of some few stretches, remote management and operation, an important part of this extra-long main distribution system needs further investment to rehabilitate impervious surface, in order to prevent water losses, and to increase operational efficiency. This context justifies the choice of measures listed in Chapter 5.3.

### 5.1.3 Tagus case context for water resources governance improvement

The Tagus River Basin is an international basin, shared with Spain. It is a heavily modified basin, mainly in the Spanish upstream catchment. In the Portuguese downstream part of the basin the main water consumptive uses are agricultural and public water supply. Hydroelectricity is also relevant in the basin. Although considered a non-consumptive use, from the point of view of the large shared Castelo de Bode reservoir, hydro electrical production is in fact a consumptive use. All the Zêzere and Tagus rivers Portuguese dams are operated by the EDP (the Portuguese Company of Electricity).

EPAL water utility, supplies drinking water to 35 municipalities of the right margin of the Tagus River, with a population of more than 2.9 million inhabitants, from which almost 500 thousand are inhabitants in Lisbon municipality (retail wholesale). The PWS has a nominal production capacity that can reach over 1 000 000 m³/day. In the lower Tagus (BINGO study area), the supplied municipalities are all located in the right margin of the Tagus river. EPAL doesn't hold private water sources. The shared main water sources are (Figure 5.7): i) surface intakes at Castelo do Bode reservoir, located in Zêzere river, and at Valada, located in Tagus upper transitional waters limit; and ii) small underground sources located in Ota, Alenquer, and Valada, and very important, the reserve strategic abstractions of Lezíria Grande de Vila Franca de Xira, in case a problem exist with the main superficial water sources.

EPAL intake at Castelo do Bode has a daily production capacity of 625,000 m³. Shared cordially with EDP (the dam owner) has always satisfied the public water supply needs, although with hydroelectric production restriction in some very dry years.

**a)** **b)**

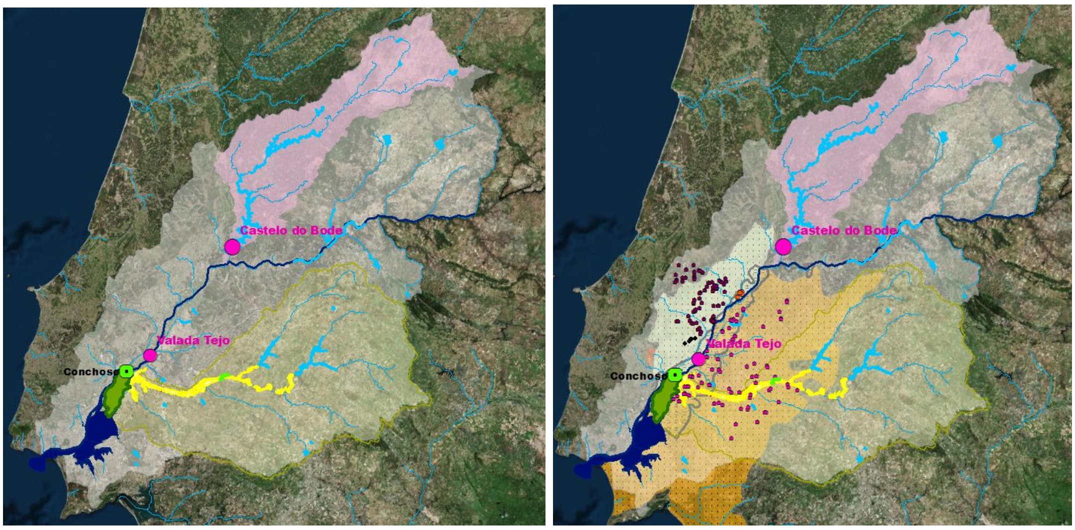



**Figure 5.7: Water Tagus Portuguese basin: a) Main surface water intakes; b) main groundwater PWS intakes**

The Valada surface intake in Tagus River is a secondary water source, and contributing with 12 to 23% of the total volume supplied. It is the most vulnerable intake of the overall abstraction system. The water abstraction is operated according to tides. Its water availability and quality is very dependent on upstream operational discharges either from Zêzere River (Castelo do Bode) or from Tagus dams (Belver and Fratel), all operated by EDP. The latter dams are also dependent on inflows from upstream Spain. Unlike Castelo de Bode, with low storage capacity they have only some few days of regulating capacity for low flows. Conchoso, the water intake for irrigation in Lezíria Grande de Vila Franca de Xira, is located downstream of Valada. It has the same dependency on EDP and Spain discharges regime, aggravated by the fact that has a closer vicinity to the estuary and high salt water content during some periods of the day, dependent on combined tide and Tagus flow.

Many other private abstractions for irrigation exist along the Tagus river and transitional waters. Many other underground abstractions exist either for agriculture or public water supply.

Water resources management practices are considered to affect water dependent activities in the Tagus basin as much as climate variability. It represents an external vulnerability to those activities that could be significantly reduced if improved water resources governance was implemented. It becomes even more important under a context of climate change, where events of water resources deficit may exist. In Deliverable 5.4 the main issues concerning policy and governance were identified.

The inexistence of a Tagus basin's water resources management model, as a basic communication tool among all the users and the Water Authority is considered an important gap to support effective and transparent water resources governance.

### *Risk associated with climatic scenarios for the next decade*

Tagus River represents a climatic pattern division in the basin. Sorraia is a good example of expected behaviour south of Tagus River. Figure 5.6 showed that the average annual precipitation tends to decrease in the Sorraia basin as well as the inflows to Maranhão and Montargil. Zêzere basin represents the behaviour at north of the river. Figure 5.8 depicts the flow duration curves coming from the 10 rainfall-replicas' input and, by comparison with the historical curve for the 1999-2008 period, the majority of the replicas for the Castelo de Bode basin headwaters present longer durations for the same magnitude of flows. Therefore, in average, average mean annual precipitations are expected, and the hydrologic hazard resulting from the climatic projections does not increase (D3.4). Being Castelo de Bode a pluri-annual regulation reservoir, in average the situation is comfortable. Nevertheless if a long period (3 years or more) of significantly reduced precipitation occurs, multi-use restrictions need to exist (D4.3).

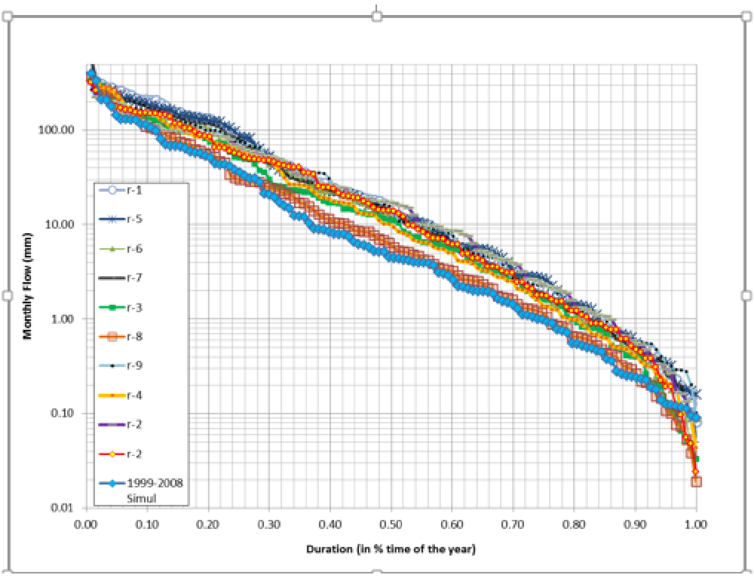


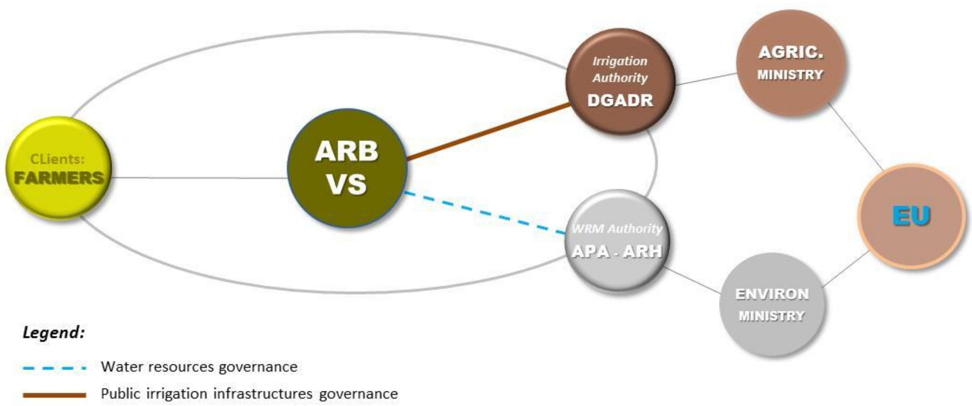

**Figure 5.8: Duration curves for the 10 rainfall-replicas' input to the model and comparison with the last monitored decade data in the headwaters of the Castelo do Bode basin.**

## 5.2. Stakeholders involved

The stakeholders depend on the focus of analysis.

For Sorraia PIP water use efficiency, the Directorate General for Agriculture and Rural Development (DGADR) as regulator is the owner of the Sorraia irrigation scheme, which has a concessionary the Irrigators Association (ARBVS). The risk owner is the entity responsible for implementing the selected measures, in this case, the Irrigators Association.

In the context (D4.1, Figure 6.17) it were identified the direct and indirect relevant stakeholders of the ARBVS. Figure 5.9 and Table 5.2 are present the relevant stakeholders for the measures under analysis (Chapter 5.3.). The first direct beneficiary is the Irrigators' Association (ARBVS) itself that can sell more water to the farmers, but the real important beneficiaries are the farmers, that have more irrigation water available in dry years, allowing for more production. Agroindustry (rice, tomato and maize canning) are indirect beneficiaries.



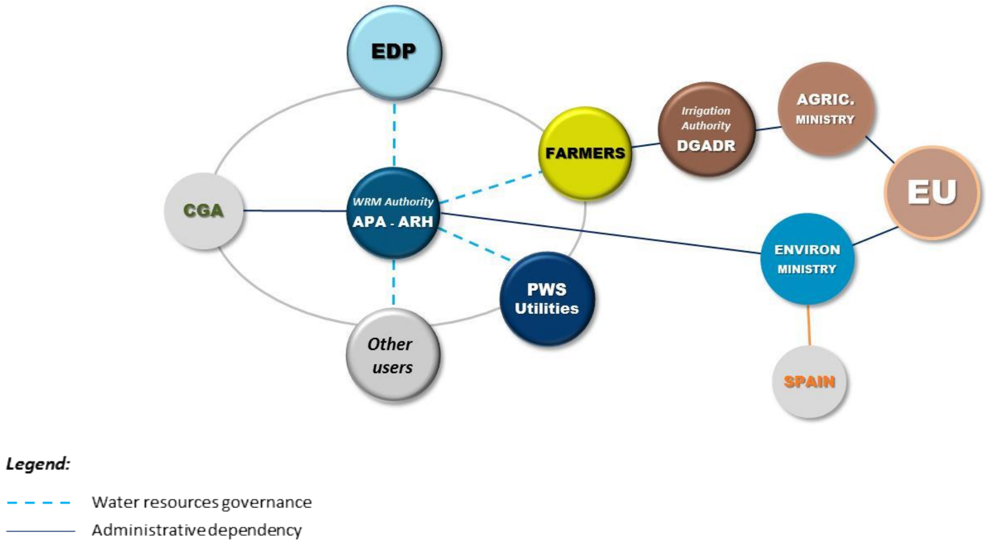

APA Portuguese Environment Agency (National Water Authority)

ARBVS Association of Irrigators and Beneficiaries of Sorraia Valley
ARH River Basin District Administration or Hydrographic Region Administration
DGADR Directorate General for Agriculture and Rural Development
EU European Union

**Figure 5.9: Key stakeholders for the Sorraia Irrigators Association (ARBVS)**

For the water resources governance improvement focus of analysis the Water Authority is considered the risk owner, as being the entity in charge of performing efficient water resources management and assuring adequate governance (stakeholder's active participation in decision). The most relevant stakeholders are identified in

Figure **5.10** and their roles in Table 5.2.




APA Portuguese Environment Agency (National Water Authority)
ARBVS Association of Irrigators and Beneficiaries of Sorraia Valley
ARH River Basin District Administration or Hydrographic Region Administration
CGA Reservoirs Management Commission
DGADR Directorate General for Agriculture and Rural Development
EDP Electricity of Portugal
EU European Union

**Figure 5.10: Key stakeholders for efficient water resources governance in Tagus lower basin**

**Table 5.2: risk owners and stakeholders roles**

| ENTITY | Responsibilities | Representing which sector/activity |
|---|---|---|
| ***ARBVS*** | Public Irrigation infrastructures maintenance and operation (retention, transport; distribution and supply);<br>Water resources management | Agriculture/ Irrigation water supply |
| **AGRIC. Ministry** | Agricultural policy.<br>Investment funds allocation | Agriculture and Agroindustry |
| **APA-ARH - Portuguese Agency for Environment** | Water Resources management<br>Droughts management | Public Administration/ Environment |
| **CGA - Reservoirs Management Commission** | Droughts management | Water resources |
| **DGADR - Directorate General for Agriculture and Rural Development** | Sorraia Irrigation infrastructure system owner;<br>infrastructural assessment, management and monitoring, | Public Administration/ Agriculture |
| **EDP - Electricity of Portugal** | Hydroelectric production | Energy |
| **ENVIRONM. Ministry** | Water policy | Water resources |
| E**U** | Common Agriculture Policy<br>Environmental Policy | Agriculture<br>Water resources |
| **FARMERS** | Farming, irrigation.<br>Members of Irrigator's Association | Agriculture/ irrigation |
| **PWS utilities** | Manage the urban water cycle | Public water supply |

## 5.3. Measures, data and assessment methods

### *5.3.1 Measures and data*

#### 5.3.1.1. Sorraia PIP - efficiency of water conveyance and use

The measures selected aims agriculture sustainability and to reduce water resources deficit for irrigation in Sorraia Valley during long severely dry period (years).

The necessity to rehabilitate and modernize the collective irrigation network is of top priority in order to reduce water deficit, either by reducing losses in the transportation system or by enhancing operational efficiency. This rehabilitation comprehends a set of interventions not solely oriented for water losses reduction. Some envisage infrastructure stability (e.g. surrounding soils drainage, bottom outlet); delivery time efficiency, operational comfort, people security, accessibilities for maintenance and region mobility, etc. not all of them within the scope of this analysis.

The rehabilitation project covers the transport and distribution networks. As network dimension decreases (from transport to local distribution) the number of necessary interventions increase. The purpose of this analysis is not to exhaustively analysis all the required interventions but compare the relative effectiveness of types of intervention measures if a limited budget is available for investment. DGADR, the regulator entity, in charge of supervising this and other national public irrigation schemes, is also interested in using the outcomes of this analysis in order to plan interventions on the other schemes, as many of them present equivalent state of degradation by years of usage.

This rehabilitation benefits all the farmers supplied by the Sorraia irrigation scheme.

On the farmers side there's the need to implement measures to increase water use efficiency. Several measures can be adopted. Increasing irrigation efficiency has been a large concern in the region. Several type of measures were implemented, either by upgrading infrastructures or by optimizing irrigation dotation. In very dry years, the choice for less water demanding crops can be suitable to guarantee revenue. Nevertheless, as benefit is individual rather than collective, the focus will rely upon Sorraia irrigation scheme.

The measures selected for the purpose of this analysis are presented in Table 5.3, where the main impacts and side effects are indicated.

**Table 5.3: Sorraia Measures, impacts and side effects**

<table>
<tr><th colspan="2">Measure</th><th>Expected Direct Impacts</th><th>Side effects</th></tr>
<tr><td>1</td><td>Rehabilitation and Waterproofing of Furadouro-Peso main canal<br>(Primary network - P04)</td><td>- Increase of total water availability for irrigation;<br>- Improved and more flexible operating conditions and hydraulic operation (farmers evolve from requesting water in 1 day advance to supplies on demand);<br>And also:<br>- Allow full remote digital operation;<br>- Reduced labour and costs requirements for exploration and conservation;<br>- Increased accuracy in flow control and volume measurement.</td><td>- Assure continuity of an important public irrigation scheme;S<br>- Increase farmers security for campaigns planning (both for winter and summer campaigns);<br>- Possibility of extending supply to other areas (extension of area equipped for irrigation);<br>- Increase agriculture sustainability in the region;<br>- Contribute for agroindustry stability in the region, employment and all inherent socio-economic effects.</td></tr>
<tr><td>2</td><td>Rehabilitation of Erra transport and distribution system<br>(Secondary and tertiary networks - P09)</td><td rowspan="2">The impacts referred for the former measures; and<br><br>- Increase in Association' energy consumption (collective pumping) but decrease in farmers energy consumption, with an overall net reduction.</td><td rowspan="2">The side effects referred for the former measures; and<br>- Gain of pressure on delivery allows reduction in farmers' energy bill and other operational costs (individual pumps, etc.);<br>- Possibility of irrigation overnight reduces farmers water bills;<br>- Water metering allows farmer to perform crops' water balances and apply for efficient irrigator award;<br>- Automatization and gain of pressure allows water availability for farmers 24 hours/ 7 days (higher flexibility);<br>- Reduction of basin carbon footprint;<br>- Co-accountability of irrigators.</td></tr>
<tr><td>3</td><td>Modernization of Formosa secondary irrigation system<br>(P02)</td></tr>
</table>

The data used to estimate cost-effectiveness of each measure had several sources:

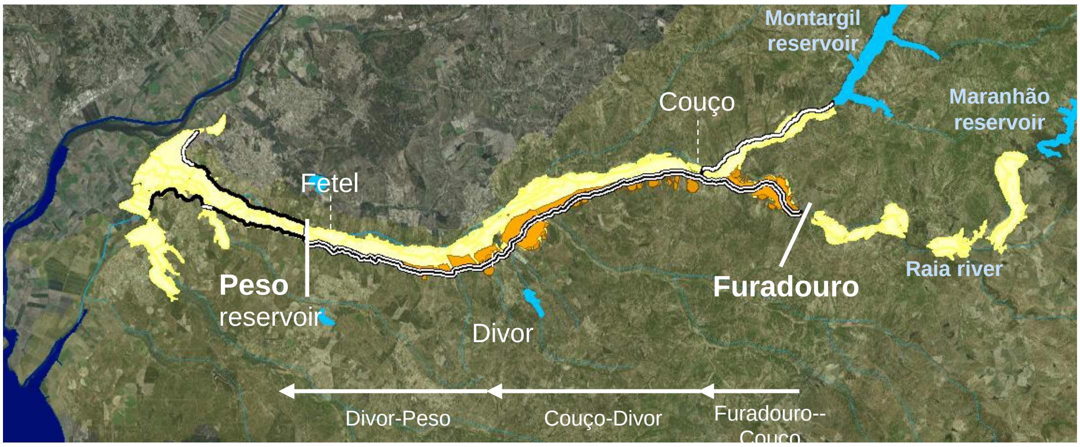
- The Investment project reports developed by ARBVS: for project rationale and costs estimation;
- Data in ARBVS website (http://www.arbvs.pt/) either as processed available data or from the annual reports;
- Contributes from ongoing AGIR project to water losses estimation;
- Data produced by ARBVS at BINGO team request.

## *Measures description*

### *Measure 1 - Rehabilitation and Waterproofing of the Furadouro-Peso main canal*

*Main objective*: Increase agriculture sustainability and water availability for irrigation by reducing water losses through leakage (along the canal and in diversion equipment's) and by increasing operational performance.

Sorraia transport system is a rather complex system. The main canal (primary network) feeds the secondary transport network and the ramified distribution (tertiary) network. Furadouro-Peso canal is part of the main primary transport canal, flowing along around 50 km, from Furadouro weir till Peso reservoir (Figure 5.11), a compensation reservoir that stores exceeding volumes transported by the canal. After Couço, were Rivers Sor and Raia converge, originating the Sorraia River, this canal transports water proceeding from both Maranhão and Montargil reservoirs. Besides feeding the secondary network, it also provides direct water supply to the adjoining areas.




Legend:

| | |
|---|---|
| ═ | Furadouro-Peso canal to be rehabilitated |
| ═ | Primary canal already rehabilitated (Montargil – Couço) |
| ▬ | Primary canal not yet rehabilitated |
| ■ | Irrigated areas during the winter, with intakes in Furadouro-Peso canal |

**Figure 5.11: Measure 1 - Rehabilitation and waterproofing of Furadouro-Peso canal**

It is an open canal, mainly with trapezoidal section, with some stretches with rectangular shape. Some few stretches are also in bridge (rectangular section) or in tunnel. For operational purposes (water plan regulating), the canal is sectioned by several AMIL gates (working by hydraulic pressure differential) and have several devices, as for example, water outlets to supply farmers directly or for derivation to secondary canals.

**Figure 5.12: Canal walls deterioration**

Aged 60 years this canal suffered the effects of up-lift pressures that damaged the structure along time, presenting many cracks and showing evidence of deterioration by erosion, mainly in the expansion joints of the inner coating (high roughness) (Figure 5.12). Due to water nutrients enrichment, limes and infesting macrophytes proliferate. As a result, cross section is reduced affecting flow capacity and the fulfilment of farmer's needs.

Some of the AMIL gates also present deterioration and do not assure water tightness inside the canal. This introduces a significant operational water loss during the winter. Winter crops, mainly peas, in the adjoining areas to the canal (orange areas in Figure 5.11) need to be irrigated during 17 weeks of the winter, with low volumes. As AMIL gates are not water tight, in order to achieve the hydraulic requirements inside the canal to assure efficient water outlets, a much larger flow has to be introduced into the canal in order to satisfy the low water requirements from farmers. This represents an inefficient operational water use that, if stored, could be later consumed during the summer.

The winter irrigation, although important, has a reduced expression, not justifying the placement of all stretches of canal under load nor the operation of the canals permanently, as it happens during the summer irrigation campaigns. It is only necessary that some canal stretches maintain certain volumes of stored water, sufficient for winter irrigation needs (1000 $m^3$/winter/hectare $\Leftrightarrow \approx$ 60 $m^3$/week/hectare). The solution cannot be based on AMIL gates as they do not assure adequate water tightness, even in good conditions. It involves the replacement of the AMIL gates by a double duckbill weirs cross regulators (equipped with a vertical flat beater with electric actuator), only in each stretch of the canal that directly serves the winter irrigation. This storage potential will also allow retaining the run-off due to precipitation, reducing the water use from the reservoirs.

Other sort of related problems exist, therefore it is not effective to improve water proofing without performing a complementary set of improvements. In summary, measure 1 includes:

1.1. Cleaning, rehabilitation and waterproofing of the canal.

Includes: covering existing canal walls with concrete, reinforced with metallic fibres, with 10 cm thickness; repair and reinforcement of canal structures as bridges and tunnels; rising walls in 15 cm to restore flow capacity; complementary works related with structure stability (soils drainage; bottom outlets); equipment replacement (e.g. some control AMIL gates, water outlets); etc.;

1.2. Conversion of certain stretches of the canal into reservoirs through replacement of some control AMIL gates by duckbill weirs regulators (Figure 5.13) in sectors of the main canal: Furadouro-Couço; Couço-Divor and Divor-Fetal (upstream Peso).

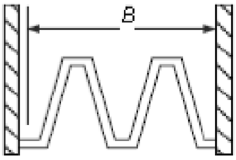



**Figure 5.13: duckbill weirs regulators**

The ARBVS original project also includes a set of complementary works related with canal accessibilities and safety that were not considered in this analysis.

Table 5.4 resumes the data used and assumptions for the effectiveness indicator estimate.

The most direct impacts of this measure are:

- Potential water savings: With the works proposed, the efficiency of the use of water resources in the Furadouro - Peso canal will be of the order of 95%, leading to an annual saving of around 3.65 million cubic meters. On average, an improvement in the efficiency of the use of water resources of around 10% is expected;
- Operational efficiency and flexibility increase with potential labour savings: With the implementation of this measure, it is expected to reduce the maintenance team affected to the Furadouro - Peso canal, implying a labour economy of 16%. It will also lead to the reduction of other maintenance and operational costs.

Other very important side effects are referred in Table 5.3.

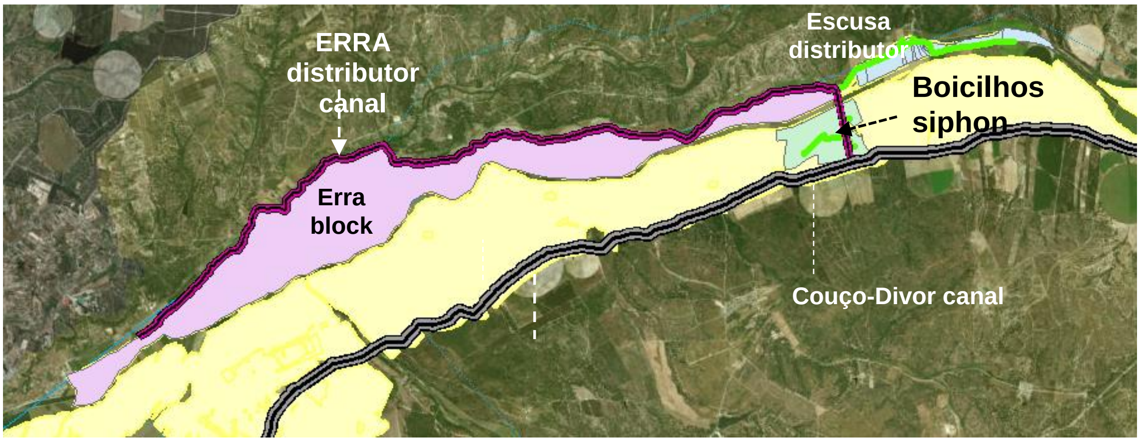
**Table 5.4: Measure - Data and assumptions**

| | Variable | Units | Data | | Assumptions / Calculations |
|---|---|---|---|---|---|
| DATA | ***Canal Length*** *to be rehabilitated* ***(1)*** | *km* | ***50.34*** | ***Furadouro-Peso (Total)*** | |
| | | | *10.72* | *Furadouro-Couço (Sector 1)* | |
| | | | *14.64* | *Couço-Divor (Sector 2)* | |
| | | | *24.98* | *Divor-Peso (Sector 3)* | |
| | ***Canal Area*** *for water losses estimation in the canal* ***(2)*** | *km²* | *9.32* | *Furadouro-Couço (Sector 1)* | *Estimated as the canal wet perimeter per type of section multiplied by the respective length.* |
| | | | *12.44* | *Couço-Divor (Sector 2)* | |
| | | | *18.05* | *Divor-Peso (Sector 3)* | |
| | | | *1 656 582* | *Divor-Peso (Sector 3)* | |
| | *Storage capacity with duck weirs* ***(3)*** | *m³* | ***289 800*** | ***Furadouro-Peso (Total)*** | |
| | | | *57 600* | *Furadouro-Couço (Sector 1)* | |
| | | | *124 500* | *Couço-Divor (Sector 2)* | |
| | | | *107 700* | *Divor-Peso (Fetel) (Sector 3)* | |
| | ***Total irrigated area*** *by Montargil and Maranhão* ***(4)*** | *ha* | *15 365* | *All irrigation perimeter* | |
| | ***Area directly benefited*** *by the measure* ***(5)*** | *ha* | *13 762* | | |
| | ***Winter Irrigated areas*** *by each canal sector* ***(6)*** | *ha* | *945 642* | *Furadouro-Couço (Sector 1)* | |
| | | | *911 472* | *Couço-Divor (Sector 2)* | |
| | | | *1 656 582* | *Divor-Peso (Sector 3)* | |
| | *Winter campaigns: <u>Maximum</u> water requirements* ***(7)*** *(Maximum requirement ⇔ all area being irrigated and growing grain peas)* | *m³/week* | ***206 688*** | ***Furadouro-Peso (Total)*** | *<u>Assumptions</u>:* *Nº weeks/ winter campaign = 17;* *Taking grain peas as reference:* *Winter irrigation/ campaign ≈1000 m³/ winter/ hectare* *Winter irrigation / week ≈60 m³/ week/ hectare;* |
| | | | *55 626* | *Furadouro-Couço (Sector 1)* | |
| | | | *53 616* | *Couço-Divor (Sector 2)* | |
| | | | *97 446* | *Divor-Peso (Fetel) (Sector 3)* | |
| | | *m³/winter* | ***3 513 696*** | ***Furadouro-Peso (Total)*** | |
| | | | *945 642* | *Furadouro-Couço (Sector 1)* | |
| | | | *911 472* | *Couço-Divor (Sector 2)* | |
| | | | *1 656 582* | *Divor-Peso (Fetel) (Sector 3)* | |
| | ***Water use*** | *m³/year* | ***Before measure implementation*** | | *<u>Assumptions</u>:* ***Before measure implementation*** *Water loss along the canal: 50 l/m²/day* *Period of operation = 270 days/year* ***After measure implementation*** *Water loss estimate along the canal: 15 l/m²/day* *Period of operation = 365 days/year* *<u>Water losses estimate =</u>* *Water loss along the canal (l/m²/day) x wet perimeter x extension x Nº days* |
| | | | ***4 831 910*** | ***Furadouro-Peso (TOTAL)*** | |
| | | | *1 258 154* | *Furadouro-Couço (Sector 1)* | |
| | | | *1 678 770* | *Couço-Divor (Sector 2)* | |
| | | | *1 894 986* | *Divor-Peso (Sector 3)* | |
| | | | ***After measure implementation*** | | |
| | | | ***1 191 086*** | ***Furadouro-Peso (TOTAL)*** | |
| | | | *510 251* | *Furadouro-Couço (Sector 1)* | |
| | | | *680 834* | *Couço-Divor (Sector 2)* | |
| | | | *988 100* | *Divor-Peso (Sector 3)* | |
| EF FI | ***Δ Annual Water losses*** | *m³/year* | ***Net benefit*** | | |
| | | | ***-3 640 824*** | ***Furadouro-Peso (TOTAL)*** | |

| | | | | | |
|---|---|---|---|---|---|
| | | | -747 903<br>-997 935<br>-906 886 | Furadouro-Couço (Sector 1)<br>Couço-Divor (Sector 2)<br>Divor-Peso (Sector 3) | |
| ***INVESTMENT*** | ***CAPEX*** | *€* | *23 000 000* | | *From the total budget presented for this project it was deducted the investment not directly related with water use efficiency or with structure stability (e.g. accessibilities, people safety, etc.)* |
| | ***△ OPEX*** | *€/year* | *-60 000* | | ***After measure**: OPEX costs calculated as percentage of the investment on civil works (1%) and equipment investment (2%); a labour and equipment use reduction of 16%* |
| | | *€* | *-1 800 000* | | *Considering 30 years period* |
| | ***TOTAL*** | | *21 200 000* | | ***TOTAL = CAPEX + △ OPEX***<br>*Considering 30 years period* |

### *Measure 2 - Rehabilitation of Erra transport and distribution system*

<u>*Main objective*</u>: Increase agriculture sustainability and water availability for irrigation by reducing water losses through leakage (along the canal and in diversion equipment's) and by increasing operational performance.




Legend:
- Couço-Divor canal (part of Furadouro-Peso canal)
- ERRA canal
- Escusa distributor
- Bocilhos block
- Escusa block
- Erra block

**Figure 5.14: Erra transport and distribution system**

The ERRA system includes several components. The Boicilhos siphon is responsible for deriving water from the mail canal, close to the beginning of Couço-Divor stretch, and transporting the necessary flows (dimensioned for the supply of 1.20 m³/s ) to feed the Erra canal and Escusa distributor, which benefit the agricultural lands on the right bank of the Sorraia river (Erra and Escusa blocks). In the way, the Boicilhos siphon also feeds the Boicilhos, in the left side bank of Sorraia block (Figure 5.14).

From the origin of the siphon to the intersection with the road EN 251, in a section of 182.52 m, the flow occurs in an open canal with trapezoidal section, with a slope of 200 cm/km, and a concrete coating of 250 kg / m3, 0.06 m thick. From then until its end (1182.80 m), the flow is under pressure, in a circular pipe, in shackles of inner diameter 1.10 m of reinforced concrete of 450 kg/$m^3$, with reflective joints. In the zone corresponding to the crossing of the Sorraia river bed, the shackles are laid on concrete cushions (200 kg/$m^3$).

The Erra Distributor originates at the downstream mouth of the Boicilhos siphon and is the irrigation conductor of the right bank of the Sorraia Valley, showing a total development of 14252.30 m. According to the available load, the distributor was designed with a greater slope in the initial sections. Thus, the first and second sections, with flow rates of 1.1 $m^3$/s and 1.0 $m^3$/s, have a slope of 45 cm/km and the remaining sections with flow values of: 0,5 $m^3$/s; 0.3 $m^3$/ s; 0.2 $m^3$ / s and 0.1 $m^3$/s have a slope of 25 cm/km. In sections where the distributor develops in a rectangular section, it is verified that the sections have the following inclinations: 1st section - 200 cm/km; 2nd section - 190 cm/km; 3rd section - 120 cm/km. The small surface free conduit of Escusa, similarly to Erra distributor, originates from the downstream mouth of the Boicilhos siphon, presenting a development of 2,063.48 meters, part with rectangular section (sections 1 and 3) and part with trapezoidal section (section 2). It is coated with concrete of 250 kg/$m^3$, slope of 20 cm/km, and an initial transport flow of 0.10 $m^3$/s. The total area benefited by this distribution system is 69.08 ha. Irrigation is done by means of 10 outlets, but only one of them is a water conduit, with a total development of 1130.26 m.

Information concerning sections and inclinations was used to estimate water losses in the canal and pipes. It is also relevant to allow comparison among different infrastructures dimensions. Water losses and cost-benefit were estimated based on certain assumptions (Table 5.5).

These infrastructures present evident deterioration, in particular with regard to water losses and excessive proliferation of limes in the Erra canal during the irrigation campaigns. The open canal present similar problems of those described for the main canal, where the siphons are partially obstructed due to the accumulation of sediments inside the shackles, causing limitations to the transport of water. Several ruptures have also been identified, leading to water losses, particularly in the joints connecting the shackles. In the particular case of the Boicilhos siphon, in the zone of crossing of the Sorraia river, the pipeline is unprotected, due to the entrainment of sediments. The system needs rehabilitation, waterproofing and modernization, namely of the siphon and transport and distributions canals, distribution manholes and derivation equipment’s. Like the main canal it requires complementary works as drainage, among others.

Relevant data for cost-effectiveness estimation is summarised in (Table 5.5).

**Table 5.5: Measure 2 - Data and assumptions**

| | | Units | Data | Data and assumptions |
|---|---|---|---|---|
| DATA | **Water distribution network** | km | 33 | **Before measure**: Total length channel and tertiary low pressure pipe distribution network |
| | | | 34.4 | **After measure**: total length of new pipe medium pressure distribution network (replaces old channel and pipe system) |
| | **Irrigated Area** | ha | 708 | **Before measure** |
| | | | 928 | **After measure** |
| | **Energy use (application)** | MWh/year | 343 51 | ***Before measure***: This sector has no energy spent on water distribution; 37% of the area is covered with rice fields that have no advantage in pressurized water service; only 35% of the vegetable and maize farmer's use drip and spray methods, that spend energy on their private pressurization system |
| | | | 770 | ***After measure***: energy costs per hectare increase as more non rice farmers will be using drip and spray methods |
| | **Water use** | $hm^3$/year | 8.548 | ***Before measure*****:** water abduction (at sector origin) |
| | | | 6.4 | ***Before measure***: water delivered to farmers<br>Water loss are around 25% of total abstracted water (according to a measurement done in 2013) |
| | | | 8.4 | ***After measure***: water abduction (at sector origin) |
| | | | 08 | ***After measure***: water delivered to farmers<br>Water loss are around 10% |
| INVESTMENT | **CAPEX** | € | 3525 423 € | From the total budget presented for this project it was deducted the investment not directly related with water use efficiency or with structures stability such as accessibilities, people safety, etc. |
| | **△ OPEX** | €/ha/year | -29 | ***Before measure*****:** only a part of the potential irrigated area is being used, but maintenance and repair costs are growing each year<br>***After measure***: OPEX costs calculated as percentage of the investment on civil works (1%) and equipment investment (2%) |
| | | €/year | -26 912 | Considering area after measure implementation |
| | | € | -807 360 | Considering 30 years period |
| | **TOTAL** | € | 2 718 063 | **TOTAL = CAPEX + △ OPEX** Considering 30 years period |
| EFFICIENCY | **△ Annual Water losses** | $m^3$/year | -1 300 000 | Water loss reduction =Water Loss before - Water Loss after<br>Net benefit of 15% |
| | **△ Annual Energy / water irrigation volume** | $kwh/m^3$ | + 0.048 | ***After measure****:* final global energy use may increase as more non rice farmers will be able of using efficient irrigation methods (drip and sprinklers) |

The direct benefits of this measure are the following:

*a) Efficiency of transport*

The rehabilitation of Siphon of Boicilhos, which foresees the replacement of the conduit and consequent reduction of the roughness, will allow the recovery of the capacity of transport of the siphon, also verifying a decrease of the water losses. With the intervention provided in the

Erra Distributor, the canal geometry will be regularized and the cross section will be recovered, reducing roughness by about 20%, reducing the weeds' fixation and proliferation, and the transport capacity of the channel will retrieve the values for which it was designed, in addition to the improvement in response times.

*b) Potential water savings*

The transport capacity of the distributor is currently limited to a flow rate of 1,10 m3/ s, since the flow admitted at the beginning of the Siphon, 1,20 m3 / s, does not reach the irrigation nozzles in their entirety. By recovering the transport capacity, a water saving of around 8.3% is foreseen. The losses due to infiltration in the canal, assuming they can be of 50 l / m2 in 24 h due to the concrete coating deterioration, represent a decrease of 26.81 l / s in the transport capacity, so the rehabilitation of the lining of the canal will represent an economy of about 0.42 hm3.

*c) Quality of service*

The loss of water transport capacity of the Siphon of Boicilhos, Erra Distributor and water conduit of Escusa limits the water supply to the agricultural parcels. With the proposed intervention, irrigators' needs can be met more quickly and efficiently, since current supply constraints will be eliminated, with evident gains in the quality of service provided. The improvement of the quality of the water distribution service provided to the irrigators will cover all the farmers located in the area of influence of these infrastructures.

*d) Operational water management*

By implementing this measure, all response times will be substantially reduced and automatic, system reliability will increase and risks reduced.

The improvement of the transport capacity of the canal, by means of a reduction of roughness, will also allow a more rational and flexible exploration of this sector, as well as ensuring a more efficient use of these infrastructures.

The fact that the operation of the Escusa water conduit being changed from upstream on-demand control to downstream control at low pressure, will also allow for more rational and flexible operation and will ensure efficient use of new technologies with all economic and environmental advantages.

*e) Saving of repair / maintenance costs and of manpower*

Directly, the gains in the economy of means will be significant, in particular the conservation and rehabilitation works carried out annually in the preparation of each irrigation campaign, in the order of € 97,080.39/year for machinery, materials and labour.

In what concerns energy uses presently this sector operates by gravity with no related energy uses. 37% of the area is covered with rice fields that have no advantage in pressurized water service; only 35% of the vegetable and maize farmer's use drip and spray methods that spend energy on their private pressurization system). After implementation of this measure the final global energy uses may increase as more non rice farmers will be able of using drip and sprinkler methods, although these are much more water efficient irrigation systems.

***Measure 3 - Modernization of Formosa secondary irrigation system***

*Main objective*: increase operational performance, reduce water losses and enhance energy optimal use, through pressurization of the system at water delivery points.

The distributor of Formosa is located in the irrigation block number 7 (block of Coruche), a plateau zone on the left banks of both Divor and Sorraia Rivers (Figure 5.15). For high-altitude areas irrigation is done using pumping.

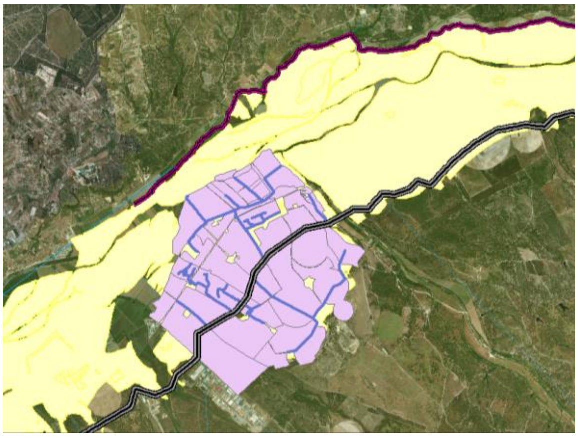


**Figure 5.15: Formosa distribution system**

Due to the long years of use, in addition to the misappropriation of the distribution system to reality, the degradation begins to become evident, with the abandonment or not appropriate use of the productive potential of the areas benefited. In order to optimize the proper functioning, rehabilitation works and the implementation of more modern systems will be necessary.

This rehabilitation will benefit 1118 ha. This area includes not only the agricultural area, but also the national and municipal roads, and the areas occupied by agricultural roads, infrastructures, ditches, fences, etc., which will not be effectively irrigated and which are designated by social areas.

The Formosa irrigation block will be fed from a new pumping station, whose water intake will be located on the main Divor-Peso canal. The pumping station to be constructed will be positioned in the centre of gravity of the block, and will be sized to ensure a pressurized delivery at all points in the block.

The proposed network is about 21.4 km long and has been developed along existing roads or property boundaries in order to facilitate its installation and future maintenance and conservation operations. It is recommended that the watering system be made up of HDPE pipes (110 mm ≤ DN <500 mm), FFD (600 mm ≤ DN <700 mm) and reinforced / pre-stressed concrete with steel core (DN ≥ 800 mm) including 159 hydrants and 290 watering nozzles. It is also planned to install control and manoeuvring equipment necessary for the operation and maintenance of the system, namely hydrants, isolating valves, bottom discharges and air valves.

The project flow at the beginning of the network is 2600 l/s.

The main advantages of the rehabilitation and modernization measure are:

- Increase in the quality of service and improvement of the conditions of access to the water outlets by the farmers:
  - by the increase of the unitary flows provided by outlet;
  - by the abolition of the limitations of time in the access to the intakes, allowing to be "on request" 24h/day;
  - by the supply of water under pressure;
- Increased efficiency in the use of water for irrigation through the operation of the system under pressure and "on demand", which will allow the farmer to better adjust irrigation to soil and climate conditions and reduce losses in the system;
- With on-demand distribution and on-demand access, labour costs will be significantly lower than those currently required by existing systems;
- The new access conditions will allow an optimization of energy costs since there will be better conditions to adjust the irrigation schedules to the energy tariffs schedules;
- The new system will benefit areas that are not currently cultivated;
- With the new system it is possible to extend the possibility of watering every day of the year, thus allowing the intensification and/ or production of two or three crops per year;
- The new system will allow abandoning the current canal system, which does not adapt to current agricultural practices, conditioning the use of new technologies and mechanized means.

As direct results of this measure the increase in efficiency is:

- Potential water savings: Improvement of 64% in transportation and distribution by water losses reduction (≅ 50%) and operational efficiency improvement;
- Potential labour savings: operational labour economy of 50%.

Table 5.6 resumes the data used and assumptions for the cost-effectiveness ratio estimate.

**Table 5.6: Measure 3 - Data and assumptions**

| | | Units | Data | Data and assumptions |
|---|---|---|---|---|
| DATA | **Water distribution network** | km | 16.9 | ***Before measure***: Total length canal and tertiary low pressure pipe distribution network |
| | | | **!Syntaxfehler, .** | ***After measure***: total length of new pipe medium pressure distribution network (replaces old canal and pipe system) |
| | **Irrigated Area** | ha | **!Syntaxfehler, .** | ***Before measure*** |
| | | | 1 118 | ***After measure*** |
| | **Energy use (water transport, distribution and application)** | MWh/year | 775 | ***Before measure***: energy spent in water elevation for canal subsector plus energy spent by farmers in their irrigation systems |
| | | | 02 | ***After measure***: energy for water pressurization into new pipe medium pressure network |
| | **Water use** | $m^3$/year | 2 614 680 | Water abduction (at sector origin) |
| | | | 1 414 717 | ***Before measure***: water delivered to farmer<br>Water loss around 46% of total abstracted water (according to a measurement done in 2013) |
| | | | 2 353 212 | ***After measure***: water delivered to farmer<br>Maximum water loss estimated as 10% (possibly 5%) |
| INVESTMENT | **CAPEX** | € | 8474 710 | From the total budget presented for this project it was deducted the investment not directly related with water use efficiency or with structures stability such as accessibilities, personnel safety, etc. |
| | **△ OPEX** | €/ha/year | 113 | ***Before measure*:** only a part of the potential irrigated area is being used, but maintenance and repair costs are growing each year<br>***After measure***: OPEX costs calculated as percentage of the investment on civil works (1%) and equipment investment (2%) |
| | | €/year | - 126 334 | Considering area after measure implementation |
| | | € | -3 790 020 | Considering 30 years period |
| | **TOTAL** | € | 4 684 690 | **TOTAL = CAPEX + △ OPEX** Considering 30 years period |
| EFFICIENCY | **△ Annual Water losses** | $m^3$/year | **-3 200 000** | Water loss reduction =Water Loss before - Water Loss after<br>Net benefit of 40% |
| | **△ Annual Energy/ water irrigation volume** | kwh/$m^3$ | -0.087 | ***Before*:** total energy budget (distribution and farmer's private pressurization) has high costs and prevents small farmers to upgrade from old furrow irrigation methods to smart/efficient sprinkler and drip irrigation methods;<br>***After measure***: final global energy costs per hectare are reduced, because water will be delivered with pressure for the whole sector (4.5 bar guaranteed at farmers outlets). The farmers will have zero water costs, although ARBVS energy costs increase, with a final net benefit exits |

### 5.3.1.2. Tagus - water resources governance improvement

**Measure 4 – Tagus water resources management model**

Stakeholder engagement is crucial when developing management plans and operational practices for water resources usage in river basins. In Tagus basin stakeholders feel that there is no productive involvement or real saying on the planning process and that decisions taken are more casuistic than based on an integrated approach. When sharing water resources there is a common feeling of lack of transparency and even lack of knowledge of how each user is relatively affecting the water bodies environmental objectives either from the quantitative or qualitative points of views.

Recognised as being an important inexistent tool, this measure concerns the development of a Tagus water resources management framework, aiming to support integrated water resources analysis, planning and management of Tagus river basin. It will allow defining solutions for problems of water allocation; optimization of the existing reservoirs operation, water uses management and evaluation of water quality indicators during the exploration. This tool will not only allow to outline strategies to adapt to the challenges posed by the various simultaneous uses of water resources, mainly during periods of water resources deficit, but will also allow to analyse the occurrence of extreme meteorological phenomena, assessing their impacts on the basin and the selection of adequate prevention and control options. Nevertheless, the present focus relies mainly on the planning process related with:

- multisector solution alternatives to water allocation and water shortage problems;
- climate change impact assessments on water resources availability and quality;
- exploration of conjunctive groundwater and surface water usage;
- optimisation of reservoir and hydropower operations;
- agricultural water use efficiency;
- integrated water resources management (IWRM) studies.

This measure will promote transparency among stakeholders while assisting on the analysis of water-sharing issues at international, national or local river basin scale, investigating options and making reliable decisions.

By reducing the presently existing vulnerabilities in WRM, this measure aims to enhance resilience to cope climate change.

The model being used is the MIKE HYDRO BASIN, a multipurpose, map-based decision support tool (Figure 5.16). MIKE models are composed of several modular components that can be linked among them. Therefore it is possible to integrated superficial runoff modelling with groundwater transport processes by linking MIKE HYDRO (the hydrologic module) with MIKE FeFLOW model, or to link with water quality module (ECO LAB). For stakeholders engagement specific modules also exist (MIKE PLANNING and MIKE OPERATIONS).

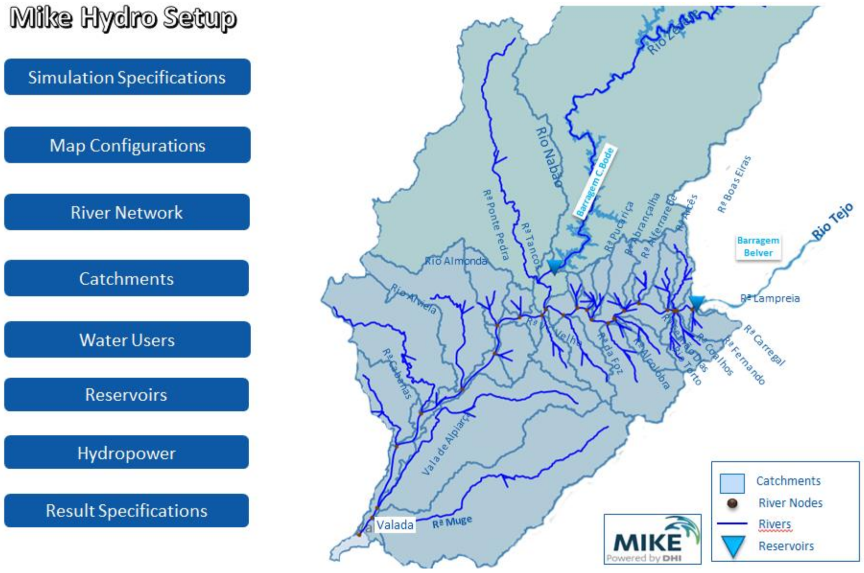



**Figure 5.16: Tagus model setup**

The model requires various input data that includes:

- parameters to define the catchment,
- model parameters, initial conditions,
- hydro-meteorological data: the basic meteorological data requirements are precipitation, potential evapotranspiration and temperature. For water quality modelling is also required solar radiation and number of hours of light/day;
- stream flow data: flows or levels for model calibration;
- parameters for soil moisture content and groundwater recharge;
- reservoirs characteristics, storage capacity, water heads, operational rules;
- water quality data: oxygen, carbon and nutrients cycle parameters; phytoplankton biomass;
- water uses: abstraction volumes, regime and location; discharge volumes and associated pollutant loads;
- economic data associated with water uses.

This measure, being a governance supporting tool, has modelling costs and continuous monitoring costs, but does not represent a measure with direct benefits over a sector. Therefore no cost-benefit is estimated and in fact its benefit will depend on the extent of its future exploitation.

### *5.3.2 Assessment method*

The effectiveness of the measures was only estimated for the measures selected for the Sorraia PIP. The development of the Tagus water resources management model has important relevant impacts that cannot be directly numerically accounted for.

In order to compare the effectiveness of each Sorraia's measure a cost effectiveness ratio (CER) was established. To define this ratio it was taken into consideration that:

- Benefited areas of each measure are of substantially different sizes;
- The effectiveness is analysed in terms of increase of water use efficiency, resulting in additional available volume of water for irrigation, but also in operational efficiency improvement (with all the referred related advantages) and in other important side effects. As measures were designed for several purposes and the estimated investments reflect the diversity of purposes, the cost effectiveness indicator has to translate this diversity.

A measure that impact a substantial percentage of the PIP area has obviously greater relevance that one affecting a small area. The percentage of directly benefited area was assumed as an effectiveness increase factor of the additional available volume of water gained. For means of simplicity, the operational efficiency improvement and side effects were also considered as part of the effectiveness increase factor and as being, as well, proportional to the percentage of the overall benefited area. It resulted in the cost effectiveness ratio (CER) represented by eq. 1 and eq. 2.

$$CER = \frac{\text{COST of the measure}}{\text{EFFETIVENESS } (\Delta \text{ Water VOL})*(\text{Increase factor})]} \quad \left[\frac{€}{\text{m3}}\right] \qquad \text{eq. 1}$$

$$CER = \frac{\text{COST of the measure}}{\text{EFFETIVENESS } (\Delta \text{ Water VOL})*(1+\% \text{ AREA}_{\text{benef}}+\Delta \text{ OPER}_{\text{benef}}+\Delta \text{ SIDE Effects } )]} \qquad \text{eq. 2}$$

Where:

$\Delta$ Water VOL - Additional available volume of water ($m^3$)

$\Delta$ $AREA_{benef}$ – Ratio Area directly benefited / Total PIP Area

$\Delta$ $OPER_{benef}$ – Operational efficiency improvement, considered as the Ratio Area benefited / Total PIP Area

$\Delta$ SIDE EFFECTS – Side effects effectiveness, considered as the Ratio Area benefited / Total PIP Area

**Table 5.7: Cost Effectiveness ratio**

| Measure | AREA Directly Benefited | INVESTMENT | | | EFFICIENCY INCREASE | | | | COST EFFECTIVENESS |
|---|---|---|---|---|---|---|---|---|---|
| | | CAPEX | $\Delta$ $OPEX_{\_30\ years}$ | Total | $\Delta$ Water Volume | Increase Factor | | | |
| | ha | € | € | € | $m^3$ | % $Area_{Benef}$/ $Area_{PIP}$ * | $\Delta$ OPER_ Benef | $\Delta$ Side effectsf | € /$m^3$ |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Rehabilitation and Waterproofing of Furadouro-Peso main canal | 13 850 | 23 000 000 | -1 800 000 | 21 200 000 | **3 640 824** | 0.904 | 0.904 | 0.904 | **1.57** |
| 2 | Rehabilitation of Erra transport and distribution system | 928 | 3 525 423 | -807 360 | 2 718 063 | **1 300 000** | 0.061 | 0.061 | 0.061 | **1.77** |
| 3 | Modernization of Formosa secondary irrigation system | 1 118 | 8 474 710 | -3 790 020 | 4 684 690 | **938 495** | 0.073 | 0.073 | 0.073 | **4.10** |

Total Area_PIP= 15 325 ha

## 5.4. Assessment results and discussion

Figure 5.17 summarizes the cost effectiveness of each Sorraia measures, considering both the benefit associated only with the additional available water volume (risk reduction) and the combination of this and other related benefits.

The lower the ratio the more cost-effective is the measure supposed to be. Measure 2 is the most effective one under this rationale. Measure 1 is the less cost-effective considering solely the increase in water availability, although, considering the relevant operational benefits and other side effects it is the most effective one, as it is when considering the impacted area rather than the volume availability (Figure 5.18).

In fact the selection of measures to be implemented will be very dependent on investment budget available and external funding.

Measure 1 is quite important from all points of view but requires a large investment. Measure 3, at the tertiary hierarchical level, it is important but in order to be relevant to the overall scheme requires reproduction in other blocks. Altogether, they also represents a large investment, but which can be phased along time.

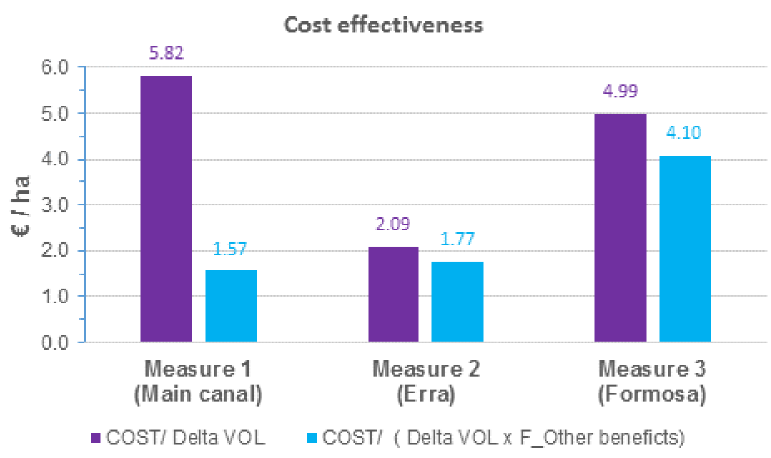



**Figure 5.17: Measures cost effectiveness considering reduction of water losses and other benefits**

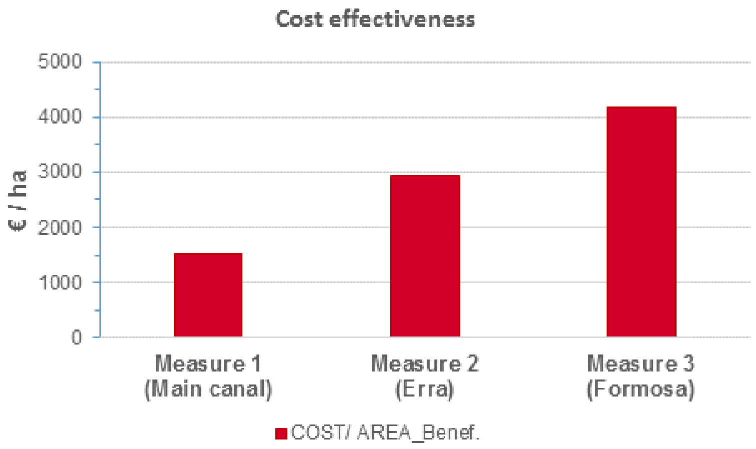



**Figure 5.18: Measures cost effectiveness considering area benefited**

It will also allow DGADR to extrapolate this analysis to other public irrigation perimeters in the country, aged approximately the same.

The other relevant measure, the Tagus water resource management model, intends to be an important communication toll among all the stakeholders and the Water Authority. It will integrate all relevant data concerning the water cycle and anthropogenic water uses and will put in evidence all the existent gaps in information requirements. It will demonstrate the lack of a real operational water resources management and provide the support to develop it, in what concerns water uses allocation, Tagus river regulation, needs to improve international articulation with Spain, etc. If fully exploited it will be highly cost-effective but, in fact, its effectiveness will depend upon the level of use that the Water Authority will promote.

**Results derived from the social justice questionnaires**

Apart from the detailed exploration of risk reduction, potential for adaptation measures, quantitative data analysis and assessment results as presented in the paragraphs above, also an additional so called “social justice analysis” has been conducted, based on questionnaires about the adaptation measures explored for the Targus region (Annex II). The results are presented in this section.

*Social justice analysis - Measure: Rehabilitation and modernization of transport and irrigation system*

The measure rehabilitation and modernization of transport and irrigation system in the area of Sorraia has the main aim, to increase the total water availability for irrigation and making the irrigation system more flexible. Besides that there are negative and positive side effects. The negative side effect are the cost, first borne by the ARBVS, then allocate to the farmers through taxes and other dues. This is the reason the egalitharian principle applies. The irrigation system for the farmers is improved, but they also have to pay for the measures. This means the negative effects for the society as a whole is minimized. To mitigate this negative effect the ARBVS also can apply for different funds.

The main positive side effect for the farmers, but also for the DGADR (the Agricultural Authority) and inhabitants of the area is the assured agriculture sustainability in the region, agro-industry and rural employment. The ARBVS will maybe benefit in the future, because the measure helps to contribute the Portugal Public Irrigation Perimeter (PT PIB).

*Social justice analysis - Measure: Tagus water resources management model*

The water resource management model is aiming to support integrated water resources analysis, planning and management of the Tagus river basin. This has several positive side effects, besides the optimization of the planning and managing. The measure can best be assigned to the solidarity principle. With a better managing the chances for all increases, but especially for those who otherwise find little attention, to successfully carry out projects.

The measure improves for the government and for the water authorities the general resilience of the system and supports the decision making. This in turn is also positive for the DGADR (the Agricultural Authority) and for the water users, since the water resources deficit and the exposure (risk reduction) of water related sectoral activities is reduced. It could also promote the climate change adaptation for the systems and the environment.

The costs, as a negative side effect, are borne by the water authorities and then allocated to a water resources tax all water users pay. Depending on how the allocation is conducted, this may but does not have to affect socially weaker classes disproportionally.

## 5.5. Conclusions and outlook

Sorraia PIP has two reservoirs assuring storage for its own irrigation consumption. Measures analysed assure the continuity of the existing irrigation scheme and agriculture sustainability in the Sorraia Valley, along with the improvement on water use efficiency. It is a closed system, but the overall research site benefit of these measures, besides their real local effectiveness, is the demonstration that climate change adaptation comes with a high cost. This is an important point when sharing water resources, to be integrated in the water resources oriented measure.

The Tagus water resource management model is of utmost importance, as a communication tool among all the stakeholders and the Water Authority.

This measure is already under development by BINGO team, the model will set up till the end of 2019, but its effectiveness will depend upon the level of use that the Water Authority will promote. Hopefully, it will enhance transparency in WRM and will allow to evolve from a top-down water resources management approach to a water resources governance model. If that is the case, this model will contribute to support the establishment of a missing operational water allocation policy, based in fair and equitable principles and in the socio-economic sectoral values of water uses. The main existing barriers are lack of important information to fully set and calibrate the model, related with financial limitations, and uncertainty about the Water Authority willingness or ability to promote and lead the necessary alterations.

Once the present WRM weaknesses are overcome, climate change can deeply be addressed. As an example, a debate on whether water allocation strategies and water resources tariffs should reflect water use efficiency, is an important issue, to help promoting adaptation. Sorraia measures cost effectiveness analysis is quite relevant to support this debate. In the future, during water resources deficit periods, the allocation of water among conflicting uses should take into consideration water use efficiency, and reward efforts developed to achieve it.

These measures are promoted by different actors, so they are not exclusive. Within Sorraia, measures prioritization will be very dependent upon investment budgets available. This is linked with national and European policies and the development budgets allocated to water use efficiency.

# 6 ADAPTATION MEASURES AT PERISTERONA WATERSHED RESEARCH SITE

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## 6.1. Introduction

### *6.1.1 Setting the Economic and Social Analysis into the BINGO and the WP 5 context*

In the BINGO Project, under Work Package 5, risk treatment and adaptation strategies for extreme weather events are developed and analysed, at each of the six research sites. Task 5.2 proceeds from task 5.1, i.e. from the development of such strategies, aiming at an economic and social analysis of the impacts of such measures/strategies. It includes three main activities:

- The definition of the goal of the economic and social analysis related to the topic and of the specific goals of the analysis per research site, as well as decision on the methodologies to be used (e.g. the definition of the minimum requirements and conceptual basic design for the economic analyses to be conducted at the research sites etc.).
- The composition of the approach for the analysis and the determination of the data sets to be analysed (e.g. setting the system boundaries for the economic evaluation, determining where an in-depth analysis is feasible etc.).
- The realisation of the economic and social analysis at each research site (including defining/selecting the set of measures and activities to be evaluated), including an assessment of issues related to social justice, equality and distributional effects.

This task is linked to other BINGO Work Packages, namely WP3 and WP4, and assimilates the outcomes of the workshops in task 5.1 related to the local challenges at the research sites.

Seven socio-economic analyses of possible adaptation measures/strategies are conducted within BINGO. Three of them, Bergen, Badalona and Wuppertal (first case) will follow special case-dependent in-depth methodologies. The remaining cases, namely Wuppertal (second case), Cyprus, Netherlands and Portugal will follow a common methodology for the socio-economic analyses in order to assess suitable adaption measures/strategies to face climate change impacts and be able to choose the most fitting one.

The case study discussed in this chapter, at the Cyprus research site (see chapter 6.1.2), uses the common methodology following a customized Multi-Criteria-Analysis (MCA), which is described in chapter 6.2. The measures selected are presented in chapter 6.3, and the results of the analysis in chapter 6.4. Chapter 0 presents a short discussion and analysis of the results.

### 6.1.2 Description of the Case Study area

The Peristerona Watershed (112 km$^2$) is located along the northern slopes of the Troodos Mountains in Cyprus. The Peristerona River flows from the northern flank of the Troodos Mountains into the Mesaoria Plain (Figure 6.1). The climate along the northern slopes of Troodos is classified as semi-arid, while the mountains at higher elevations are classified as dry sub-humid (Bruggeman et al., 2015). The long-term average annual precipitation (1980-2010) was 754 mm at Polystypos (1100 m above sea level (asl)) in the mountains of the Peristerona Watershed. In the foothills, precipitation was 405 mm at Panagia Bridge (440 m asl), and 270 mm at Peristerona (200 m asl) in the plain. The lowest annual rainfall in Peristerona was 126 mm, which was observed during the 2007-08 hydrologic year (in a 30 year record), followed by 138 mm (1990-91). Daily rainfall maxima during the 30 year period were 139 mm in Polystipos (2 December 2001), 157 mm in Panagia Bridge and 100 mm in Peristerona, both on 18$^{th}$ January 2010. The long-term (1980-2010) average monthly daily minimum temperatures in January (coldest month) were 3 C° in the mountains in Agros (1015 m asl) and 16 C° in Astromeritis (200 m asl) in the plain. The average daily maximum temperatures in July and August were 31 C° in Agros and 35 C° in Astromeritis.


**Figure 6.1: Google Earth image (4th April 2015) of the Peristerona Watershed (green), Panagia Bridge Station (light blue), the community boundaries (pink), the UN buffer zone (red) and the research focus area (yellow).**

The Peristerona River is an ephemeral stream, which does not flow in summer. Surface runoff is highly variable. The average long-term annual stream flow at Panagia Bridge station in the foothills of Peristerona Watershed is 11.75 Mm$^3$ (1980-2010). Lowest annual flow was 1.85 Mm$^3$ (2008) and the maximum was 25.94 Mm$^3$ (2002). The streamflows from the Troodos recharge the groundwater formations in the Mesaoria Plain. Gabion check dams have been established across the riverbed to slow the stream flow and increase groundwater recharge in the downstream areas of the watershed.

Agricultural cropland, including fallow, in the Peristerona Watershed's communities covered 3,407 ha in 2010 (Cystat, 2014). In 2013, lands in good agricultural conditions, which were submitted and qualified for Single Area Payment support, totalled 3,546 ha (Cyprus Agricultural Payment Organization datasets). In the foothills and downstream areas, both rainfed and irrigated crops are grown. Cereals, especially barley, are the main rainfed crop. Barley is generally grown for animal feed and often harvested and bailed whole, especially in dry years. Irrigated crops are found on small fields and terraces along the river (olives, vegetables), especially in Agia Marina and in the plain downstream from Peristerona community. Throughout the watershed there are diversions from the stream, which supply irrigation water to the fields by gravity through a system of open channels. Groundwater pumping is also common, especially in the alluvial river aquifer. Agricultural water demand exceeds sustainable supply, especially in dry years (Zoumides et al., 2013). Streamflow does not reach the downstream communities during dry years. Downstream, the research system is defined by the boundaries of the communities of Kato Moni, Orounda, Peristerona and Astromeritis. The community of Astromeritis lies outside the watershed boundaries but receives irrigation water, diverted through open canals, from the Peristerona River. The downstream area of the Peristerona Watershed is very narrow, but the land of the communities also covers the neighbouring plains.

The BINGO research in Peristerona Watershed focuses on the two main water uses in the region, namely agriculture and domestic water supply. The main hazards for both water uses are the decrease in rainfall and the increase in temperature, which directly affect irrigation water demand and the streamflow from the upstream areas. The reduction in streamflow reduces the groundwater recharge in the downstream areas of the Peristerona Watershed. During the 1980/81-2009/10 period there were six years (21%) in which groundwater recharge was constrained (three-year moving average flow less than 7.8 $Mm^3$/yr), fourteen average years and eight wet years (three-year moving average more than 15.6 $Mm^3$/yr) (Figure 6.2).

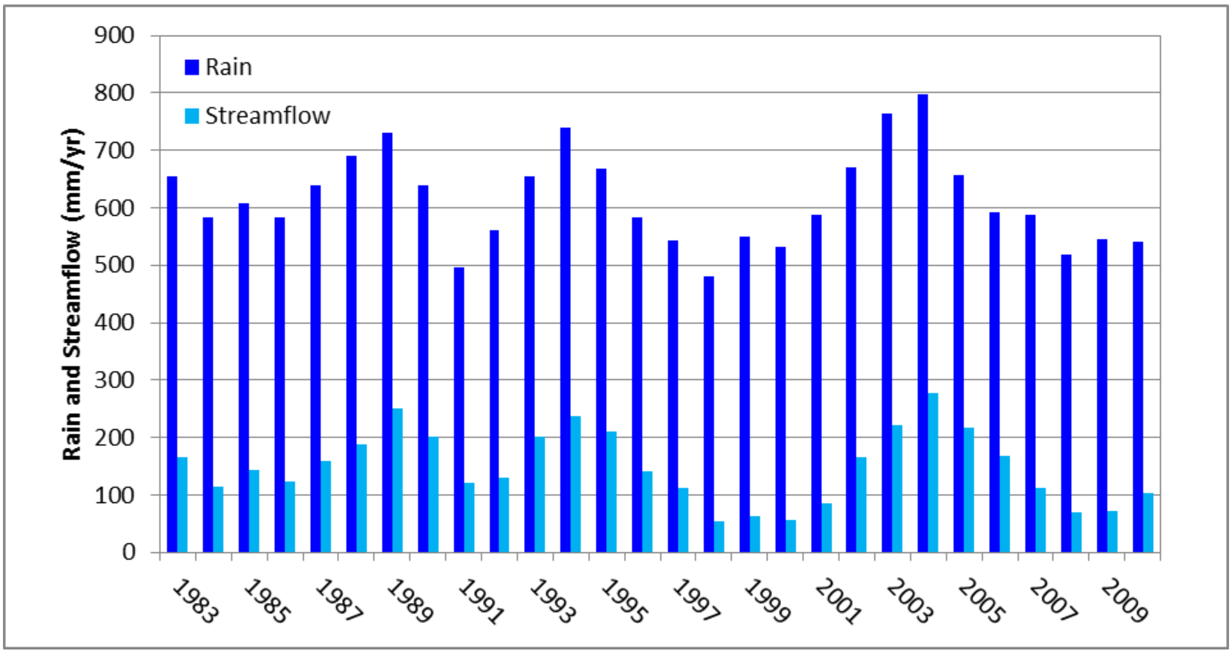


**Figure 6.2: Three-year moving average rainfall and streamflow at the upstream Peristerona Watershed, for 1980-2010 (observed)**

By using the Cyprus Institute's MENA-CORDEX simulations (http://mena-cordex.cyi.ac.cy/) and the RCP8.5 scenario for the period 2020-2050, it is foreseen that in the period from 2020/21 to 2049/50, the number of drought years where public water supply will be constrained will increase to 15 drought years (53%), with 10 average (36%) and 3 wet years (11%). For irrigated agriculture, the number of drought years increased from 20% (1980/81-2009/10) to 53% (2020/21-2050/51), whereas the wet years decreased from 60% to 10% (Figure 3) (for more details on hazard assessment see BINGO Deliverable 4.3)

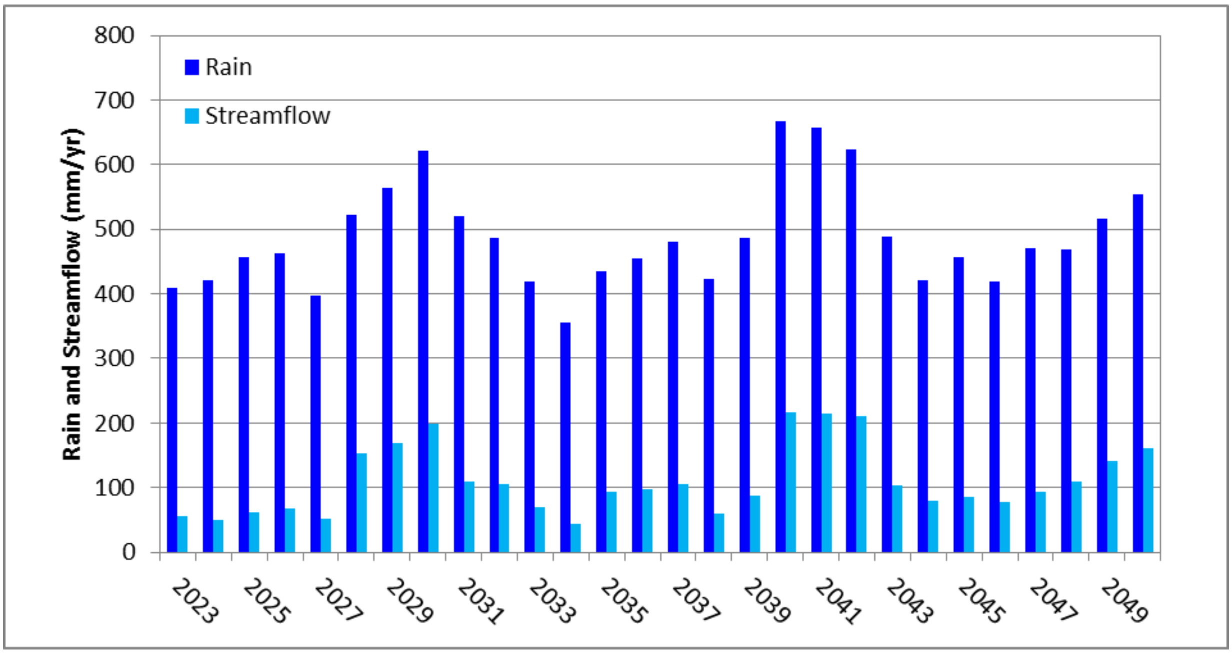


**Figure 6.3: Three-year moving average rainfall and streamflow at the upstream Peristerona Watershed, for 2020-2050, under RCP8.5 (modelled).**

The objective of the BINGO risk management process for the agricultural sector is to develop strategies for climate change adaptation that match irrigation water demand with available water supply (i.e. groundwater) and reduces water losses, thus ensuring a sustainable management of irrigation water supply. The risk owners for the agricultural sector of Peristerona Watershed are the irrigation associations of the downstream communities (Kato Moni, Orounda, Peristerona and Astromeritis), which aim to:

- ensure sufficient amount of water for irrigated agriculture and
- maintain irrigation water supply system in good condition (e.g., pumps, pipes, concrete channels).

The selected risk treatment options for ensuring a sustainable management of irrigation water supply by matching irrigation water demand with available water supply and reducing water losses are:

- the adoption of irrigation scheduling decision support systems to improve irrigation water use efficiency, and
- the use of treated sewage water for irrigation in the downstream communities of the Peristerona Watershed.

The objective of the BINGO risk management process for the domestic water supply is to develop strategies for the adaptation of the sector to climate change that manage the risk of water supply continuity failure. The risk owners for the domestic water supply sector are the community councils of the downstream communities, which rely exclusively on groundwater for domestic water supply. The risk scopes of the community councils are:

- to ensure the continuity of water supply to rural households for domestic use, and
- to ensure the supply of good quality drinking water.

The selected adaptation measures for ensuring the continuity of domestic water supply to rural households are:

- the use of desalinated water for the downstream communities of the Peristerona Watershed, and
- the maintenance of groundwater recharge systems along the Peristerona River.

## 6.2. General Approach and Methodology

### 6.2.1 General approach used in all Case Studies

The general approach in all case studies is quite similar, depicted already in Figure 4.3 in chapter 4.2.1. A three-step approach was employed, starting with the formulation of the problem/challenges and a long list of risk reduction measures to address these. In the second step, in a pre-assessment, this long list of measures was reduced to a shortlist, and the final selection of the "most promising" (i.e. the most effective with regard to risk reduction) measures was done. The third and final step encompassed the cost assessment and the setting of the scope for the economic and social analysis.

### 6.2.2 Methodology applied in the Peristerona Case Study

Measure selection

In the Peristerona case study area, the preparation of the long list of risk reduction measures, and the final selection of the measures to be analysed in the economic and social analysis, was done over the course of several stakeholder workshops in the framework of the BINGO Community of Practice (CoP)[5]. The final selection of measures (presented in chapter 6.3 below) took place at the M22 workshop held on 25 May 2017 in Peristerona, Cyprus.

Cost assessment and case study template

More detailed information on the case study area, as well as the selected measures, was thereafter elicited via a template, prepared by InterSus and IWW. The "case study template" set the basis for the economic and social analysis, aiming at gathering the relevant information necessary for conducting the economic and social analysis. First, it provided a detailed description of the research site, summarizing the research problem in terms of describing the

[5] M8 Workshop 'Setting the Scene'; M15 Workshop 'Stakeholder Perceptions on Climate Adaptation Strategies & Measures'; M22 Workshop 'Participatory Evaluation of Climate Change Adaptation Measures'; M28 Workshop 'Solving the Insolvable'

site specific climate change effects, both spatially and from a user perspective (e.g. economic activities), drawing on results of the BINGO WPs 3 and 4. Second, it provided the data relevant for the case specific economic and social analysis (e.g. spatial and land use-related information, such as agricultural data, data on geology and hydrogeology). Third, it obtained detailed information on the selected measures to reduce climate change induced risks at the site, such as the expected effects of these measures, the challenges in implementing them (e.g. key sectors/economic used, water quantity/quality, stakeholder affected, etc.), and any quantitative figures, specifying the risk reduction measure’s implementation, costs and expected effects.

Selection of criteria for the Multi-Criteria-Analysis

In the framework of the BINGO Community of Practice, i.e. the stakeholder workshops, criteria for the analysis of the measures were also selected, similarly to the measures in two steps: from a "long list" to a "short list", which was finalized also at the BINGO M22 workshop in Peristerona, on the basis of the criteria from the previous workshops.

It was decided that criteria on cost and effectiveness will be calculated quantitatively and not via the scoring.

A total of 15 criteria were finally identified; 7 for irrigation and 8 for domestic water supply. At BINGO M22 workshop, stakeholders gave each criterion a score from 0 (least important) to 5 (most important). The average score of criteria for irrigation and domestic water supply according to stakeholder´s preferences are presented in Table 6.1 and Table 6.2, respectively. These scores will be used as weight factors in the MCA.

**Table 6.1: Criteria for irrigation water use**

| | Scoring | Rank |
|---|---|---|
| Relevance (extent to which the measure addresses the objective) | 3.86 | 1 |
| Economic robustness (ability of the measure to perform satisfactorily under changing economic conditions) | 3.76 | 2 |
| Climate robustness (ability of the measure to perform satisfactorily in dry and wet years) | 3.62 | 3 |
| Feasibility (ability to implement the measure under the current physical, technical, regulatory or organizational conditions) | 3.57 | 4 |
| Social acceptability (ability of the measure to meet society and user acceptance) | 3.52 | 5 |
| Flexibility (ability of the measure to meet changing water demands) | 3.33 | 6 |
| Technical readiness (ability of the measure to be implemented with relative ease (e.g., technicians can be easily trained to maintain the system) | 3.33 | 6 |

**Table 6.2: Criteria for domestic water supply use**

| | Scoring | Rank |
|---|---|---|
| Water drinkability (ability to meet domestic water quality standards) | 4.67 | 1 |
| Relevance (extent to which the measure addresses the objective) | 3.90 | 2 |
| Social acceptability (ability of the measure to meet society and user acceptance) | 3.86 | 3 |
| Climate robustness (ability of the measure to perform satisfactorily in dry and wet years) | 3.81 | 4 |
| Feasibility (ability to implement the measure under the current physical, technical, regulatory or organizational conditions) | 3.76 | 5 |
| Economic robustness (ability of the measure to perform satisfactorily under changing economic conditions) | 3.76 | 5 |
| Flexibility (ability of the measure to meet changing water demands) | 3.76 | 5 |
| Technical readiness (ability of the measure to be implemented with relative ease (e.g., technicians can be easily trained to maintain the system) | 3.52 | 8 |

Scoring and development of a ranking of the selected measures

During the fifth BINGO stakeholder workshop on 20th February 2019, the selected four measures for irrigation and domestic water supply were scored against each of the 7 and 8 abovementioned criteria, using a scale ranging from 1 (low/negative effect) to 5 (high/positive effect). Multiplied with the MCA factor according to the weighting of the criteria, each measure was assigned a final "MCA score", resulting in a new ranking.

The qualitative analysis of MCA will be complemented with a quantitative estimation of cost-effectiveness ("Euro per saved m³ of water") of each measure (see Chapter 0).

### 6.2.3 Acquisition of data and information: stakeholder meetings and expert opinion

The Cyprus Institute collected all necessary data for the selection and the cost-effectiveness analysis of the adaptation measures, over the course of four major stakeholder workshops in the frame of the BINGO CoP. Additionally, experts and other stakeholders were met and interviewed individually, to solicit expert knowledge on specific questions.

Quantitative impacts of measures were calculated via hydrological modelling (see BINGO Deliverable 4.3 for details).

The stakeholders and experts participating and providing expert knowledge were from the following organisations and societal groups:

**Table 6.3: Stakeholder in Cyprus case**

| **Stakeholder/organization (including contact data)** | **Area of expertise** | **Representing which sector/activity** |
|---|---|---|
| Irrigation Associations and Divisions | Management of irrigation water | Agriculture |
| Farmers | Users of groundwater and surface water | Agriculture |
| Geological Survey Department | Regulatory authority for the detection and protection of groundwater resources | Agriculture/Domestic Water Supply |
| Water Development Department | Regulatory authority for implementing water policy and sustainable management of water resources | Agriculture/Domestic Water Supply |
| Department of Agriculture | Regulatory authority for implementing agricultural policies including the preparation and implementation of development projects and the provision of educational and advisory services to farmers and to rural population. | Agriculture |
| District Administration | Provision of administrative and technical assistance to communities; Approval of annual budgets of community councils; Control of irrigation divisions | Agriculture/Domestic Water Supply |
| Community Councils | Management and provision of drinking water to rural households; Setting of water charges (reported then annually to the District Administration and approved by the Water Development Department) | Domestic Water Supply |
| Sewage Board of Astromeritis - Peristerona - Akaki complex | Management of the wastewater treatment plant | Agriculture/ Green infrastructure |
| Water Board of Nicosia | Domestic water supply authority; network management | Domestic Water Supply |

## 6.3. Presentation of the measures selected

### 6.3.1 Description of the selected measures, their costs and effects

In the Peristerona case study, four measures have been selected for being assessed in the economic and social analysis:

1. Measure 1.1: Irrigation scheduling technologies
2. Measure 1.2: Use of treated sewage water for irrigation
3. Measure 2.1: Water desalination
4. Measure 2.2: Groundwater recharge systems

### 6.3.2 Measure 1.1: Irrigation scheduling technologies

Description of the measure: Installation of soil moisture sensor units and meteorological stations, with a decision support App, to advise farmers when and how much water to apply to a field at the right time and in the right quantity to optimize production and water resources management. This measure includes the installation of soil moisture sensor units and three meteorological stations in the downstream areas of the Peristerona Watershed, which will schedule the irrigation needs of the total land under tree (fruit, citrus, olives) orchards.

The tree crops in the downstream Peristerona Watershed (Kato Moni, Orounda, Peristerona and Astromeritis) represent 11% of the total utilized agricultural area (UAA), i.e. 358 ha (Census of Agriculture, 2010). One soil moisture sensor unit can cover an area of approximately 1 ha. Thus, 358 soil moisture units could cover the area.

The measure can be functioning and create the desired effect in short term. The installation and tuning of the system will be done in the first year, while the full operation of the system will be achieved by the second year.

Costs of the measure[6]: The implementation of the measure entails

- the installation of three meteo stations: 15,000€ (5,000€ each);
- the installation of 358 soil moisture sensor units: 1,074,000€ (3,000€ each); and
- annual maintenance cost of 107,400€ (300€ per soil moisture sensor unit).

These costs are based on current market prices of state of the art equipment and expert estimations for installation and maintenance, based on field experience in Cyprus (e.g., Siakou et al., in press). It should be noted that equipment costs and mobile data transfer costs are becoming more competitive all the time.

[6] Source: ENORASIS …

Risk/challenge targeted: Ensure sufficient agricultural water supply under climate change and expected drought years by increasing the irrigation efficiency.

Quantitative effects/impacts: The water demand of the tree crops (358 ha) is approximately 2.3 $Mm^3$ (Christou et al., 2017). The application of the soil moisture sensor units can result in annual water savings of about 0.35 $Mm^3$ (i.e. water savings of 10-20%).

Moreover, irrigation scheduling can reduce nutrient leaching by not irrigating at rates and depths that exceed the soil water deficit.

Also, the effectiveness of the technology per se does not change under climate change.

### 6.3.3 Measure1.2: Use of treated sewage water for irrigation

Short description of the measure: This measure includes the construction of a supply network via pipeline, for treated sewage water to be used in irrigated agriculture. The treated water will be transferred from the recently established waste water treatment plant in Astromeritis through an irrigation water supply network to irrigate the agricultural land of the Astromeritis community.

The maximum annual wastewater production that can be transferred from the treatment plant for irrigation in the Astromeritis community is 360,511 m3/year [7]. Around 78 ha can be irrigated with this amount of recycled water[8], which corresponds to 6% of Astromeritis UAA.

The project will take 1 year to design and construct.

Costs of the measure[9]: The construction cost of the measure includes:

- the cost of the irrigation pumping station (55,000€), and
- the cost of irrigation supply network (130,000€), i.e., the total construction cost is 185,000€.
- the annual operational cost of the project is estimated around 2,000€.

Risk/challenge targeted: Ensure sufficient agricultural water supply under climate change and expected drought years.

Quantitative effects/impacts: During the 19 years of the operation of the irrigation water supply network (the first year relates to the establishment of the system) about 6,849,700 $m^3$ treated

[7] We estimated that the wastewater production from the households of Peristerona, Astromeritis and Akaki communities amounts to about 85% of their potable water consumption (Charalambous et al., 2012), which is 424,130 m3/year (WDD, 2006).
[8] The estimated water demand of irrigated crops, i.e., tree crops and potatoes (170 ha) in the agricultural land of Astromeritis community is approximately 790,956 m3/year (Christou et al., 2017).
[9] Source: Water Development Department (2006; 2011); personal communication with the Sewage Board of Astromeritis - Peristerona - Akaki complex

sewage water will be used for irrigation. The use of treated sewage water for irrigation can alleviate the pressures on groundwater resources and increase the water availability for domestic uses.

Wastewater reuse will become more necessary as climate change accelerates. However, under a high CC impact scenario, the proportion of the consumed tap water that ends up as sewage will be decreased due to higher evaporation, thus reducing the supply of wastewater production. Moreover, the long-term impacts of emerging contaminants such as pharmaceuticals, which are present in the treated sewage water, on soils, groundwater, ecosystems and human health are not known.

### 6.3.4 Measure 2.1: Water desalination

Short description of the measure: Expansion of the water distribution pipeline network up to the downstream communities of the Peristerona Watershed.

The Western Nicosia Conveyor Water Supply Project includes a pipeline from the Vasilikos desalination plant to the Nicosia service area, pumping stations, storage reservoirs and local conveyor pipelines. The project is implemented in phases; the downstream Peristerona area is the last phase of the project, and is expected to be completed in 2021. It includes a conveyor pipeline (53.3 km), two storage reservoirs (2,500$m^3$ & 1,200$m^3$) and three pumping stations.

The project will take 5 years to design and construct.

Costs of the measure[10]:

- The construction cost of expanding the water distribution pipeline network up to Western Nicosia district is 11.4 M€, with an annual operational cost of 117,000€. The Western Nicosia district includes 28 communities, including Peristerona and Astromeritis, and two municipalities with a total population of 84,944 persons. The population of Peristerona and Astromeritis communities, i.e. the two biggest downstream communities of the river basin, is 4,533 persons.
- Based on the cost of the project per inhabitant (136€), the construction cost of the part of the project supplying Peristerona and Astromeritis is estimated to be 609,241€ and the operational cost 6,256€.
- Considering that the annual water consumption for Peristerona and Astromeritis communities is estimated to be 266,815 m3 (2015) and the price for the desalinated water with full cost recovery would be around 1€/$m^3$, the cost for the supply of the desalinated water would be 266,815€.
- Thus, the total operational cost of the project, assuming that desalination would satisfy almost all domestic water demand, would be 273,071€.

[10] Source: Water Development Department (2017).

Risk/challenge targeted: Ensure sufficient domestic water supply under climate change and expected drought years.

Quantitative effects/impacts: This measure ensures a reliable and continuous potable water supply for the downstream communities of Peristerona Watershed. However, the price of the water will increase. Currently, the cost of groundwater abstraction for Astromeritis community, including its transfer, is 0.30 €/m3. The Water Development Department will sell the desalinated water to community councils at a price of 0.82 €/$m^3$ (including the environmental cost[11], that is, 0.05 €/$m^3$). Considering the operational costs of communities, the final water price for households will be more than 1 €/$m^3$.

Under a high CC scenario, the streamflow will be significantly reduced, which will substantially reduce groundwater recharge. This could possibly lead to the full substitution of groundwater as the primary source of drinking water, by desalinated water. External effects include the increase of greenhouse gas emissions due to the energy intensive desalination processes and the energy needed for pumping the water from the coast to Peristerona Watershed, which could exacerbate climate change. Additionally, the chemical discharges and byproducts may negatively affect coastal water and marine life.

### 6.3.5 Measure 2.2: Groundwater recharge systems

Short description of the measure: The proper maintenance of check dams along the Peristerona River for groundwater recharge. This measure includes: (a) the removal of sediment (once a year in wet years), and (b) the maintenance of gabions, from seven check dams that have been constructed across the river streambed in the downstream area of Peristerona Watershed. Also, it includes research on the effect of sediment on groundwater recharge and water quality during at least two wet years (4-5 year total). Full implementation after that.

Costs of the measure:

- Seven groundwater recharge check dams have been constructed along the Peristerona River. The annual maintenance cost of the most upstream check dam (named Orounda check dam), which was completed in 2011, is approximately 1,000€.
- It is estimated that within a five-year period, the cost of removing the sediment is around 3,000€, including labour cost, bulldozer and truck operating costs and fuel. Around 1.350 tonnes of sediment needs to be removed from the check-dam within this period (Djuma et al., 2017).

[11] Environmental costs represent the costs of damage that water uses impose on the environment and ecosystems and those who use the environment (WATECO, 2003)

- Within this period, the maintenance cost of gabions (e.g. replacing lost stones, repairing damaged wire mesh with new wire) is estimated around 2,000€.

The costs are expert estimates by the WDD Nicosia District Office and the Community Councils.

Risk/challenge targeted: Ensure sufficient domestic water supply under climate change and expected drought years.

Quantitative effects/impacts: Previous research (Djuma et al., 2017) has shown that the Orounda check dam (storage capacity of 25,000 $m^3$) recharged the aquifer with an average of 3.1 $Mm^3$ of the 10.4 $Mm^3$ of annual streamflow (i.e. 30%), which is 1.25 $Mm^3$/year (5 $Mm^3$ for a four-year period of operation) higher than the recharge without the check dam.

Under a high CC scenario, the river flow will be significantly reduced, thus reducing the capacity of check dams to recharge groundwater. For the RCP8.5 scenario for the period 2020-2050, the streamflow will be reduced by approximately 27%.

## 6.4. The Multi-Criteria-Analysis

### *6.4.1 Scoring of the measures*

As explained above, the selected measures were then scored against each of the 7 (for irrigation) and 8 (for domestic water supply) criteria, using a scale ranging from 1 (low/negative effect) to 5 (high/positive effect)[12]. Multiplied with the MCA factor according to the weighting of the criteria, each measure was assigned a final "MCA score", resulting in a new ranking. The scoring and new ranking for irrigation and domestic water supply sector are depicted in Table 6.4 und Table 6.5, respectively.

For the irrigation sector, irrigation scheduling technologies measure had the highest MCA weighting score (13.5) compared to the treated sewage water option (12.1). Stakeholders' preferences on uptaking irrigation scheduling technologies versus the use of treated water for irrigation were also revealed through the original, i.e., the unweighted, scoring of the measures.

For the domestic water supply sector, groundwater recharge systems received the highest final MCA score (14.6) compared to the use of water desalination (13.3). Similarly, stakeholders' preferences on properly maintaining the groundwater recharge systems versus the use of desalinated water for domestic water supply were also revealed through the original, i.e., the unweighted scoring of the measures.

Across the four selected measures, the maintenance of the groundwater recharge systems received the highest ranking[13] followed by the irrigation scheduling technologies, the use of desalinated water and the use of sewage water.

[12] Ten stakeholders ranked the four adaptation options against each criterion including representatives from community councils (3), irrigation associations (4), water utility authority (1), environmental consultants (2).
[13] Both in weighting and unweighting terms

**Table 6.4: Final scoring of the irrigation water use measures against each criterion**

| | MCA weighting factor | Measure 1.1: Irrigation scheduling technologies: Original score | Measure 1.1: Irrigation scheduling technologies: Weighted score | Measure 1.2: Treated sewage water: Original score | Measure 1.2: Treated sewage water: Weighted score |
|---|---|---|---|---|---|
| Relevance | 3.9 | 4.1 | 15.8 | 3.5 | 13.5 |
| Economic robustness | 3.8 | 3.4 | 12.8 | 3.4 | 12.8 |
| Climate robustness | 3.6 | 3.7 | 13.4 | 3.7 | 13.4 |
| Feasibility | 3.6 | 4.0 | 14.3 | 3.1 | 11.1 |
| Social acceptability | 3.5 | 4.4 | 15.5 | 2.7 | 9.5 |
| Flexibility | 3.3 | 3.4 | 11.3 | 3.8 | 12.7 |
| Technical readiness | 3.3 | 3.5 | 11.7 | 3.5 | 11.7 |
| **AVERAGE** | | **3.8** | **13.5** | **3.4** | **12.1** |

**Table 6.5: Final scoring of the domestic water supply measures against each criterion**

| | MCA weighting factor | Measure 2.1: Water desalination: Original score | Measure 2.1: Water desalination: Weighted score | Measure 2.2: Groundwater recharge systems: Original score | Measure 2.2: Groundwater recharge systems: Weighted score |
|---|---|---|---|---|---|
| Water drinkability | 4.7 | 3.0 | 14.0 | 4.2 | 19.6 |
| Relevance | 3.9 | 3.6 | 14.0 | 3.8 | 14.8 |
| Social acceptability | 3.9 | 2.5 | 9.7 | 4.2 | 16.2 |
| Climate robustness | 3.8 | 4.0 | 15.2 | 3.1 | 11.8 |
| Feasibility | 3.8 | 3.6 | 13.5 | 4.1 | 15.4 |
| Economic robustness | 3.8 | 3.2 | 12.0 | 3.8 | 14.3 |
| Flexibility | 3.8 | 3.8 | 14.3 | 3.1 | 11.7 |
| Technical readiness | 3.5 | 3.8 | 13.4 | 3.8 | 13.4 |
| **AVERAGE** | | **3.4** | **13.3** | **3.8** | **14.6** |

### 6.4.2 Cost effectiveness - discussion and ranking

**Measure 1.1:** For a 5-year period the discounted value of the investment including both capital and operational cost would be 1,553,986€ (discount rate: 5%[14]). The total water savings of the 358 soil moisture sensor units for a 4-year period (establishment and learning/testing of the system in the first year) would be 1.40 $Mm^3$, thus resulting into a 0.90 $m^3$ water savings per euro invested in irrigation scheduling technologies.

Considering that (a) the price for individuals to pump groundwater is 0.17€/$m^3$ (plus electricity cost), (b) the price for irrigation associations is 0.15€/$m^3$ (here in most of the cases water is charged by time rather than volume, according to the electricity cost of operating the pumps) and (c) the farmers in Astromeritis village can buy the recycled water at a rate of 0.12€/$m^3$, the results of the cost assessment of this measure highlight the need of subsidizing the irrigation scheduling technologies for farmers not having access to recycled water in terms of social justice between farmers having and not having access to recycled water and in terms of improving groundwater resources protection and management.

**Measure 1.2:** For a 20-year period the discounted value of the investment including both the capital and the operational cost of the pipeline treated sewage water supply network would be 209.924€ (discount rate: 5%). During the 19 years of the operation of the irrigation water supply network (the first year relates to the establishment of the system) about 6,849,700 $m^3$ treated sewage water will be used for irrigation, which correspond to 32.6 $m^3$ recycled water used per euro invested in this specific project. The farmers will buy the recycled water at a rate of 0.12€/$m^3$.

**Measure 2.1**: For a 30-year period the discounted value of the investment including both the capital and the operational cost of the water distribution pipeline network would be 4.457.889€, which corresponds to 1.5 $m^3$ desalinated water consumed per euro invested in this specific measure.

**Measure 2.2:** Previous research (Djuma et al., 2017) has shown that the Orounda check dam (storage capacity of 25.000 m3) recharged the aquifer with an average of 3.1 $Mm^3$ of the 10.4 $Mm^3$ of annual streamflow (i.e. 30%), which is 1.25 $Mm^3$/year (5Mm3 for a four-year period of operation) higher than the recharge without the check dam. This

[14] Proxy for capital cost based on the long-term real interest rate on commercial loans in Cyprus

additional recharge corresponds to 1,250 $m^3$ of groundwater recharge per euro spending in the maintenance of the Orounda check dam.

Comparing the costs per saved/newly gained $m^3$ of water, a significant range between the four measures can be determined:

- Measure 2.2: 1,250 $m^3$ additional groundwater recharge per euro spending in the maintenance of the check dam.
- Measure 1.2: 32.6 $m^3$ recycled water used per euro invested in this specific project.
- Measure 2.1: 1.5 $m^3$ desalinated water consumed per euro invested in this specific measure.
- Measure 1.1: 0.90 $m^3$ water savings per euro invested in irrigation scheduling technologies.

Hence, measure 4 is by far the most cost effective of the four measures in terms of "water saved/water resource gained".

### 6.4.3 *Ranking according to the scores and the costs/effects*

The uptake of irrigation scheduling decision support systems and the use of treated sewage water for irrigation were selected by stakeholders for ensuring a sustainable management of irrigation water supply in Peristerona Watershed. Similarly, the use of desalinated water for the downstream communities of the Peristerona Watershed and the maintenance of groundwater recharge systems along the Peristerona River were selected for ensuring the continuity of domestic water supply to rural households.

The maintenance of the groundwater recharge systems (measure 4) received the highest score in the multi-criteria analysis. Stakeholders perceive check dams as the most economically and socially feasible solution for increasing groundwater resources. Stakeholders' preferences are in accordance with the results of the cost-effectiveness analysis, where measure 4 is by far the most cost-effective measure in terms of ''water gained''.

Irrigation scheduling technologies (Measure 1.1) measure was also highly ranked in the multi-criteria analysis (2nd in rank). A divergence was noted between stakeholders' preferences and the results of the cost-effectiveness analysis, where measure 1.1 is the least cost-effective measure in terms of water savings per euro invested. Stakeholders identified the high cost as the main barrier for the uptake of these technologies, and stressed the need for subsidizing this measure.

A divergence between stakeholders' preferences and cost-effectiveness analysis results was also noted for the treated sewage water measure. Although the implementation of the measure results in large use of recycled water (32.6 $m^3$) per euro invested in the measure, the measure received the lowest MCA score because stakeholders were sceptical about the impact of emerging contaminants, which are present in the treated wastewater, on ecosystems and human health.

Finally, a convergence between stakeholders' preferences and cost-effectiveness analysis results was noted for the desalinated water measure. The measure was ranked 3rd in the preferences of stakeholders mainly due to the expected increase in the water price. However, stakeholders acknowledged that the measure will ensure a reliable and continuous potable water supply for the downstream communities of Peristerona Watershed.

## 6.5. Summary and discussion

### 6.5.1 Analysis and discussion of the results

The combination of the multi-criteria analysis and the cost-effectiveness analysis revealed that stakeholders' preferences are to a large degree aligned with the results of the economic analysis. The maintenance of the check dams along the Peristerona River is the most cost-effective solution to mitigate the effects of climate change on groundwater recharge. According to stakeholders' preferences, under the current physical, technical and regulatory conditions, this measure is the most feasible one to implement, meeting societal acceptance and domestic water quality standards.

The largest divergence between MCA results and cost-effectiveness analysis results refers to the treated sewage water measure. Although this measure is the second most cost-effective solution to mitigate water scarcity associated risks in Peristerona Watershed, yet it is least preferable by the stakeholders mainly due to potential unknown long-term effects on ecosystems and human health. The results highlight the need of adopting a holistic approach to assess the effectiveness of risk mitigation measures.

### 6.5.2 Social justice and distributional effects

Within WP 5, adaptation measures have been identified at each research site, which have been assessed by the WP5-team in terms of their governance needs and socio-economic effects. As a last step in the assessment of selected adaptation measures, an analysis of the impact of these measures on social justice was done.

Social justice in this case refers to "how the basic structure of a society distributes advantages and disadvantages to its members" (Miller 1999). These distributions are often based on, and legitimized through, "distributive" or "equity" principles (Cook 1987, Caney 2005). Equity principles appeal to general conceptions of what is good and what is bad. Besides notions about fair distributions, they are closely related to considerations of vulnerability (Adger 2006). Generally, the political-philosophical literature distinguishes between three general equity principles (Shue 1999, Low and Gleeson 1998):

- The deontological principle is based on Kant's notion that people are rational and act intentional, and can therefore be held responsible for their choices and actions. The "polluter pays" principle is an example of this principle.
- The solidarity principle aims to neutralize "involuntarily inequalities" between people. Distributions follow Rawls' "maximin" principle which involves maximizing the well-being of those who are worst-off.
- The egalitarian principle is based on Mill's and Benthams' utilitarian "greatest happiness principle". Distributions aim to maximize the positive effects and minimize the negative effects for society as a whole.

The analysis on social justice, equality and distributional effects is based on a questionnaire sent to the Case Study partner in Cyprus in December 2018, and which can be found in annex I (original questionnaire) and annex II (answers) to this report.

All four measures proposed in the Cyprus Case Study are financed at least in part by the sectoral groups/communities that benefit directly and/or indirectly:

- For Measure 1.1 (Irrigation scheduling technologies), the farmers bear the cost of installing and operating the technologies; the equipment itself can be subsidised through the Rural Development Programme (i.e., tax payers). Farmers will benefit from the implementation of the measure, as increasing the irrigation water efficiency can: (a) reduce water and pumping costs, (b) reduce costs for fertilizers and other agricultural chemicals.
- For Measure 1.2 (Use of treated sewage water for irrigation), communities bear the cost of the construction of the pipeline, farmers pay on top of the recycled water charge (0.07 euro/$m^3$) an additional charge (i.e., 0.05 €/$m^3$) that covers the treatment and maintenance cost as well as the payoff cost of the construction. The measure benefits the farmers having access to the recycled water.
- Measure 2.1 (Water desalination) is paid for by the state (i.e. the tax payers), while users (households) will pay a higher price for the desalinated water to cover the operational and maintenance costs of the pipeline network. The water price for households will be more than 1 €/m3 including the selling water price of Water Development Department to community councils (0.82 €/m3) and the operational costs of communities. The measure ensures a reliable and continuous potable water supply for the households of the downstream communities of Peristerona Watershed.
- Measure 2.2 (Groundwater recharge systems) is paid by the downstream communities in the Peristerona Watershed, which bear the cost of the maintenance of check dams along the Peristerona River. The check dams slow

down the river flow and improve groundwater recharge and water quality, thus increasing water availability for domestic water supply and irrigation.

At the same time, measures 1.1 & 2.2 have potential side effects which benefit the general, unspecified public (..."the uptake of irrigation scheduling technologies can result in water savings (10-20%) and reduce nutrient leaching, thus improving the quantitative and qualitative status of groundwater"; … ‘‘recharge of aquifer’’). Measures 1.2 & 2.1 benefit only a specific group of people, or have positive side effects on other water users by increasing the general amount available (however, this is just a substitution, and benefits only other water users in the same area).

Negative side effects can be incurred by measure 1.2 (long-term impacts of emerging contaminants not known) and measure 2.1 (carbon emissions, disturbance through pipeline construction, discharges). In both cases, the main mitigation "measure" to avoid such negative side effects is research towards the mitigation of the negative effects - which would be paid by the general public. Also, it is stated that the burden of the negative side effects will be carried by future generations (both measures) and the environment (measure 2.1).

Agricultural water demand in the Peristerona watershed exceeds sustainable supply, especially in dry years (Zoumides et al. 2013) and the streamflow does not reach the downstream communities during dry years. Considering the equity principles outlined above, agriculture which is negatively affected by climate change needs to be supported. Moreover, domestic water supply prices should be the same island-wide, independent of the source.

- Measure 1.1 (Irrigation scheduling technologies) is in line with the solidarity principle, as it provides farmers without secure access to irrigation water with an affordable irrigation water supply source, in terms of not disrupting the competition between farmers with and without access to recycled water. The measure is also in line with the equity principle considering the public good nature of groundwater.
- Measure 1.2 (Use of treated sewage water for irrigation) is to a large part not in line with all three principles, as the investment costs for pipelines are borne by the communities/the public, whereas only agricultural water users benefit from it. Also, the potential negative impacts are laid upon the shoulders of future generations, and research to mitigate these impacts should be financed by the general public.
- Similarly, measure 2.1 (Water desalination) is also to a large part not in line with all three principles, as the tax payer pays the investment, and the households of the downstream communities will pay a higher price for the desalinated water. They on the other hand profit from a secure domestic water supply - but a water supply that is threatened from climate change. Also, upstream communities

abstract groundwater for domestic water supply, thus these households will have lower water charges compared to the households in the downstream communities using desalinated water.

- Measure 2.2 (Groundwater recharge systems) is in line only with the egalitarian principle, as the proper maintenance of the check dams will improve groundwater recharge, i.e., improve the provision of a public good.

Summarising, measure 1.1 is in line with two out of three equity principles and measure 2.2 is in line with one of the three equity principles. If the focus of the assessment would be widened, e.g. to the national level, other perspectives could arise, for example the equity between a well-supplied urban and the rural population. Also, it is quite common in general that negative impacts of sectoral activities ("externalities") - be it agriculture, industry, traffic, trade - are paid for by the general public instead of the polluters/the entity responsible.

# 7 ADAPTATION MEASURES AT BERGEN RESEARCH SITE

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## 7.1. Brief introduction to the case study

Bergen has a very high annual rainfall. Additionally, the city has a pronounced topography, facing runoff from a mountainous area, entering the residential area close to the fjord. Thus, combined sewer overflow is a critical issue during heavy rainfall events, leading to a high level and fast flow rate of combined sewer flow. This causes a high risk of combined sewer overflow to the Puddefjord leading to water quality degradation (compare previous BINGO deliverables, e.g. Deliverables from work package 4).

In the past, the rainfall has let to CSO from Bergen's sewer system a number of times. Additionally, according to recent studies of local climate changes in Bergen the intensity and frequency of heavy rainfall events is expected to increase (Kristvik and Muthanna 2017, Hanssen-Bauer et al. 2015). The risk is likely to rise and climate change adaptation is envisioned by the city.

This case study focusses on a city quarter of Bergen called Damsgård area. This part of the city is undergoing a substantial transition from industrial to residential purposes as a reregulated area. The combined sewer outlets connected to the sewer system part of Damsgård seem to be among the most active ones. Also, just to the opposite of the case studies area at the other side of the fjord, a new beach site has been constructed as recreational area. This underlines the municipalities vision to reduce CSO, especially but not only in the Damsgård area.

## 7.2. Stakeholders involved

The Community of Practice (CoP) in Bergen was composed of stakeholders from several agencies and departments of the municipality, which are all involved in the large-scale area lift and development of Damsgård. In Bergen, and Norway in general, the agency for water and sewerage works (AWSW) have been the responsible party for stormwater management because stormwater traditionally is handled through buried infrastructure along with sewage systems. Thus, AWSW has been the primary driver and contributor of the end-user group of the Bergen case study. AWSW have been the primary contact with the research partner, provided the necessary data for all data requiring analyses, and decisively involved in scoping and pointing out the direction of the Bergen case study of the BINGO project. In addition, AWSW has been responsible for inviting and engaging relevant stakeholder to the CoP. As reflected in the choice of adaptation measures, Bergen wish for a more surface based stormwater management to increase blue-green elements in the cityscape and account for the uncertainties of a changing climate. Relevant stakeholders there for were all actors involved in the physical layout of the Damsgård area. This involved actors from the Department of Urban Development, Department of Climate, Culture and Business Development, Agency for Planning and Building Services, Agency for Housing and Redevelopment, and the Agency for Urban Environment.

## 7.3. Measures, data and assessment methods

**Generic assessment approach**

For the Bergen case the approach was to conduct a quantitative analysis as a decision support study on how to reduce  the risk of CSO to the Puddefjord. Therefore, a quantitative analysis of the risk reduction effectiveness using a SWMM model was envisioned. The primary aim of the study was to produce a quantitative decision support table for the municipality, which guides about the potential to reduce runoff from different sub catchments of the Damsgård area. This decision support table was ought to give key figures like the area of sealed surfaces, municipal area with transition potential and a quantification of the potential to reduce runoff per sub catchment in case of a disconnection from the combined-sewer system. The idea behind this assessment was to help prioritizing effective spots for transition in the city, e.g. where to implement a more sustainable urban drainage system most effectively in first place, increasing decentralized infiltration and evapotranspiration to the expense of runoff to the combined-sewer system. Thus, the decision support table was supposed to be the data bases for a multi-criteria decision analysis, based on quantitative indicators to derive optimal climate change adaptation in the case study area of Bergen.

Based on this primary study objective the secondary aim was to compare discrete, alternative risk reduction measures by their effectiveness in terms of CSO reduction. This quantitative risk reduction assessment should be based on the simulated results from the different sub catchments in the decision support table. Furthermore, the costs for measures should be estimated, at least in a qualitative way, to rank the alternatives accordingly. The cost of adaptation measures should be quantified, as far as data availability and research-economic reasons allowed for that.

The basic framework to compare adaptation measures is aligned to the cost-effectiveness analysis, as explained in more detail in the BINGO-Toolbox (Koti et al.

2017). The basic idea for the Bergen case was to relate the costs for a measure to the reduced CSO-pressure for each measure as a ratio, in order to rank them by their cost-effectiveness.

**Measures**

The measures to explore in the Bergen case are ranging from conventional to innovative, non-conventional measures:

- M1: Sustainable urban drainage
- M2: Road as emergency flood way
- M3: Separation of sewer system

The first measure, M1: Sustainable urban drainage, was meant to cover measures increasing decentralized infiltration and decrease the runoff from paved surfaces to the combined sewer system in the city area. This can be e.g. achieved by using solutions like building greening with green roofs, rainwater use for irrigation or as process water in buildings, de-paving of sealed surfaces and exchanging with permeable pavement, by infiltration schemes like infiltration trenches or by retaining water with artificial waterways like ponds.

M2: Road as emergency flood way is an innovative approach, meant as risk reduction in case of extreme precipitation events. The idea of this measure is to route stormwater via the urban street down the hill through the Damsgård area down to the fjord. By this, the stormwater does not enter the combined-sewer system and thus reducing the risk of CSO.

The third measure, M3: Separation of sewer system, is a rather conventional technical solution to reduce the risk of CSO. This measure, depending on the extend of course, increases the overall sewer capacity in the network and separates a part of the runoff completely from the combined-sewer system with an additional network draining runoff directly to the fjord or an intermediate storage facility like a retention basin.

**Data and tools overview**

The subsequent Figure 7.1 summarizes the basic data and tools used to work, calculate with and analyse the case studies data.

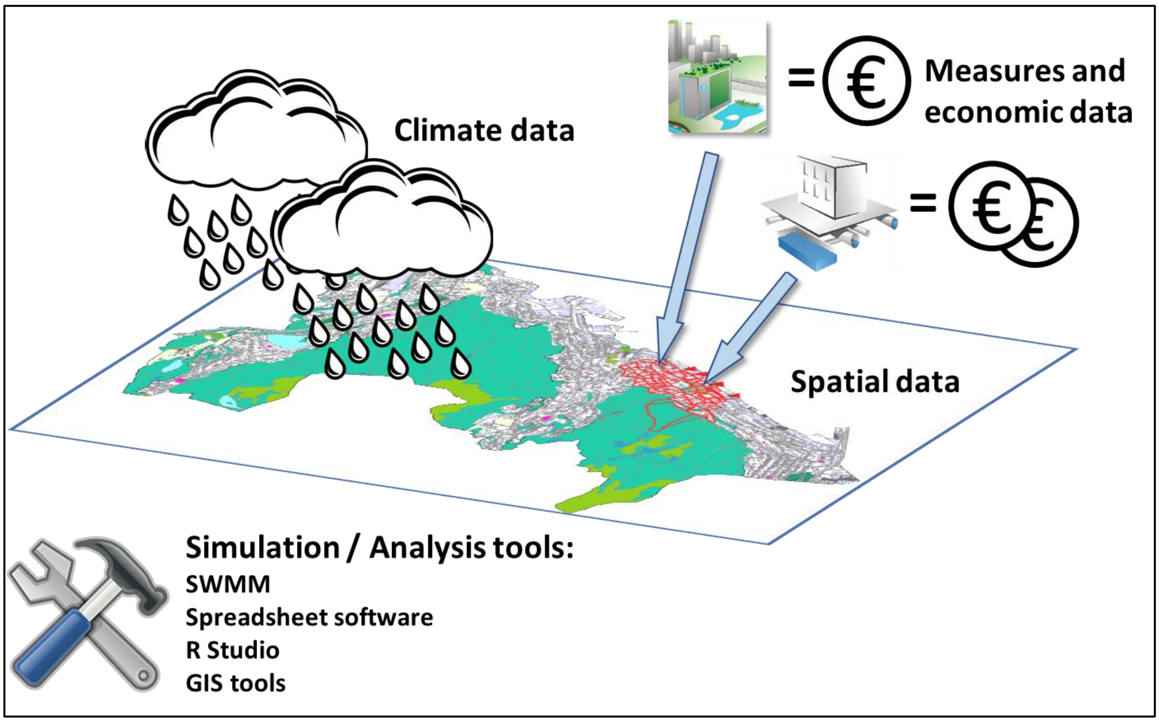



**Figure 7.1: Type of data and tools used for the analysis; Sources: Bing.de (creative commons CC0 licence), NTNU and Matzinger et al. (2017)**

Climate data is used for modelling the stormwater and effects in the combined sewer overflow within the case studies boundaries, using a SWMM. The spatial data showing the land use and giving details on the sub catchments is combined with the SWMM data. Potential risk reduction measures and their respective economic data (as far as available) is combined with data from the sub catchments locations and their quantitative boundaries. Additional analysis tools used to conduct the explorations and calculations are GIS software to work with the spatial data from the municipality, R Studio to run complex time series analysis with climate data and spread sheet software to integrate the different data sets in the decision support table (case studies primary objective).

**Spatial and technical boundaries of the case study**

Figure 7.2 illustrates the Damsgård area in Bergen as well as the selected case studies sub catchments, represented in red lines, and sewer outlets to the fjord, represented as red triangles.

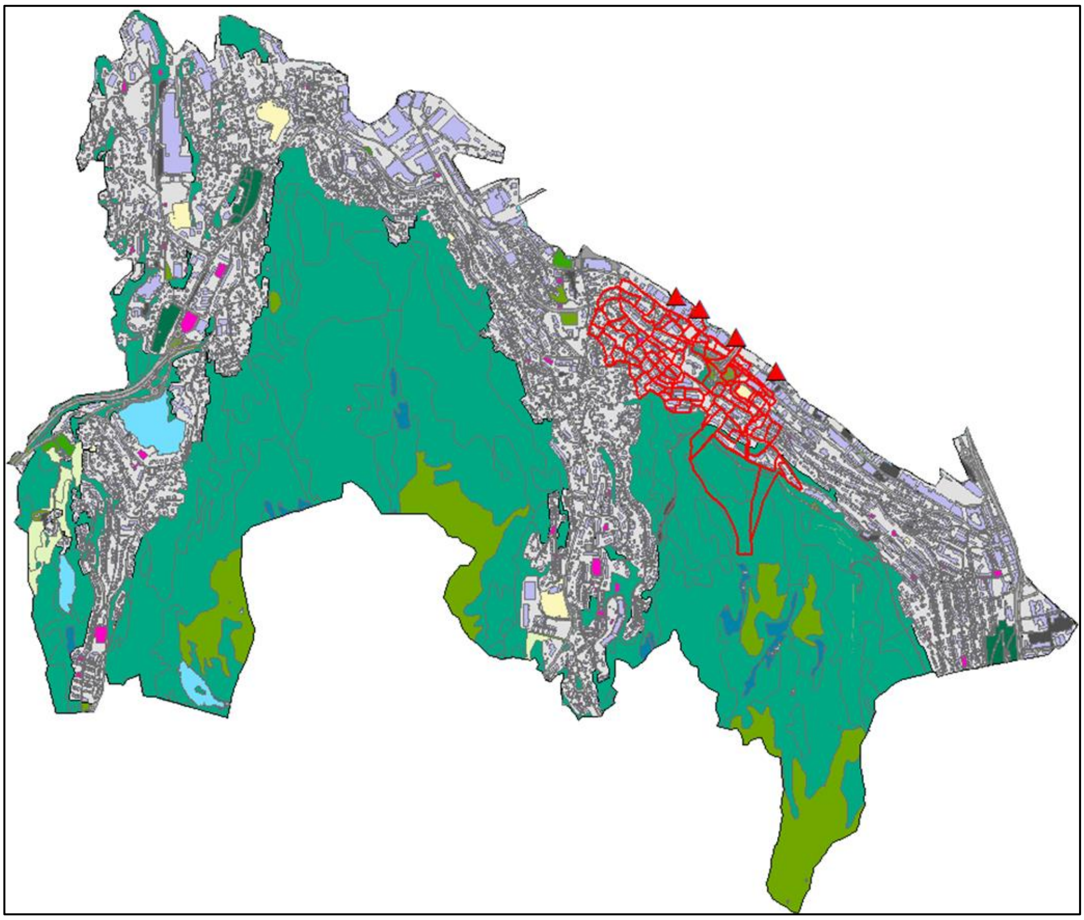


**Figure 7.2: The Damsgård area in Bergen, selected case studies sub catchments and sewer outlets to the fjord (Source: NTNU, Bergen K)**

The respective area was selected for the case, since it includes all relevant attributes, interesting to explore in order to find smart climate change adaptations for the city of Bergen:

- direct connection of four sewer outlets to the fjord,
- a model wise good separable part of the combined sewer network connected to these four outlets,
- Potential area for M1: Sustainable urban drainage type of measures,
- Step hill section in the back, with potentially fitting sub catchments to be drained by measure M2: Road as emergency flood way,
- Strategically a good position to reduce CSO in the future, since it is directly opposite a new opened bathing beach.

Additional spatial and technical boundaries of the case study are summarized in the table following.

**Table 7.1: Summary of spatial and technical case study boundaries for Bergen (source: NTNU)**

| Indicator | Value |
|---|---|
| Sub catchments (count) | 1705 |
| Total area ($km^2$) | 13.4 |
| Pipes length (km) | 141.0 |
| Pipes (count) | 5340 |
| Manholes (count) | 5353 |
| Pumping stations (count) | 8 |
| Weirs (count) | 29 |
| Outlets (count) | 39 |
| Sub catchments (count) | 88 |
| Total area G1 ($km^2$) | 0.42 |
| Outlets (count) | 4 |

### GIS Analysis of spatial data

In order to derive relevant key figures to integrate in the decision support table for each of the 88 explored sub catchments the ArcGIS (ESRI) was used. Shape files from Bergen had been made available, giving the land cover in classes for buildings and roads. Roads included also sidewalks, traffic islands, walking and bikeways as well as parking lots. An additional shape file was available for municipal property. Also the exact locations of each sub catchment connected to the sewer system was available in shape-format.

This data sets have been intersected derive these key figures for each sub catchment:

- area of the sub catchment in $m^2$
- area public property in $m^2$ and in %
- area with buildings in $m^2$ and in %

- area with roads in m² and in %
- natural or non-build up area in m² and %

The calculations have been conducted by condensing the dbf files with quantitative data results from the intersections in a complex spread sheet model.

**SWMM model set up and sensitivity analysis**

The SWMM model set up for the Bergen RS is run in two steps. Firstly, the runoff from all sub catchments is generated. Secondly, the runoff from each sub catchment is fed into the respective intakes (nodes) and the hydraulics calculated. A sensitivity analysis of the sub catchments was performed to quantify the potential effect of implementing adaptation measures. To simulate the implementation of a measure in a sub catchment, the runoff from each sub catchment was withheld (not entered into the hydraulic network) one by one. In order to do this, a simple R-script was set up. The R-script removed each sub-catchment one by one, launched and ran the SWMM model with a selected historical extreme rainfall event, and stored the results. In total, there are 88 sub catchments, and the approach thus required 88 (+1 full model) model runs. To reduce computational time, a short and intense precipitation event was selected. The selected event is one recorded from November 15 2013 known to have produced CSO and flooding. The described approach was highly effective in identifying the most relevant sub catchments for measure implementation, but it also entails some limitations: 1) to save computational time, the full precipitation event was not run and only 7h of the event was extracted. To allow for some pre-wetting of the soil and system, the event was extracted such that the peak precipitation occurred 2h after the start of the event. 2) By removing a sub catchment completely, the approach only account for the total potential effect of local measure implementation. In reality, a total disconnection may be difficult, especially with regards to the SUDS measure. A condensed aim of the sensitivity analysis was to deliver a key figure for each of the 88 sub catchments explored:

- sum of reduced volume of CSO (if fully disconnected) in 10^6 litre

**Cost analysis for SUDS**

The aim was to define a set of cost data figures to implement and operate specific SUDS measures in Bergen. For simplicity reasons cost is understood equal to expenditure here.

Cost data was not directly available from Bergen. But for several types of SUDS-measures data was available as annualized investment expenditures as well as annual operational expenditures from a German project on SUDS from 2017 (Strehl et al. 2017).

To convert these cost figures to appropriate figures for Norway in 2019, three adjustments have been conducted based on the original data:

To mind inflation from 2017 to 2019 for construction work costs the German price indices for construction works have been applied (Statistisches-Bundesamt 2019) to the cost data from KURAS.

Additionally, the figures haven converted to Norwegian price levels using Eurostat data on comparative price levels among European countries, based on the purchasing power parities concept (eurostat 2019).

Exchange rates between the Norwegian currency NOK and the European currency EUR have also been applied in a third step. Therefore the average exchange rate from 2019 (avg. for 1.1.19-24-6-19: 9.73 NOK/EUR) according to exhange-rates.org have been used (exchange-rates.org 2019).

## 7.4. Assessment results and discussion

**Decision support table**

The main aim of the case study was to derive a decision support table for a case specific climate change adaptation in Bergen, based on a quantitative analysis of the selected sub catchments. In addition, it was found relevant to provide stakeholders and decision makers with a proposal how to sort and prioritize the 88 sub catchments by the derived key indicators of this decision support table. The result was a case specific weighting method, presented below:

First, the expectable effect of risk reduction in terms of reduced CSO load for a sub catchment, if disconnected, should be a major key figure for prioritization. Secondly, also the implementation chance in terms of feasibility should be emphasized. A good fitting and relevant indicator for that is the area per sub catchment owned by the municipality. This is because it is much easier to implement a change or transition in the urban drainage system, if the property where changes ought to happen belongs to the municipality and not to private property owners. The higher the municipal owned property share of the sub catchment, the easier the implementation of a new urban drainage approach will be there. Thus, the share of public property area per sub catchment should have a high weight in the prioritization of sub catchments.

In order to mind the relation among the different sub catchment the first additional indicator calculated was labelled as “normalized score for the CSO reduction”. It is defined as the relation of the CSO volume reduction (by complete disconnection of the respective sub catchment) in 10^6 litre to the sub catchment with the highest CSO volume reduction in 10^6 litre. Following this logic, the best score (1) is given to the sub catchment with the highest CSO volume reduction. All other values receive a score below 1.

The second additional indicator useful for prioritization was labelled as “normalized score for public property share”. This is defined as the relation between the public property of the respective sub catchment in m² in relation to the public property in m² of the sub catchment with the highest value. Similar to the previously explained normalized score, this means that the best score (1) is given to the sub catchment with the highest public owned property. All other values receive a score below 1.

To aggregate these two prioritization indicators into one “combined normalized score” a weight of 50% was allocated to each of them. This means for the calculation the result for both normalized scores is multiplied with 50% and subsequently summed up to one value. This is based on the assumption, both indicators to have the same weight. For subsequent calculations and additional analysis it is easy to adjust these weights with different values.

In the table below on the next page, the extract of the decision support table is shown with the top ten scoring sub catchments, ranked by the combined prioritization indicator. The full table, containing results for all 88 sub catchments can be found in annex III.

The normalized score for public property is in row No. 4, the normalized score for CSO reduction volume is in row No. 13, and the combined score in row No. 14 included.

Interestingly, the first three sub catchments, scoring the best, are those relevant for the measure M2: Road as emergency flood way.

**Table 7.2: Decision support table including normalized ranking indicators and top 10 scoring sub catchments in Damsgård, Bergen**

| **Subcatch-ment number [FID_Nr.]** | **Area subcatch-ment [m²]** | **Area public property [m²]** | ***Normal-ized score public property-*** | **Area public property [%]** | **Area buildings [m²]** | **Area buildings [%]** | **Area roads [m²]** | **Area roads [%]** | **Area natural / non-build-up [m²]** | **Area natural / non-build-up [%]** | **CSO reduction volume [10^6 litre]** | ***Normal-ized score of CSO reduction volume [%]*** | ***Combined normal-ized score*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 76 | 79788.24 | 27668.61 | 1.00 | 34.68% | 0.00 | 0.00% | 1059.56 | 1.33% | 78728.68 | 98.67% | 2.34 | 1.00 | **1.00** |
| 55 | 12834.67 | 9329.37 | 0.34 | 72.69% | 990.33 | 7.72% | 706.75 | 5.51% | 11137.59 | 86.78% | 0.53 | 0.22 | **0.28** |
| 77 | 17543.60 | 5571.50 | 0.20 | 31.76% | 2.81 | 0.02% | 766.59 | 4.37% | 16774.20 | 95.61% | 0.72 | 0.31 | **0.26** |
| 71 | 6918.68 | 6918.68 | 0.25 | 100.00% | 24.06 | 0.35% | 2336.27 | 33.77% | 4558.35 | 65.88% | 0.19 | 0.08 | **0.17** |
| 40 | 10658.21 | 3614.37 | 0.13 | 33.91% | 2206.46 | 20.70% | 1969.95 | 18.48% | 6481.80 | 60.82% | 0.41 | 0.18 | **0.15** |
| 80 | 6302.49 | 6098.75 | 0.22 | 96.77% | 0.00 | 0.00% | 5968.62 | 94.70% | 333.87 | 5.30% | 0.14 | 0.06 | **0.14** |
| 87 | 6063.01 | 4053.90 | 0.15 | 66.86% | 0.00 | 0.00% | 1807.71 | 29.82% | 4255.30 | 70.18% | 0.27 | 0.12 | **0.13** |
| 60 | 4859.86 | 4631.96 | 0.17 | 95.31% | 915.09 | 18.83% | 1032.17 | 21.24% | 2912.61 | 59.93% | 0.21 | 0.09 | **0.13** |
| 58 | 8228.19 | 6794.07 | 0.25 | 82.57% | 3084.16 | 37.48% | 374.32 | 4.55% | 4769.72 | 57.97% | 0.01 | 0.00 | **0.13** |
| 83 | 4366.82 | 4311.70 | 0.16 | 98.74% | 10.01 | 0.23% | 788.05 | 18.05% | 3568.77 | 81.72% | 0.19 | 0.08 | **0.12** |

Apart from the option to rank the sub catchments by a priority order for transition to a more climate change robust city (by implementing adaptation measures in the respective sub catchments), also the various key figures presented above are valuable. So for instance the table gives the area or buildings, roads and non-build up area per sub catchment. These indicators can be useful for a more detailed, but strategic adaptation planning in the city, in terms of infrastructural changes.

**Risk reduction effectiveness**

Simulated results for the risk reduction effectiveness can be derived from the decision support table for the three measures.

The most valid sub catchments from which runoff could be routed through the streets are sub catchments with FID No. 76, 55 and 77 (compare table Table 7.2). Their combined risk reduction potential in terms of CSO reduction volume by an extreme rainfall event sums up to **3.59x10^6 litre per event** for M2: Road as emergency flood way.

For the other two measures, M1: Sustainable urban drainage and M3: Separation of sewer system, the expectable risk reduction is relying on the degree of implementation. The decision support table gives the maximum level achievable for each sub catchment, if disconnected (indicator: CSO reduction volume, row 12 in Table 7.2). In theory, both measures, as well as a combination of sustainable urban drainage measures, as well as the separation of the sewer system can archive the full reduction potential. In other words, the maximum risk reduction effectiveness is given for all sub catchments with the indicator "CSO reduction volume" for both, M2 and M3 identically. Summing up, this amounts to a full maximum potential of **309,607.71x10^6 litre per extreme rainfall event** for either M1 or M3, if leading to a full disconnection of all sub catchments (except FID Nr. 76, 55 and 77 which are relevant for M2).

**Calculated costs for SUDS measures**

Table 7.3 below at the end of this section summarizes the calculated cost figures for selected SUDS measures. Both, annual investment and operational expenditures are calculated per directly connected impervious area (DCIA) in square metres. This means they are fitting to be used to explore and define SUDS scenarios in Bergen. This can be done e.g. by deciding on a sub catchment, defining the respective area to be disconnected with SUDS from the sewer system, and multiplying this area with the investment and operational expenditures of a fitting SUDS measure type. For example in sub catchment with FID No. 60 there are 915 m² of buildings according to the decision support table. In addition to this, the expectable runoff reduction in percentage by a

SUDS measure is given in that table, which is important for risk reduction effectiveness calculations in terms of CSO reduction. Now assuming that these buildings do offer the capability to be upgraded by extensive green roofs would mean the following cost estimation for a SUDS measure in sub catchment No. 60:

| | |
|---|---|
| *Annual costs for green roofs in sub catchment No. 60* | *= area buildings [m²] x (annual CAPEX + OPEX [NOK/m² DCIA])* |
| | *= 915 x (10.19 + 17.66) NOK = 25,482.75 NOK* |

The expectable risk reduction in terms of CSO volume reduction can also be calculated for this example, by multiplying the relative share of the building area in sub catchment No. 60 of the overall sealed surfaces with the maximum CSO volume reduction of that sub catchment and weighting it by the expectable runoff reduction factor. According to the data in the decision support table this is:

| | |
|---|---|
| *Risk reduction by green roofs in sub catchment No. 60* | *= area buildings [%] x CSO reduction volume [10^6 litre] x expectable runoff reduction factor [%]* |
| | *= 18,83% x 0.21x10^6 litre x 55% =0.022 x10^6 litre* |

This example illustrates the flexibility of the results. Both, the decision support table with basic data about the sub catchments and the table with generic cost figures for selected SUDS represent ready to use tools to support stakeholders and decision makers to define appropriate climate change adaptation measures in Damsgård, Bergen.

**Table 7.3: Generic cost figures and technical specifications of selected SUDS for Bergen**

| Lifetime of measure [a] | Category of measure | Type of measure | Annual CAPEX[15] [NOK/m² DCIA] | Annual OPEX [NOK/m² DCIA] | Medium Rainwater runoff reduction [%] |
|---|---|---|---|---|---|
| 40 | Building greening | Extensive green roof | 10.19 | 17.66 | 55 |
| 40 | | Intensive green roof | 29.03 | 47.09 | 66 |
| 40 | Rainwater use | Rainwater use for irrigation and process water | 11.20 | 2.71 | 70 |
| 60 | De-paving | Permeable pavement | 21.27 | 0.00 | 39 |
| 40 | Infiltration | Infiltration basin / surface infiltration | 2.55 | 8.24 | 100 |
| 40 | | Infiltration trench | 6.11 | 1.18 | 100 |

### Qualitative cost-effectiveness ratios

The potential for risk reduction by all three measures has been quantified, as presented above. Costs are available for M1: SUDS measures, but for research-economic reasons no estimation was derived for M2 and M3. Thus, in order to present at least a formal

[15] Please note: The annuity has been calculated using a discount rate of 3 % based on recommendations for cost comparisons from DWA (2012) Leitlinien zur Durchführung dynamischer Kostenvergleichsrechnungen (KVR Leitlinien) (translation: Guidelines to conduct dynamic cost comparisons).

comparison of the three alternative adaptation measures qualitative cost-effectiveness ratios have been produced, as stated below.

For the qualitative assessments in a generic way, three precipitation levels have been defined: The effectiveness of the measure for an

- “everyday rain” as step 1,
- “design rain” as step 2,
- “extreme rain” as step 3.

The idea behind these steps is to mind, that some adaptation measures may work sufficiently e.g. to reduce the CSO during a normal, “everyday rainfall event” but eventually not for an “extreme rainfall event”. Other measures may score better for extreme situations. The “design rainfall” is defined as the one defining the return period to be at least met with the measure by common technical / engineering rules. This is also the reason why in addition to the comparison of all three measures solely, also the combination of M1 and M2 is considered in the assessment below. M2: Road as emergency flood way, is a good complementing measure and should not only be considered mutually exclusive to the others.

To score the effectiveness and costs in a semi-quantitative way, a straightforward three point scale has been used:

**Table 7.4: Qualitative score for costs and effectiveness**

| Cost and effectiveness score | | |
|---|---|---|
| Low | Medium | High |
| 1 | 2 | 3 |

The following tables show the qualitative assessment for all three measures:

**Table 7.5: Qualitative cost assessment for adaptation measures in Bergen**

| | Step 1 Everyday rain | Step 2 Design rain | Step 3 Extreme rain | Average in total |
|---|---|---|---|---|
| **M1 SUDS** | 3 | 3 | 1 | 2.3 |
| **M2 Safe flood ways** | 1 | 1 | 3 | 1.7 |

| | | | | |
|---|---|---|---|---|
| **M3 Sewer separation** | 3 | 3 | 2 | 2.7 |
| **M1 + M2 Combination** | 3 | 3 | 3 | 3 |

SUDS measures deliver a good risk reduction for everyday rainfall situations as well as considering their design rainfall. But they usually reach capacity limits once dealing with extreme rainfall events. In contrast, using urban streets as safe flood ways is not a feasible option for everyday rainfall situations, but rather useful and thus most effective in extreme precipitation events, serving as a reduction of peak flows into the sewer system.

Regarding the qualitative assessment of the costs, the resulting summary table is presented below:

**Table 7.6: Qualitative cost assessment for adaptation measures in Bergen**

| | **Capital expenditures** | **Operational expenditures** | **Average in total** |
|---|---|---|---|
| **M1 SUDS** | 1 | 1 | 1.0 |
| **M2 Safe flood ways** | 1 | 1 | 1.0 |
| **M3 Sewer separation** | 3 | 2 | 2.5 |
| **M1 + M2 Combination** | 2 | 2 | 2.0 |

From a qualitative perspective traditional engineering solutions like M3: Separation of the sewer system are more expensive than e.g. M1: SUDS. This is to be expected because of all the underground construction works necessary to place new pipes and to construct a separated sewer system. For M2: Road as emergency flood way, less costs can be expected, since by using the road no new infrastructure would be needed to be constructed in general.

Now combining both qualitative assessments, the following overall ranking of measures can be derived:

**Table 7.7: Cost-effectiveness ratios based on qualitative assessments for M1-M3**

| | Cost-effectiveness ratio |
|---|---|
| **M1 SUDS** | 0.4 |
| **M2 Safe flood ways** | 0.6 |
| **M3 Sewer separation** | 0.9 |
| **M1 + M2 Combination** | 0.7 |

Thus, from a qualitative assessment point of view, M3 seems to be expensive in relation to the risk reduction achievable with it. M1 has a good cost-effectiveness, and M2 as well as the combination of M1 + M2 have a medium cost-effectiveness. In terms of prioritizing adaptation measures this can be interpreted as follows: It seems to be worthwhile starting the adaptation in Bergen with the implementation of SUDS measures, since they are relatively low priced when related to their benefit in terms of expectable CSO reduction. But since SUDS can not reduce the risk for all kind of rainfall events (they reach a capacity limit when it comes to extreme events), complementing measures should be taken into consideration. Using the road as emergency flood way seems to be a good alternative to conventional approaches like sewer separation in order to handle peak flows in urban drainage.

### Results derived from the social justice questionnaires

Apart from the detailed exploration of risk reduction, potential for adaptation measures, quantitative data analysis and qualitative assessment results as presented in the paragraphs above, also an additional so called "social justice analysis" has been conducted, based on three questionnaires about the adaptation measures explored for Bergen (compare annex I for the original questionnaire and annex II for the answers). The results are presented in this section.

*Social justice analysis - Sustainable urban drainage systems (SUDS)*

Apart from main aim, to improve the stormwater management, the side effects of the Sustainable urban drainage systems (SUDS) enhancing the social justice for the public, if designed as multi-functional solutions and/or located in places where the public can enjoy them. Thus the main side effect is following the solidarity principle. Also the deontological principle can apply, if the direct side effect of the at-side control for stormwater are considered and the 'polluter pays' principle applies.

Depending on where the measures are build either the municipality or the owners of the measure have to pay for implementation and maintenance. The municipality, if the measure is built on public buildings or other buildings belonging to the municipality. In addition it is possible that private developers could imposed by municipality to manage stormwater at-site through SUDS. In this case the private developers would pay for the implementation and the owners of the measure would just pay for the maintenance. Because the AWSW is fully financed by water and sewerage fees, a possible extension of the sewer network could lead to higher prices for the inhabitants. Beside this monetary burdens the measure could also start some positive side effects. For actors and suppliers of the SUDS industry and research and likewise the general public would benefit from incur the economic revenue and development of solutions which leads to a monetary benefit and creates new jobs.

As positive side effects for the general public it is reported that blue-green SUDS may incur effect such as pollution control, noise reduction, CO2- capturing, better air quality and biodiversity. In addition, it is expected the green environment resulting of some SUDS (e.g. open rivers and creeks, dams, and open, vegetated dry basins) invite to recreational activities that are positive for mental and physical health. Traces of natural elements (such as running water or water mirrors) can have positive effects on children's learning and development. These positive side effects also outweigh the non-monetary negative effect, The SUDS measure requires surface area, so the measure owner has to give less priority to other wishes and proposals within this context.

*Social justice analysis - Roads as emergency flood way*

Apart from main aim, to route the water in a controlled manner during very extreme events, rather than letting the water flow freely and uncontrolled, the side effects of roads as emergency flood ways during extreme precipitation evens is supposed to benefit the society as a whole and strengthen the social equalities. The measure benefits the whole system and thus the society so that the egalitarian principle applies.

A large portion of the costs should be paid by the AWSW, because they are having a leading role in the planning and implementation. These costs are indirectly shared with the public, due to the fact that the AWSW are fully financed by public fees. In addition, road owners and the municipality, depending on who is considered as the owner of the measure, have to pay for the implementation and the upkeep of the measure. The Norwegian Road Authority should be provided with the investigations and evaluations necessary to develop guidelines, regulations and a design for the roads, which leads to costs for this authority too. In the planning also other stakeholders, like neighbours, local associations, road owners and civil protection authorities, having the opportunity to object the planning. Another monetary burden for the inhabitants or municipality could be the costs after an extreme precipitation event such as damages to cars (drivers), pedestrians and cyclists or damaging effects such as clogged drains/intakes, erosion, fractures in the road and reduced life expectancy of the road cover. In this case the municipality would be responsible for regulating the floods paths safely. However, overall the costs of the municipality will be reduced as the measure involves adding functionality to existing infrastructure (road). The inhabitants could be confronted with a temporal parking restrictions or an early warning system to mitigate the damage before a flooding of the streets occurs.

The benefit for the public and the municipality is a low level of physical intervention (public works), compared to traditional measures and it will help maintaining the reputation and image of the municipality.

*Social justice analysis - Separation of sewer system*

Apart from main aim, mitigating CSO spills to receiving water bodies, the aim of a separated sewer network is to provide the same service (safe transportation of sewage and storm water) to all inhabitants and is therefore strengthens the social equalities. For the separation of the municipal sewer system, the egalitarian and solidarity principle due to the measure being a system-level measure seems to be fitting principles. For private owners being requested to separate their private sewers due to the municipal system being separated, the deontological ('polluter-pays') principle applies.

The sewer system is owned by the municipality and governed on behalf of the municipality by the municipal AWSW. AWSW is responsible for planning and initiating of the measure but the maintenance is performed by the municipal owned company Bergen Vann (Bergen Water) upon request from AWSW. Thus, AWSW is also responsible for all the costs related to the measure. The implementation and also the costs of a separated sewer system on private properties is paid by the property owner.

The general public is effected through construction work related to new sewers and trenches which causes noise and lowers mobility for pedestrians, bikers and drivers. This burden can be mitigated by the contractor responsible for the construction work. The choice of equipment will impact the noise level and a proper logistical plans can countervail the lowered mobility.

The benefits for the public and also for AWSW are a reduced risk of flooded basements during extreme precipitation, a decrease of the load on treatment facilities, on pumping stations, and thus reduced operation and maintenance costs and an upgrade of the capacity of the storm sewer such that climate change and increased area of impermeable pavements may be accounted for.

## 7.5. Conclusions and outlook

The interdisciplinary approach followed in the Bergen case produced a detailed quantitative decision support table, relevant for climate change adaption in Damsgård, Bergen. It offers specific key figures, valuable to plan adaptation measures on a detailed level (sub catchment) in order to reduce future risk of CSO, beneficial for the environment (fjord water quality) and the quality of live in the city quarter.

Additionally, generic cost figures based on Norwegian price levels have been derived, ready to be combined with the basic data from the decision support table to work out specific adaptation scenarios in future projects, following BINGO. Moreover, this study generated the basis to work on a more detailed cost assessment for the innovative approach of using roads as emergency flood ways in order to reduce CSO.

In summary, this case study did highlight considerable potential for risk reduction by the measures explored, valuable for consecutive research and ongoing stakeholder discussions for climate change adaptation in Bergen.

# 8 ADAPTATION MEASURES AT BADALONA RESEARCH SITE

## 8.1. Brief introduction to the case study

The present case study appraises the impact of the proposed adaptation measures to be implemented in Badalona, a city located on the metropolitan area of Barcelona, Northeast coast of Spain. For detailed information read D3.1 “Characterization of the catchments and the water systems”. The impacts of the proposed adaptation measures are analysed in terms of risk reduction capacity and with a Cost-Benefit-Analysis.

The morphology of Badalona presents areas with high gradients (close to Serra de la Marina) and flat areas near the Mediterranean Sea. These characteristics, added to the Mediterranean rainfalls with high intensity and short duration, leave the city in a prone situation to be flooded. Moreover, the land was strongly urbanized during the last decades. All these aspects facilitate urban flash floods in several critical areas with significant economic damages and high hazard conditions for pedestrian and vehicular circulation.

The flat area close to the seafront, which is the most densely populated area in the city, presents a highest flood vulnerability in terms of people safety and vehicular circulation. In addition, in case of moderate and heavy storm events, combined sewer overflows (CSOs) occur generating significant impacts on the receiving water body (Mediterranean sea), as well as in terms of people’s safety, indirect losses to specific urban sectors (tourism, leisure, fishery, etc.) and on the image and reputation of the stakeholders involved in the sewer system and beaches management.

In this context, the proposed adaptation measures will be analysed based on a risk analysis and also on the economic and societal impacts. Particularly, floods and CSOs will be analysed:

1. Urban floods :
   - ❖ Direct economic impacts (e.g. damages to buildings and vehicles)
   - ❖ Indirect economic impacts (e.g. business interruption and cascading effects)
   - ❖ Impacts on risks
2. CSOs spills:
   - ❖ Impacts on the quality of the receiving water bodies and potential affectation on human health
   - ❖ Intangible damage to citizens and businesses and analysis of impact on reputation of stakeholders involved in the water management system

Four adaptation measures/strategies were proposed (described in the following sections) together with the project stakeholders in order to cope with the potential impacts due to the considered hazards.

Based on the assessment methods for the evaluation of adaptation measures (developed in the framework of task 5.2), a Cost-Benefit Analysis (CBA) was proposed for the Badalona Case Study (further described in the following section).

Following the structure of the damage assessment, the CBA has been divided into two different frameworks: the flood framework and the CSO framework. Both are based in similar principles and methodologies, although differences are addressed through the document.

## 8.2. Stakeholders involved

The following list contains the major stakeholders involved in the Badalona case study, their expertise and their area of influence.

**Table 8.1: Stakeholders details for the Badalona Case Study**

| Stakeholder/organization (including person of contact) | Expertise | Area of influence |
|---|---|---|
| Badalona city council<br>*Josep Montes Carretero* | Urban planning, environment protection, urban drainage planning and management, and coast management | Local (public) administration |
| AMB (Metropolitan Area of Barcelona)<br>*Ester Suárez* | Territorial planning, transport and mobility, urban development and housing, environment and water cycle, economic and social development, social and territorial cohesion | Supra-municipal administration (public) |
| Aigües de Barcelona<br>*Albert Pérez* | Water cycle management | Public-private water management in the metropolitan area of Barcelona |

| Stakeholder/organization (including person of contact) | Expertise | Area of influence |
|---|---|---|
| ACA (Catalan Water Agency)<br>*Mariona de Torres* | Water cycle planning management and regulation | Regional administration (public) |
| Catalan Office of Climate Change (OCCC) and the Interdepartmental Commission of the Climate Change<br>*Ester Agell Mas* | Climate change adaptation and mitigation | Regional administration (public) |
| Technical Office of Climate Change and Sustainability (Barcelona province government)<br>*Laia Soler Serra* | Climate change adaptation and mitigation | Provincial administration (public) |
| Insurance Compensation Consortium (CCS)<br>*Francisco Espejo* | Damages costs related to natural phenomena such as extraordinary floods | Public business organization |

The primary risk owner is the Badalona City Council. Although the responsibility for risk reduction and adaptation measures is shared between the Municipality and the Metropolitan Area of Barcelona. The beneficiaries of the improvements obtained from the measures implementation include the two mentioned before, *Aigües de Barcelona*, the water company, as it is expected to reduce repair and maintenance costs, and finally, the citizens of Badalona, who will benefit from a more resilient infrastructure against climate change risks.

## 8.3. Assessment of adaptation scenarios: methods and data

The socio-economic assessment of the adaptation measures has been divided in two frameworks of analysis, floods and combined sewer overflows (CSO). Both frameworks are described in the following subsections, as well as the measures to counteract their risks, and the valuation methods to assess them.

### *8.3.1 Flood Framework*

In this section, a description of the adaptation measures to cope with flood risks is presented. For each set of measures a scenario has been created to define their risks and impacts expected to occur. A summary of the measures is available at Table 8.2.

**Table 8.2: Summary of scenarios and measures included in the analysis of Badalona Case Study**

| Scenario ID | Measure | Type | Description |
|---|---|---|---|
| M0 | Baseline/ BAU | - | Baseline is the do-nothing scenario under present rainfall conditions. Business As Usual (BAU) is the do-nothing scenario under future rainfall conditions. |
| M1 | Inlets increase | Structural | Increase by 12,427 the current number of sewer's inlets to increase the collection capacity of the surface drainage system. |
| | New pipes | | A total of 9,478 m of new pipes to increase the capacity of the sewer system. |
| | Retention tanks | | Four (4) detention tanks with a total volume of 150.000 $m^3$ |
| M2 | Green roofs | Sustainable Urban Drainage SUDS | Implement extensive green roofs in 5% of Badalona's roof area. |
| | Permeable Pavement | | Eight (8) parks and public squares have been identified to implement permeable pavement. |
| | Infiltration Trenches | | Infiltration trenches in 5 parks. Total permeable surface of 20 hectares. |
| M3 | Early Warning System (EWS) | Non-structural | Development and implementation of EWS to support prevention of flood risk. |

The methodologies used for the assessment of risks and impacts, as well as the financial and economic assessment framework are described below. The financial assessment is based on initial investment costs (CAPEX) and operating and maintenance costs (OPEX) estimated for the different strategies. Whereas the economic assessment focuses on the assessment of variations of Expected Annual Damage (EAD) and welfare. In addition, the **risks** expected under these adaptation scenarios were simulated using the 1D/2D urban drainage model (Infowork ICM) and different indicators were used to evaluate their capacity of reducing risk:

- Reduction of pedestrian high risk area
- Reduction of vehicle high risk area
- Reduction of Expected Annual Damage (EAD)

The complete methodology and results of risk and damage assessment was developed in WP4 and is available at deliverables D4.2 and D4.3. Therefore, in the present report there is only a summary. Also, both present and future rainfall conditions (D3.4) were used in order to simply address future climate uncertainty.

#### 8.3.1.1. Adaptation Measures Scenarios

##### 8.3.1.1.1 Do-nothing scenario (Baseline/Business As Usual)

The do-nothing scenario, named baseline for the present rainfall conditions (PRC) and BAU for the future rainfall conditions (FRC) assumes there are no changes in the current drainage system. The baseline operating costs (OPEX) are the reference point for analysis of the adaptation measures that to facilitate the interpretation of results, they have been considered zero. However, the OPEX of the current urban drainage network of Badalona are presented for reference in Table 8.3.

**Table 8.3: Estimation of OPEX costs of the urban drainage network of Badalona estimated in BINGO**

| Activity | Details of the activity | Cost [€/y] |
|---|---|---|
| Inspection and cleaning of the combined sewer network * | Cleaning | 241 627 |
| | Inspection | 13 500 |
| | Maintenance of critical points | 16 535 |
| | Cleaning of critical points | 20 711 |
| Planning, coordination and control of the drainage system * | Running cost of the tank Estrella | 17 400 |
| | Maintenance of the tank Estrella | 14 400 |
| | Management of the limnimeters | 10 200 |
| | Management of the warnings during wet periods | 4 200 |
| | Maintenance of the informatics system of the control center | 4 200 |
| Reparation of the sewers ** | | 450 000 |
| Total including taxes and other fixed costs | | 941 326 |
| * Estimations from the municipality<br>** Reparation expenses of 2018 | | |

Benefits are not expected to arise under this scenario. The EAD assessment, is presented in the results section (in D4.3 we presented preliminary EAD results that did not include indirect damages and the latest model updates.).

#### 8.3.1.1.2 Structural Measures

The proposed structural measures (pipes and detention tanks) for flood alleviation are shown in Table 8.4. They were designed based on design storm of 10-years return period (T10) including a climate factor (1.07) for future rainfall conditions (FRC) (equivalent to an actual return period of T16). This means that the future design storm (from the selected RCP8.5) is 7% more intense compared to a current T10 design storm (for further details see D3.4). The existing 2012 Master Drainage Plan of Badalona (with flood measures designed for an actual T10 design storm) was modified in order to include structural measures designed considering FRC design storms. The location of the structural measures are visible in the map of Figure 8.1

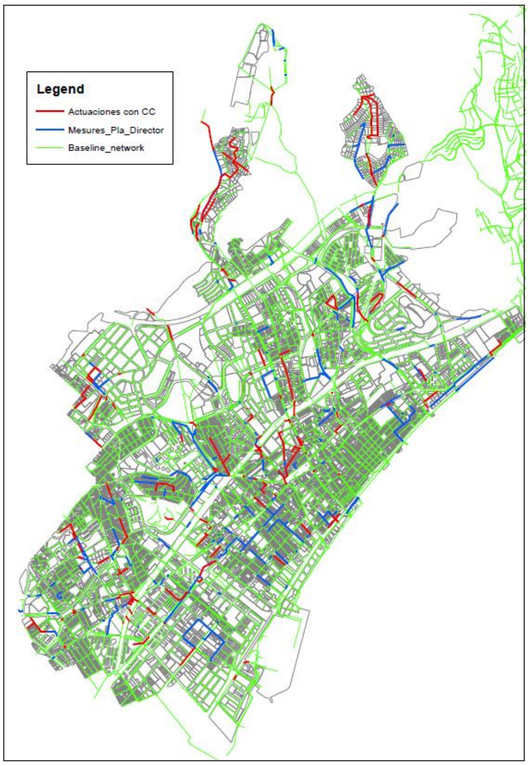



**Figure 8.1:** Map of the Structural Measures proposed in Badalona. **Green:** current sewer network**; Blue:** new pipes proposed in 2012 Master Drainage Plan (with CRF)**; Red:** additional pipes designed for a T10 considering FRC

##### Cost Analysis

The financial costs are available in Table 8.4, which shows that future design storm (7% increase of rainfall) increases the cost of these measures by 18%.

**Table 8.4: Estimated CAPEX costs of the flood structural measures. Costs (PEC+IVA)**

| Action | | CAPEX (€) | OPEX (€/y) |
|---|---|---|---|
| Flood structural measures (from the Master | 4 deposits | 101,975,023 € | 4 deposits * 50,400 €/y = 201,600 €/y |
| | new pipes (current conditions T10) | | 9,478 m * 2.97 €/m/y = 28,150 €/y |

| | | | |
|---|---|---|---|
| Drainage Plan 2012) | Gullies | 11,682,692 € | - |
| **Updated** flood structural measures of the Master Drainage Plan * | New pipes (future conditions T10) | 20,148,639 € | 20% (assumption) of 28,150 = 4,630 €/y |
| | **TOTAL** | 133,806,354 € | 234,380 €/y |

#### Economic Analysis

In the **economic assessment**, the indicator considered is the variation of the EAD. Following the flood risk methodology (D4.3), the flood risk assessment was carried out for the Structural Measures Scenario.

In the assessment, it is assumed that structural measures are implemented gradually, with expected construction completion in 20 years, i.e. 2040. Benefits from damage reduction are allocated gradually as well. The life expectancy of these measures is assumed as 60, based on previous results. The maintenance costs considered are from the higher side of the available reference cost, as the life expectancy of the measures depends on the optimal maintenance.

#### 8.3.1.1.3 Sustainable Urban Drainage System (SUDS)

Three different types of SUDS and their location were selected in collaboration with the project stakeholders of Badalona: 1) Green roofs, 2) Permeable pavements and 3) Infiltration trenches.

Table 8.5 shows the distribution of both pervious and impervious areas in Badalona for the SUDS scenario and the variation with respect to the current situation. The table shows that the SUDS measures reduce by 5% the traditional roof area and by 1.5% other impervious areas. Overall a 2% reduction of impervious area is obtained through SUDS implementation. More details about the design criteria and the costs are given in the following paragraphs.

**Table 8.5: Distribution of impervious and pervious areas both for the actual and the SUDS scenario.**

| | Scenario | | Variation |
|---|---|---|---|
| | Current [ha] | SUDS [ha] | [%] |
| Roads | 414.5 | 414.5 | 0.0% |
| Traditional roofs | 363.0 | 344.9 | - 5.0% |
| Other impervious areas (paved squares, backyards, etc.) | 433.4 | 426.9 | - 1.5% |
| TOTAL Impervious areas | 1 210.9 | 1 186.2 | - 2.0% |
| TOTAL Green areas | 1 026.0 | 1 026.0 | 0% |
| Green roofs | 0.0 | 18.2 | |

| | | | |
|---|---|---|---|
| Permeable/pervious pavements | 0.0 | 3.5 | |
| Infiltration trenches | 0.0 | 3.0 | |
| TOTAL SUDS | 0.0 | 24.6 | |

### Cost Analysis

Table 8.6 summarizes the total costs for each SUDS proposed. The costs are clearly dominated by green roofs. This is because green roofs are assumed to be retrofitted onto 5% of the total roof area of Badalona, whereas infiltration trenches are placed on 7 different parks and infiltration pavements on 5 different parks and public squares.

**Table 8.6: Total CAPEX and OPEX of SUDS measures**

| | CAPEX [€] | OPEX [€/y] |
|---|---|---|
| Green roofs | 14 534 788 | 405 157 |
| Infiltration trenches | 1 783 561 | 96 150 |
| Permeable pavements | 1 739 183 | 48 311 |
| TOTAL | 1 805 7531 | 549 618 |

- **Green roofs: design and cost estimation**

Green roofs are assumed to be implemented in 5% of the total Badalona roof area (approximately 3,633,697 m$^2$). The roof area was obtained by GIS analysis considering roofs, terraces and other covers.

In this study extensive green roofs are selected as they have the lowest structural weight, low/null irrigation requirements, plants that fit well in the Mediterranean climate and the lowest operational and maintenance costs. On the other hand, extensive green roofs are the ones that reduce less stormwater runoff.

The implementation cost of extensive green roofs is approximately 70-90 €/m$^2$ (BCN 2015) and it includes waterproofing, drainage system, substrate, vegetation and irrigation costs. The structural weight is in the range 120-225 kg/m2. The annual operational and maintenance costs are assumed to be 2.33 €/y/m$^2$ (R+I Alliance).

**Table 8.7: Green roof costs used in the CBA**

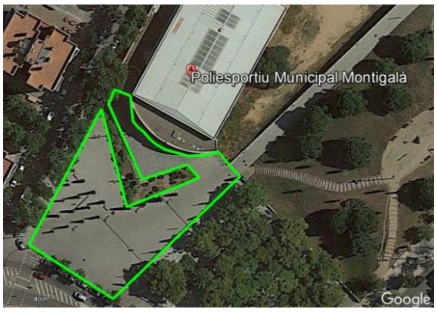
| | Per unit square meter | Total area [m2] | Total costs |
|---|---|---|---|
| CAPEX | 80 €/m2 | 181 685 | 14 534 788 € |
| OPEX | 2.33 €/y/m2 | | 405 157 €/y |

Random spatial distribution throughout the Badalona area of green roofs is assumed.

- **Permeable Pavements: design and cost estimation**

Parks and public squares where permeable pavements are assumed to be implemented are represented in Table 8.8, while the summary of costs can be found in Table 8.10.

**Table 8.8: Aerial photos of planned areas for permeable pavements implementation**

| Av. d'Itàlia | Poliesportiu Montigalà |
|---|---|
|  |  |
| Escola Jungfrau | Parc Gran Sol |
|  |  |
| Brigades Internacionals Square. | Plaça San Roc |
|  |  |
| Plaza Camaron de la Isla | |
|  | |

The considered costs are shown below. CAPEX are in the range of 33-66 €/m$^2$ and OPEX are 0.75-2 €/y/m$^2$ (R+I Alliance).

**Table 8.9: Permeable pavements unit costs**

| | Per unit square meter |
|---|---|
| CAPEX | 49.5 €/m$^2$ |
| OPEX | 1.375 €/y/m$^2$ |

Not all the area considered is suitable for the implementation of permeable pavements. The suitable percentage of area was estimated by looking at the aerial photos (see **Table 8.8**) of each different park and public squares and only the existing impervious areas of the parks/squares were assumed to be suitable for permeable pavements. The typical percolation rate from permeable pavements is approximately 400 mm/h and can be up to more than 1,000 mm/h (R+I Alliance).

**Table 8.10: Total CAPEX and OPEX costs of permeable pavements estimated in BINGO.**

| Area name | Total area [m2] | Potential pavement area [%] | CAPEX [€] | OPEX [€/y] |
|---|---|---|---|---|
| Avinguda Itàlia | 11 800 | 75 | 438,075 | 12,169 |
| Paved area in front of Polisportiv Montigalà | 2,500 | 85 | 105,188 | 2,922 |
| Paved area behind Jonfrau school | 6,600 | 80 | 261,360 | 7,260 |
| Parc del Gran Sol | 6,900 | 70 | 239,085 | 6,641 |
| Plaça Brigades internacionals | 5,600 | 50 | 138,600 | 3,850 |
| Plaça Camaron de la Isla | 9,600 | 75 | 356,400 | 9,900 |
| Plaça Sant Roc | 4,500 | 90 | 200,475 | 5,569 |
| **TOTAL** | **47,500** | | **1,739,183** | **48,311** |

- **Infiltration trenches: design and cost**

The parks where infiltration trenches will be installed are found in Table 8.12 (areas obtained from: http://badalona.cat and http://www.amb.cat). Typical installations costs are approximately 170-200 €/m3. Installation costs include: clearing, excavation, placement of the filter, monitoring well and other additional expenses like planning, geotechnical evaluation, engineering and others. Additional costs of manholes, inlets and pipes were included, assuming similar costs to the existing infiltration trenches installed in Parc Ca l'Arnús. Typical operational costs for maintenance and rehabilitation were estimated to be approximately 40-60 €/y/m3 (R+I Alliance). Table 8.11 summarizes the considered costs of infiltration trenches.

**Table 8.11: Infiltration trenches installation costs**

| | Per unit square meter |
|---|---|
| CAPEX | 185 €/m3 |
| OPEX | 50 €/y/m3 |

Table 8.12 shows the dimensions and the costs of the infiltration trenches for all the different parks where they can potentially be implemented. The volume of the trenches was estimated using the SUDS design tool developed in the R+I Alliance project. The trenches are designed for a 10 year return period design storm (T10).

**Table 8.12: Infiltration trenches dimensions and costs estimated in BINGO.**

| Park name | Park area [$m^2$] | Infiltration trench vol. [$m^3$] | CAPEX [€] | CAPEX (additional | OPEX [€/y] |
|---|---|---|---|---|---|

| | | | | Pipes, inlets, manholes) [€] | |
|---|---|---|---|---|---|
| Montigalà | 81,000 | 530 | 98,050 | 389,083 | 26,500 |
| Turó d'en Cartitg | 61,000 | 414 | 76,590 | 295,763 | 20,700 |
| Nova Lloreda | 15,000 | 87 | 16,095 | 69,990 | 4,350 |
| G5 | 42,000 | 242 | 44,770 | 195,676 | 12,100 |
| Parc del Torrent de la Font i del Turó de l'Enric | 99,372 | 650 | 120,250 | 477,294 | 32,500 |
| **TOTAL** | **298,372** | **1,923** | **355,755** | **1,427,806** | **96,150** |

For SUDS measures, re-investments are assumed to be 50% of the CAPEX after the life expectancy, which is 20 years.

### Economic Analysis

Regarding the economic assessment of SUDS, similarly to the previous scenario, they include changes in EAD as a welfare indicator. Moreover, SUDS are known to provide additional co-benefits to citizens, in the form of improvements in the ecosystem services provision (Nordman et al., 2018; Bianchi et al., 2012; Feng, 2018). Therefore, it is important to recognize the complete overview of all direct, indirect and use values provided by these measures, in order to inform decision-makers. A monetization of changes in ecosystem services due to the implementation of these measures has been performed.

The **benefit transfer method** has been used to monetize these variations in ecosystem services. It consists of using value estimations obtained in previous studies and adapt them to the context of the new study site. In this case, monetized values have been adjusted using the Purchase Power Parity (PPP) index provided by the OECD for values estimated abroad. For energy prices, national prices were taken, and if arrange of values were available, conservative values were selected, to avoid overestimation. The assessment follows the Guidelines for economic appraisal of investment projects published by the European Commission (Sartori et al., 2014). Reference values are summarized in the following Table 8.13:

**Table 8.13: Summary of socio-economic benefits estimated for SUDS scenario**

| Ecosystem Service | Estimate used | Volume | Unit Value | Total Value | Source |
|---|---|---|---|---|---|
| Air quality improvements ($CO_2$ and $NO_x$): | Value based on EU pollution tax: Negative effects of pollutants on health & environment | Emissions reduction= 0.072 t/ha | 3,051.4 €/t | 3,992 €/y | Feng, 2018; European Emissions Allowances |
| Habitat creation benefits | 15% of value of restoring land | Green roof (GR) area= 181,685 $m^2$ | 2.8 €/$m^2$ | 508,718 €/y | Bianchi et al, 2012 |

| | | | | | |
|---|---|---|---|---|---|
| Aesthetic benefits | Increase in property value | 14,534,788 € (CAPEX) | Assumption WTP= 3% (2-5%) of CAPEX | 436,044 €/y | Bianchi et al, 2012 |
| Energy reduction-cooling and heating benefit (reduction of urban heat island effect) | Reduction of energy demand, as GR regulate building temperature | Assumption 10% (10-14%) energy reduction from GR | 0.049 €/m$^2$/y | 10,770 €/y | Feng, 2018; Bianchi et al, 2012; IDEA (SECH project), 2011 |

In the assessment, it is assumed that SUDS measures are implemented gradually, with expected construction completion in 5 years, i.e. 2025. Benefits are allocated gradually as well. The life expectancy of SUDS has been assumed as 35, based on relevant literature (Feng, 2018).

### Risk and Impact Analysis

Regarding the **risk assessment**, SUDS are simulated in the 1D/2D urban drainage model using the Horton infiltration model. This is an approximate solution that can be considered acceptable for this first preliminary design phase. The idea is that SUDS increase hydrological losses (mostly continuous infiltration losses) and therefore are able to reduce stormwater runoff. The Horton model parameters were manually adjusted in order to reproduce the expected behaviour of green roofs, infiltration trenches and pervious pavements. Table 8.14 shows the parameters used to simulate the different SUDS. Permeable pavements generally have very high infiltration rates (up to 1,000 mm/h) and here it is assumed that the infiltration rates equals the maximum 5 minute rainfall intensity of a 10-year design storm event. In this way, all rain events smaller than a 10 year return period do not create stormwater runoff. Green roofs have the same initial infiltration rate as green areas. However the final infiltration rate is set to 0. The idea is that, once the roof is fully soaked, the runoff reduction capacity is insignificant. In this way, the green roofs generate a continuous loss of 15-20 mm during a 10 year design storm if the roof is initially dry. Infiltration rates of infiltration trenches were obtained by increasing the ones of green areas. These infiltration rates were adjusted in order to obtain 5-10 mm (equivalent to the storage volume of the proposed infiltration trenches) more continuous losses during a design event compared to green area losses. This is because infiltration trenches were designed for parks that are mostly green areas.

**Table 8.14: Horton parameters used for the different types of SUDS**

| Action | Initial infiltration | Final infiltration | Decay constant | Recovery constant |
|---|---|---|---|---|
| | mm/h | mm/h | $h^{-1}$ | $h^{-1}$ |
| Green areas (from baseline scenario) | 76 | 13 | 4.14 | 0.036 |

| | | | | |
|---|---|---|---|---|
| Permeable pavements | 169 | 169 | - | - |
| Green roofs | 76 | 0 | 4.14 | 0.036 |
| Infiltration trenches | 100 | 37 | 4.14 | 0.036 |

### 8.3.1.1.4 Early Warning System Measure

The Early Warning System (EWS) consists of a platform that receives and deliver information in real time. Figure 8.2 shows a conceptual model of the EWS. The platform is based on the tool AQUADVANCED that receives real time data from the drainage network sensors and rainfall forecasts. The sewer status and the rainfall forecasts are used to select the flood and CSO risk maps developed in the BINGO project. Finally, the platform can deliver flood and CSO warnings together with the information relative to actuation protocols. CAPEX and OPEX costs are shown in Cost Analysis. A summary of the expected costs of the EWS are available at Table 8.14, while more details are given in Table 8.15. These costs were internally estimated by the technical staff in AQUATEC. In this case, there are expected costs referred to the CSO framework, which are not accounted for in this flood framework.

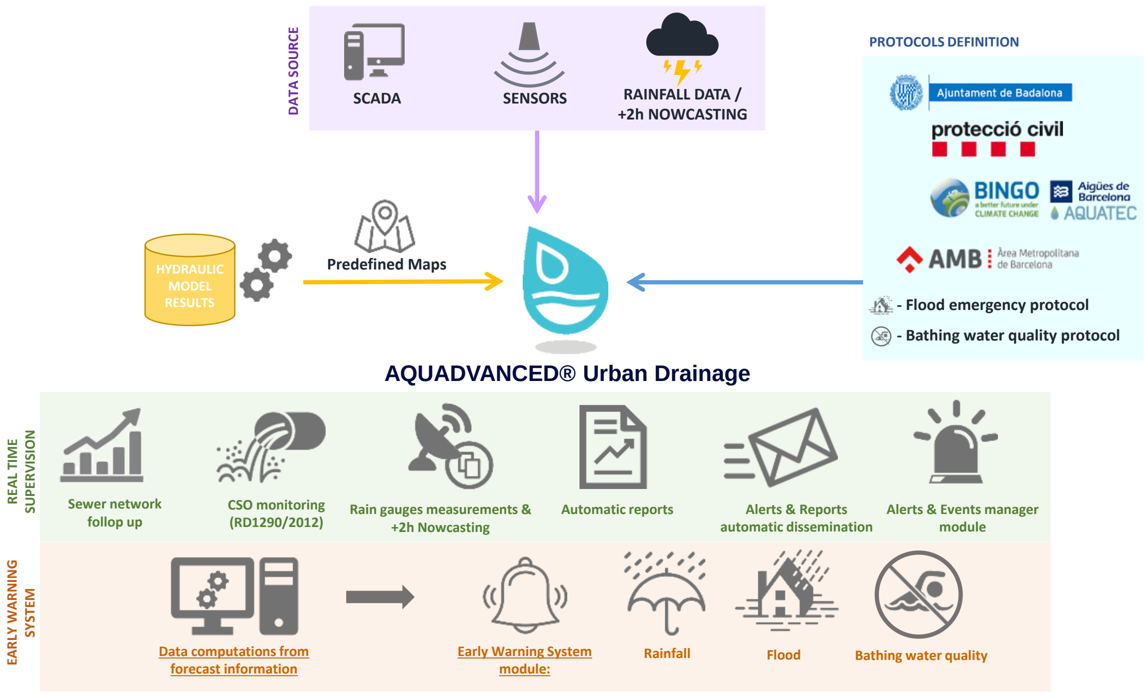



**Figure 8.2: Conceptual model of the EWS**

#### Cost Analysis

A summary of the expected costs of the EWS are available at Table 8.14, with more details are given in Table 8.15.These costs were internally estimated by the technical staff in AQUATEC. In this case, there are expected costs referred to the CSO framework, which are not accounted for in this flood framework.

**Table 8.15: Costs of the proposed EWS**

| | CAPEX (€) | OPEX (€/y) |
|---|---|---|
| Flood EWS | 160 400 | 71 000 |

**Table 8.16: Costs of the proposed EWS for both flood and CSO frameworks**

| Description | CAPEX (includes 1st year OPEX) | OPEX |
|---|---|---|
| **AQUADVANCED URBAN DRAINAGE EARLY WARNING** | **247 400.00 €** | **71 000.00 €** |
| **DEVELOPMENTS** | **64 000.00 €** | **-** |
| Activation & implementations new AQDV-UD EWS instance:<br>- Configuration of the IT infrastructure<br>- Implementation of the data import from a network remote control system (Normally SCADA)<br>- Implementation of the radar images data import | 30 000.00 € | |
| Visualisation maps | 25 000.00 € | |
| Connector between AQUADVANCED™ UD and the network's remote control data source | 6 000.00 € | |
| Connector between AQUADVANCED™ UD and the SMC system data source | 3 000.00 € | |
| **APLICATION SUPERVISION MODULE CONFIGURATION AND TEST** | **56 800.00 €** | **-** |
| Information / Documentation / Training:<br>- Network system information collection<br>- Documentation of the platform implementation<br>- Training (8h) | 10 000.00 € | |
| Level meter entity creation and configuration (15)<br>- Entity creation<br>- TAGs association<br>- Thresholds definition | 2 000.00 € | |
| Pumping Station entity creation and configuration (10)<br>- Entity creation<br>- TAGs association<br>- Thresholds definition<br>- Pumping cycles definition | 1 800.00 € | |
| Rain Gauge entity creation and configuration (4)<br>- Entity creation<br>- TAGs association | 1 000.00 € | |
| Rain model and rain classification definition and configuration<br>- Rain model definition and configuration<br>- Rain classification according to the Return Period | 2 000.00 € | |
| Alarms and Events configuration | 10 000.00 € | |
| Warning functionalities | 15 000.00 € | |
| Test | 15 000.00 € | |
| | | |
| **EW FLOODS MODULE** | **39 600.00 €** | **-** |
| Floods Early Warning Module configuration | 9 600.00 € | |
| Connector between AQUADVANCED™ UD and the pre-configured Flood Maps source<br>*Specific software licenses not included | 30 000.00 € | |
| | | |
| **SENSORS** | 34 000.00 € | 21 000.00 € |
| Recover 2 level meters from BINGO project | 1 000.00 € | |
| Recover 2 turbidimeter from BINGO project | 1 000.00 € | |
| Supply, installation and configuration of 1 new rain gauge | 6 000.00 € | |
| Supply, installation and configuration of 1 new level meter | 5 000.00 € | |
| Network sensors maintenance (Level meters & Turbidimeter & Rain gauges) | 21 000.00 € | 21 000.00 € |
| | | |
| **BATHING WATER QUALITY EARLY WARNING SYSTEM** | **3 000.00 €** | **-** |
| Bathing water quality predefined early warning configuration<br>- Based on previous studies | 3 000.00 € | |
| **QUOTATION** | **50 000.00 €** | **50 000.00 €** |
| Annual SaaS subscription AQDV-UD EWS | 20 000.00 € | 20 000.00 € |
| Radar data grid 20x20 and **+1h NOWCASTING** (Annual) | 5 000.00 € | 5 000.00 € |
| Platform functioning supervision | 15 000.00 € | 15 000.00 € |
| Technical Assistance to support event management and system analysis | 10 000.00 € | 10 000.00 € |

The EWS is simulated by modifying the vulnerability part of risk. This means that the hazards estimated are unchanged. The EWS is assumed to have an efficiency of 25%. In the EU project CORFU (http://www.corfu7.eu/) four different efficiency degrees were tested (25, 50, 75 and 100%) and here we only considered the 25% that is the most conservative one. A 25% efficiency means that one out of four vehicles and pedestrians would be able to avoid exposure. In the case of pedestrian, there is also an implicit reduction of susceptibility because less highly susceptible people (elders, foreigners, etc) would fall within dangerous flood areas. In the case of flood damage to buildings and vehicles the EWS is assumed to be able to (a) avoid damages to 25% of the vehicles and (b) reduce damage costs of 25% of the buildings. In the case of buildings it is assumed that only the costs of the movable and light assets can be reduced, and only on the first 50 cm from the floors. Therefore, the first 50 cm of the damage function were set to have zero assets damage costs. In this way, it is assumed that people would be able to move assets from the floor to a higher height in order to reduce flood damages to assets. However, flood water levels higher than 50 cm (after applying the sealing coefficients) would produce the same damage as in the baseline scenario. The other building damages: to structure and to furniture were not modified. Flood barriers were also not considered because they are generally not used in Badalona, therefore the sealing coefficient is not modified.

### 8.3.1.2. Damage assessment

The socio-economic assessment of the measures is built upon the calculation of expected annual damage to buildings and vehicles caused from floods for each of the scenarios. Damages included can be divided between direct tangible damages and indirect tangible damages. The former were presented in deliverables D4.2 and D4.3, while the latter is described in the following subsection.

#### 8.3.1.2.1 Indirect damage assessment method

While direct flood damage occurs due to the physical contact of objects with the flood water, indirect damage is induced by flooding, but may occur - in space or time - outside the actual event (Thieken et al., 2008). The focus of this study is on economic losses from the cascading effect of floods and business interruption that relate specifically to flooded business, which has been defined as primary indirect losses (Hammond et al., 2015).

The proposed methodology developed to assess indirect damages in the context of urban floods is the **input-output model**, which allows to estimate the ratio of indirect damage over direct damages across the different economic sectors of the affected area. It follows the one developed within the European project PEARL[16] (2017) with the same purpose, developed by Kowalewski (2009). It is particularly relevant for the present case study, as it was specifically developed to evaluate indirect economic damage from flood events at a regional scale, although it has been fine-tuned to the county scale and adapted to the requirements of this case study.

The input-output method is commonly used to estimate short-term impacts (Balbi et al., 2013; Ranger, 2011), because it is relatively uncomplex compared to general equilibrium models. On the other hand, they feature several restrictive assumptions. Nevertheless, taking into account data availability and uncertainty, the input-output method offered the most effective solution to reach the indirect damage estimation objective.

The data sources are the IO table for Catalonia (the latest published is for 2014) together with employment figures categorised by economic sector for Catalonia and Barcelonès County (*Idescat*, 2019), and the historical data of claims paid by the Spanish reinsurance company (CCS). The IO table is a matrix that registers the use of factors of production by each economic sector in the production of the goods and services of a certain economy. From the Catalonian IO tables, downscaling to county-level is based on simple rules relative to the size of employment in each sector in this county. Drawing on Leontief's production functions – cross-sectorial interdependencies of intermediate goods and final demand – the model interprets the data recorded in the table and assess the economic consequences of external shocks to the system (e.g. resulting from flood events). The final input-output account then captures the supply and demand interactions of the economic sectors downscaled to sub-regional level[17].

As a novelty, this version considers the IO tables of Catalonia as baseline, downscaling to county level – Barcelonès – compared to the previous work, which uses national tables as baseline and downscale to the regional level.

An exogenous shock is then introduced, obtained from the paid claims of CCS historical data. For Badalona 41 cases registered were included. This dataset is previously re-

[16] Preparing for Extreme And Rare events in coastal regions, European Union 7th Framework Programme, 2014-2018

[17] For more information on the mathematical modelling of the I/O model, see https://www.econstor.eu/handle/10419/48249

classified by economic sectors: from 4 types of land uses (industry, offices, retail and vehicles) to 10 types of economic sectors used in the IO tables. From the interdependencies of sectors, the model is able to simulate how damages spread across the economy, which is interpreted as indirect damages.

| Date of event | Risk type | Compensation € |
|---|---|---|
| 24/01/1996 | Industrial | 9,174.83 |
| 19/01/1996 | Industrial | 300,506.05 |
| 17/04/1996 | Industrial | 79,736.24 |
| 17/04/1996 | Retail | 2,562.81 |
| 06/05/1996 | Industrial | 775.24 |
| 02/06/1996 | Retail | 2,481.98 |
| 07/08/1996 | Office | 2,074.48 |
| 02/09/1996 | Vehicles | 279.54 |
| 02/09/1996 | Vehicles | 1,638.03 |
| 02/09/1996 | Vehicles | 782.21 |
| 02/09/1996 | Vehicles | 370.78 |
| 02/09/1996 | Vehicles | 2,630.50 |
| 02/09/1996 | Vehicles | 657.41 |
| 07/08/1996 | Retail | 902.67 |
| 02/09/1996 | Vehicles | 270.17 |

| | Agriculture | Manufacturing | Construction | Retailing | Information | Financial | Real Estate | Prof activities | Public admin | Artistic |
|---|---|---|---|---|---|---|---|---|---|---|
| INDUSTRY | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| REATILERS | 0.01 | 0.1 | 0.05 | 0.6 | 0.03 | 0.03 | 0.01 | 0.1 | 0.02 | 0.05 |
| VEHICLES | 0.01 | 0.1 | 0.05 | 0.5 | 0.05 | 0.03 | 0.01 | 0.1 | 0.1 | 0.05 |
| OFFICES | 0 | 0.05 | 0.05 | 0.15 | 0.1 | 0.05 | 0.05 | 0.2 | 0.25 | 0.1 |
| Employment per sector in Barcelonès | 1% | 12% | 5% | 26% | 6% | 4% | 1% | 13% | 24% | 10% |

**Figure 8.3: Example of CCS data format and transformation matrix to match I/O table distribution**

This allows to elicit an average ratio of indirect to direct damages, in order to obtain the ratio to estimate this relationship for any direct damage quantity that occurs in Badalona.

Finally, the results are applied to the direct damages to obtain the total EAD under all proposed scenarios.

### 8.3.2 CSO framework

The CSO framework entails the analysis of the current situation of Badalona regarding the CSO events occurrence and the analysis of the measures proposed to reduce them. The selected adaptation measures are similar to the ones proposed in the flood framework, although they focus on decreasing the CSO volume discharged to the marine ecosystem. A summary of the measures is presented in Table 8.17.

**Table 8.17: Summary of CSO measures**

| Scenario ID | Measure | Type | Description |
|---|---|---|---|
| M0 | Baseline/ BAU | - | Baseline (or BAU since we assume that future rainfall from decadal predictions is similar in this CSO framework) is the do-nothing scenario under present rainfall conditions. Business |
| M1 | Detention tanks | Structural | 10 CSO detention tanks with a total volume of 82.000 $m^3$. |
| M2 | Green roofs | Sustainable Urban Drainage Systems (SUDS) | Implement **extensive** green roofs in 5% of Badalona's roof area. |
| | Permeable Pavement | | 8 parks and public squares have been identified to implement permeable pavement. |
| | Infiltration Trenches | | Infiltration trenches in 5 parks, with a total permeable surface close to 20 hectares. |
| M3 | Early Warning System (EWS) | Non-structural | Development and implementation of EWS to support prevention of CSO spills consequences. |

In order to avoid duplications with the flood framework, only the different items of the measures are detailed in this section.

For the CSO framework, these four scenarios were simulated using the integrated urban drainage-sea water quality model and the following **indicators** were included to evaluate the capacity of the adaptation measures to reduce risks and impacts:

- Total annual CSO volume discharged into the sea (impact)
- Bathing season time with insufficient bathing water quality (risk)
- Number of red flag days (prohibited bathing) at the beaches (risk)
- Volume of combined sewer to be treated by the Waste Water Treatment Plant (impact)

The reduction of red flag days could only be estimated for structural measures and SUDS, as it is unknown how EWS could improve the actual bathing water quality protocol that is currently applied to avoid people bathing during the periods of insufficient bathing water quality following CSO events. Therefore, it has not been included in the CBA.

Only present rainfall conditions was simulated since the decadal predictions would not show significant rainfall changes in the coming years.

Continuous simulations of 9 consecutive bathing seasons (considered from 1st of June to 1st of September) from 2006 to 2015 were performed for the different scenarios.

Moreover, a **qualitative assessment of the intangible damages** was carried out to understand the perception and impacts of the citizens regarding CSO events and their consequences. Based on surveys to beach users and personal interviews to coastal business owners, the results provide a qualitative perspective to the results.

#### 8.3.2.1. Adaptation Measures Scenarios

##### 8.3.1.1.1 Baseline scenario

Baseline scenario was estimated using the indicators listed in the previous section. As no adaptation measures are considered in this scenario, we assume that there are not expected costs nor benefits. Only the damages to welfare and the environment are considered.

##### 8.3.1.1.2 Structural measures

The structural measures to reduce CSOs, proposed in the Master Drainage Plan of Badalona, include 10 new deposits located close to the CSO points were proposed.

###### Risk and impacts analysis

The number of red flag days per bathing season for structural measures and for SUDS was obtained by applying the “Percentage of bathing season time with insufficient bathing water quality” to the observed 5.3 red flag days of the baseline/BAU scenario. This is because a model to estimate red flag days based on actual actuation protocols was not developed.

###### Cost analysis

Table 8.18 shows the volume and investment costs of the deposits. The OPEX costs are estimated based on the total retention tank surface. Costs per unit of surface of the tank are, in this case, considered to be more appropriate than costs per unit of volume. Assuming that the average height of the detention basins is 5 m the total surface are of the tanks would be 16,400 $m^2$ (82,000$m^3$/5m). The cost per square meter is assumed to be equal to the Estrella deposit, with annual costs of approximately 24 €/$m^2$/y (60,000€/y divided by 2,500m²). The total estimated OPEX of the 10 retention deposits for CSO reduction is 393,600 €/y (16,400 m² * 24 €/m²).

| | CAPEX (€) | OPEX (€/y) |
|---|---|---|
| Structural measure | 45,265,355 | 393 600 |

**Table 8.18: Detail of location of retention deposits, DSU discharge points, volume and budget**

| Dipòsit | Punts DSU | $V_{dip}$ ($m^3$) | Pressupost (€) |
|---|---|---|---|
| La Mora 1 | 1 | 18.000 | 8.877.405 |
| La Mora 2 | 2,3 | 1.000 | 879.160 |
| El Coco | 4,5,6 | 13.500 | 7.052.370 |
| Pont del Petroli | 8,9 | 10.400 | 5.723.935 |
| Estació Renfe | 11,12 | 9.600 | 5.368.896 |
| Prim | 14 | 6.800 | 4.074.508 |
| Botifarreta | 15,16 | 2.650 | 1.917.188 |
| Riera Canyadó | 17 | 13.200 | 6.926.713 |
| Torrent Vallmajor | 18,19 | 6.200 | 3.784.264 |
| Velázquez | 21 | 700 | 660.916 |
| Total | | **82.050** | **45.265.355** |

For all measures, the maintenance costs considered are from the higher side of the available reference cost, as the life expectancy of the measures depends on the optimal maintenance. Re-investments are assumed to be 50% of the CAPEX after the life expectancy- 60 years.

### 8.3.1.1.3 SUDS

The measures proposed within the SUDS scenario are similar to the ones analysed in the flood framework. The methodology for the risk analysis was presented in deliverable D4.3.

### 8.3.2.2. Damage Assessment

The damage assessment in the CSO framework focuses on indirect damages. The methodology for the direct damage that estimates the cost of life has not been considered, as it is uncertain that CSO events threatens life. Whereas the indirect impacts assessment, for both tangible and intangible damage is presented in the following paragraphs.

### 8.3.1.1.4 Indirect Tangible Damage Assessment

The indirect tangible damages assessed under the CSO framework consist of the monetization of the environmental damage and the reduction of welfare level of affected citizens. These values are used for the estimation of benefits derived from the avoided costs.

The calculation of the environmental damage uses the annual volume of CSO under the different scenarios to evaluate the impact. The monetary value of environmental damage to the marine ecosystem was obtained from a similar study carried out in Barcelona, which estimated the cost of cleaning sewer water discharged into the sea at 1.8 Euros/$m^3$ (*Ex-post evaluation of cohesion policy interventions 2000-2006,* EC, 2010). Price adjustment has been done, using the GDP ratio between Barcelona and Badalona, obtaining a value of 0.78 Euros/$m^3$.

The estimation of welfare loss is based on the assumption that red flags (that forbid bathing) impacts negatively beach users. Built upon the travel cost method for non-market valuation (OECD, 2018), the value assumed to reflect people's welfare loss is to be the actual expenditure per day of visit to the beach. Actual travel expenditure is not considered, as the majority of users are from Badalona and the travel cost incurred are insignificant. The **estimated an average expenditure of 2.94 Euros/day per visitor,** obtained from an official survey carried out for the Badalona City Council (2012). The number of visitors was obtained from the official Metropolitan Agency (AMB, 2016) and estimated at **10,253 visitors per day of bathing season**. The estimated number of red flags due to CSO spills is the indicator used to understand the difference between scenarios.

##### 8.3.1.1.5 Indirect Intangible Damage Assessment

The aim of this impact assessment is to provide a qualitative evaluation of the perceived health risk of bathers and potential loss of reputation of the City Council caused by CSO events. Decision-makers and stakeholders might be interested in understanding the perception of affected users upon these events in order to take relevant measures to enhance awareness programmes or measures to reduce overflows.

The model uses primary data, obtained from telephone surveys collected amongst Barcelona beachgoers and in-person interviews with business owners of the relevant area for the current purpose. The geographical scope of the sample has been limited to the bathing areas where there are discharge points, which in the case of Badalona affects practically the totality of beaches. Only respondents who mentioned that visited one of the affected beaches were invited to continue in the survey. Similarly, the personal interviews were carried out in businesses located in affected areas.

A previous desk research was carried out to understand the informative methods to communicate beach closure events related to CSOs. Additionally, prior analysis of discharge points and number of events was completed, with information available from the CSO direct impact assessment of this report.

The telephone survey consisted in a 10-item questionnaire administered to 100 randomly selected individuals from a Barcelona-based database. The first part of the questionnaire focus on securing a representative sample. The second part assessed the behaviour, e.g. reasons for visiting, and the third section measured awareness and perception on the CSO events. Telephone survey method was selected because carry out on-site surveys off bathing season was not realistic.

The qualitative interviews assessed the awareness of the business owners about CSO; whether and how the spills affected them; finally the questions were oriented to understand the opinion they have upon the City Council's management of CSO spills. They were carried out to two owners of restaurants, one owner of nautical sports, and one representative of the fishermen union.

Analysis of the results was performed using standard qualitative and quantitative survey tools and related literature.

### *8.3.3 Cost-Benefit-Analysis: methodology and assumptions*

CBA is a widely spread and accepted assessment method that allows the possibility to translate social and environmental impacts into monetary values, in order to consider together with the financial expenditure of a project. In the context of climate change adaptation, it is well suited to assess present and future options, where market and non-market values can be used, and it is understood by all stakeholders.

The **time horizon** selected for the analysis is from **2020-2100** (80 years period), consistent with the damage assessment horizon for the case study of Badalona.

Consolidated **financial cost** assessment has been conducted from the viewpoint of the required investment efforts of Badalona City Council, as well as the operating costs for the life cycle of the analysis. Initial investments are included gradually in a linear trend, following the assumptions of implementation times (20 years for structural measures, 5 for SUDS and 2 for EWS).

**Benefits** are assessed using the **avoided cost method**. This approach consists in **estimating the difference between the damages in the baseline scenario and in**

**each of the alternatives**. In the Flood context, EAD is used as the damage indicator, while in the CSO context, environmental and welfare damage estimations are the indicator proposed. Similar to the procedure of initial investment costs, expected damage reductions follow the implementation time assumptions, in a linear trend until the complete implementation year.

Additionally, for the **SUDS scenarios, ecosystem services benefits are included** in both frameworks. These are the benefits that humans obtain from ecosystems, and in this case study those estimated from the green roofs and additional green areas are regulating (air quality and temperature control), supporting (habitat creation), and cultural (aesthetic). Changes on the environmental variables are estimated using market prices for the items that have them (e.g. electricity consumption), and also non-market prices for those items that do not have a market for trade (e.g. water pollution). For non-market prices, **benefit transfer method** has been applied, using reference studies and adapting the values in economic and size terms.

**Net benefits** aggregates benefits and costs to determine the complete impact of the scenarios (*j*) proposed.

$$\textbf{Net benefit}_j = \textbf{Benefits}_j - \textbf{Costs}_j$$

The next step is to bring these values, expected through the time horizon of the study, to the present. Hence Net Present Value (NPV), associated to each scenario *j*, is the result of relevant costs and benefits that incurred along the **study period** (years from t=1 to T=80), discounted at the rate *i* (1.23%):

$$NPV_j = \sum_{t=1}^{T} \frac{Benefits_{j,t} - Costs_{j,t}}{(1+i)^t}$$

The **discount rate** applied has been set equal to 1.23%, according to the rate set by the European project EconAdapt (2015), specifically for the region of Catalonia, which is the conservative rate for the economic growth scenario. Due to the large period of study, the selected rate matches the equivalency principle, and follows a precautionary approach, normally applied in long term economic analysis.

Alternatively, as investments associated to the measures are generally incurred at the beginning of the study period, while its benefits are spread over the life cycle, it is more relevant to analyse the results in terms of the **Annual Equivalent Present Value (AEPV)**. The discount factor can be applied to annualize costs and quantify them taking into account the expected life time of the solutions applied in scenarios under assessment. To do so, analysis has been carried out according with the following formula:

$$AEPV_j = \frac{PV_j}{A_{(t,i)}}$$

Where $\boldsymbol{A}_{(\boldsymbol{t},\boldsymbol{i})} = \frac{1-\frac{1}{(1+i)^T}}{i} = \frac{1-(1+i)^{-T}}{i}$ is present value (PV) annuity factor; ***t*** is time horizon, and ***i*** is discount rate

By applying this formula, it is possible to estimate the expected annual equivalent net benefit of the different scenarios, according to the estimated damages and investment costs.

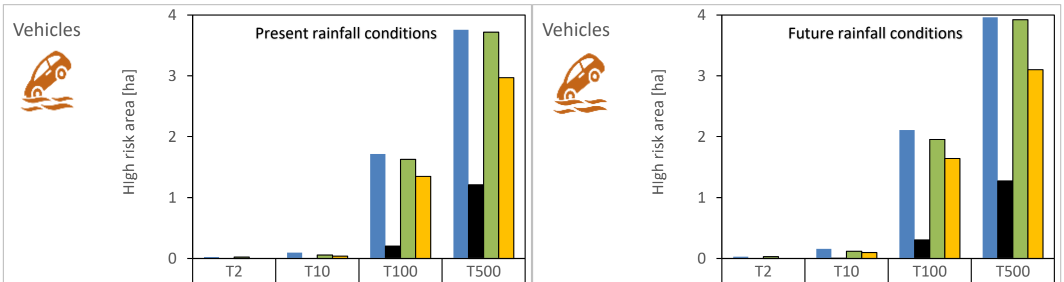
## 8.4. Assessment Results and Discussion

Following the previous structure, results are presented in two differentiated frameworks, floods and CSO. For each context, the results of the risks and CBA assessment are included.

### *8.4.1 Flood Framework*

#### 8.4.1.1. Risk and Damage Analysis Results

Figure 8.4 shows the total high risk area for vehicles in Badalona as a function of the different adaptation measures and for both present and future rainfalls. The results show a low vehicle high risk area for episodes up to 10-year return period and up to 4 ha of high risk area for 500-year return period rainfalls. Overall, the structural measures are the ones reducing the most the flood risk for vehicles, then the EWS and finally the SUDS. Future rainfall condition (Figure 8.4 right) increases the total vehicle high risk areas.

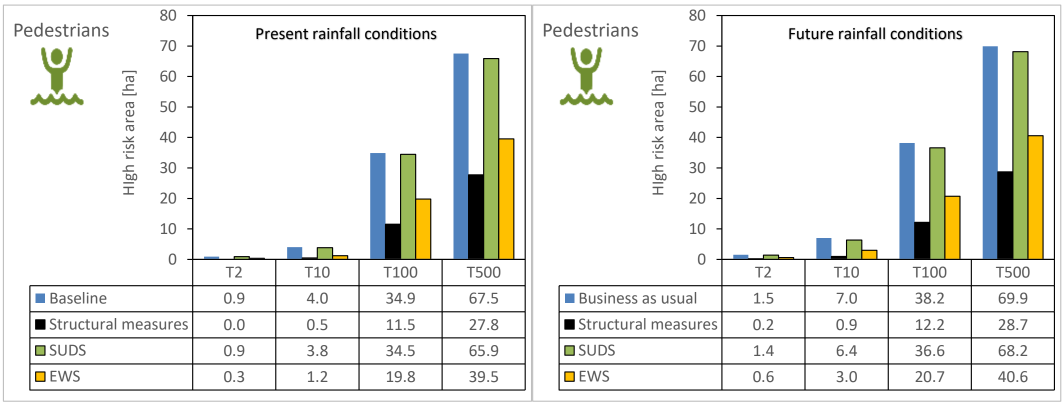



| | T2 | T10 | T100 | T500 |
|---|---|---|---|---|
| Baseline | 0.0 | 0.1 | 1.7 | 3.8 |
| Structural measures | 0.0 | 0.0 | 0.2 | 1.2 |
| SUDS | 0.0 | 0.1 | 1.6 | 3.7 |
| EWS | 0.0 | 0.0 | 1.4 | 3.0 |

| | T2 | T10 | T100 | T500 |
|---|---|---|---|---|
| Business as usual | 0.0 | 0.2 | 2.1 | 4.0 |
| Structural measures | 0.0 | 0.0 | 0.3 | 1.3 |
| SUDS | 0.0 | 0.1 | 2.0 | 3.9 |
| EWS | 0.0 | 0.1 | 1.6 | 3.1 |

**Figure 8.4: Vehicles high risk area for the different adaptation scenarios. (left) Present rainfall and (right) future rainfall conditions.**

Figure 8.5 shows the total high risk area for pedestrians in Badalona as a function of the different adaptation measures. In this case only the urban high risk area are accounted, e.g. the high risk pedestrian areas the forest areas (e.g. Serralada la Marina) are not included. Overall, the structural measures are the ones reducing the most the flood risk for pedestrians, then the EWS and finally the SUDS. In the case of pedestrians, the EWS reduces more the high risk pedestrian area compared to the case is vehicles. This is because in the case of vehicles only exposure was reduced by 25%, whereas in the case of pedestrian also susceptibility is reduced due an implicit reduction of susceptibility because less highly susceptible people (elders, foreigners, etc) would fall within dangerous flood areas. Future rainfall condition (Figure 8.5 right) increases the total vehicle high risk areas.

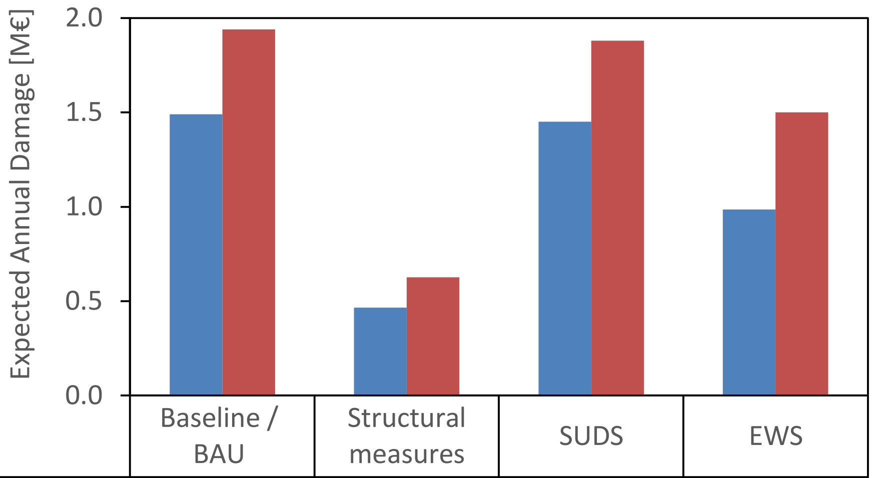



| | T2 | T10 | T100 | T500 |
|---|---|---|---|---|
| Baseline | 0.9 | 4.0 | 34.9 | 67.5 |
| Structural measures | 0.0 | 0.5 | 11.5 | 27.8 |
| SUDS | 0.9 | 3.8 | 34.5 | 65.9 |
| EWS | 0.3 | 1.2 | 19.8 | 39.5 |

| | T2 | T10 | T100 | T500 |
|---|---|---|---|---|
| Business as usual | 1.5 | 7.0 | 38.2 | 69.9 |
| Structural measures | 0.2 | 0.9 | 12.2 | 28.7 |
| SUDS | 1.4 | 6.4 | 36.6 | 68.2 |
| EWS | 0.6 | 3.0 | 20.7 | 40.6 |

**Figure 8.5: Pedestrian high risk area for the different adaptation scenarios (left: present rainfall and right: future rainfall conditions)**

Figure 8.6 shows the Expected Annual Damage as a function of the 4 different adaptation measures and for both present and future rainfalls. Overall, the structural measures are the ones reducing the most the EAD, then the EWS and finally the SUDS. Also, the EAD of the baseline scenario is approximately 1.5 M€ and of the BAU scenario (with future rainfall) is 1.9 M€. This means that tangible flood damages will increase by 30% due to future (RCP 8.5) rainfalls.




| | Baseline / BAU | Structural measures | SUDS | EWS |
|---|---|---|---|---|
| Present Rainfall | 1.5 | 0.5 | 1.5 | 1.0 |
| Future rainfall | 1.9 | 0.6 | 1.9 | 1.5 |

**Figure 8.6: EAD for the adaptation scenarios under both present and future (RCP 8.5) rainfall conditions. EAD includes direct and indirect damages**

Overall, the structural measures are the ones reducing the most the pedestrian and vehicle risks and the flood EAD (monetized damages to building and vehicles), then the EWS and finally the SUDS. Structural measures are very effective because they were designed to avoid floods in Badalona for a 10 year design storm (in this case a 10 year event including a 1.07 climate factor). Instead, SUDS were only located at few selected spots where they could potentially and realistically be implemented. Furthermore, the implementation costs of the SUDS measures are lower than the structural measures because they were not designed to reduce all floods for a 10-years design storms.

The conclusions of the above analysis for the different adaptation measures are similar for present and future rainfall scenarios. Simulating both present and future rainfall scenarios provided more robustness to the conclusions of this study and the related uncertainties associated with future rainfall scenarios.

### 8.4.1.2. Indirect Damage Analysis Results

The application of the Input/Output Method yields an estimation of indirect damages percentage over the expected direct damages. For the Badalona Case Study, the results obtained are the following:

**Indirect Damages = 0.32 * Direct Damages**

**Range [0.26 - 0.44]**

As stated above, this ratio has been included in the total EAD estimation, after adding up the sectorial impacts for each return period (T2, T10, T100 and T500). The sectorial distribution of the direct impacts, used for the estimation of the indirect damages, provides results in the form a range of values. For the EAD estimation, the average value has been used.

The results have been contrasted with relevant indirect damage studies, obtaining positive results. Carrera et al. (2013) obtained results in the range of 0.19- 0.22 for indirect damages in an Italian case study, while Hallegate et al (2008) presented results in the range of 0.13-0.44 for a case study in the USA. The validation with real data has been proved difficult since insurance figures only show the accepted claims for businesses that have contracted the premium cover for business closure due to a weather event, which is a very limited number.

### 8.4.1.3. Cost-Benefit Analysis Results – flood framework

Results of the CBA under present rainfall conditions are in Figure 8.7, presented in annual-equivalent present values (AEPV). The figure provides a complete overview of financial, economic and risks assessment results. First, the EAD indicator allows to easily see the variations in terms of damage, whereas the costs provides the financial overview. Benefits bars reflect the combination of avoided damages and ecosystem services, while the net benefits illustrate the final results of each scenario considering all variables.

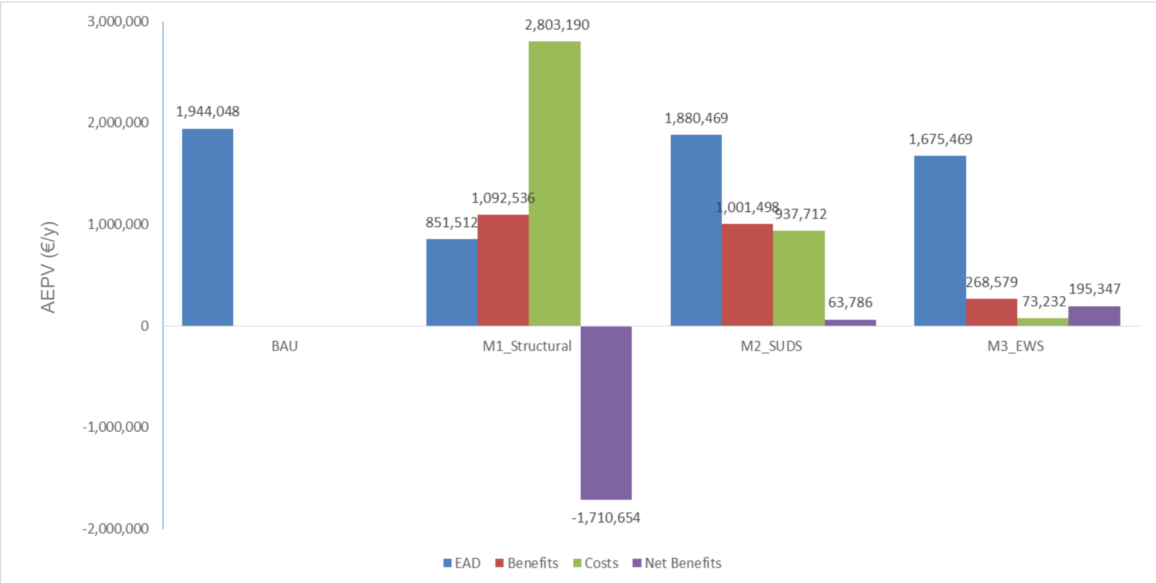



**Figure 8.7: Results CBA for floods framework under future rainfall conditions. Annual Equivalent Present Value (Euros/year)**

The bar chart shows the disadvantage of structural measure scenario (net benefits, purple bar). The high costs (green bar) do not compensate the benefits (red bar) from avoided damage, despite they are the highest of all scenarios, because structural measures are able to reduce the most flood damages (blue bar). The SUDS measures present small reduction of damage, although the large socio-economic benefits derived from improvements in the ecosystem services, and costs are approximately one third of the structural measures ones. Finally, the scenario with EWS presents a moderate reduction of expected damages, and the lowest costs amongst all scenarios. Hence, they have the highest net benefits of the scenarios presented.

The analysis under present rainfall conditions provide similar comparative results, although with a 30% less expected damages, as can be observed in Table 8.19.

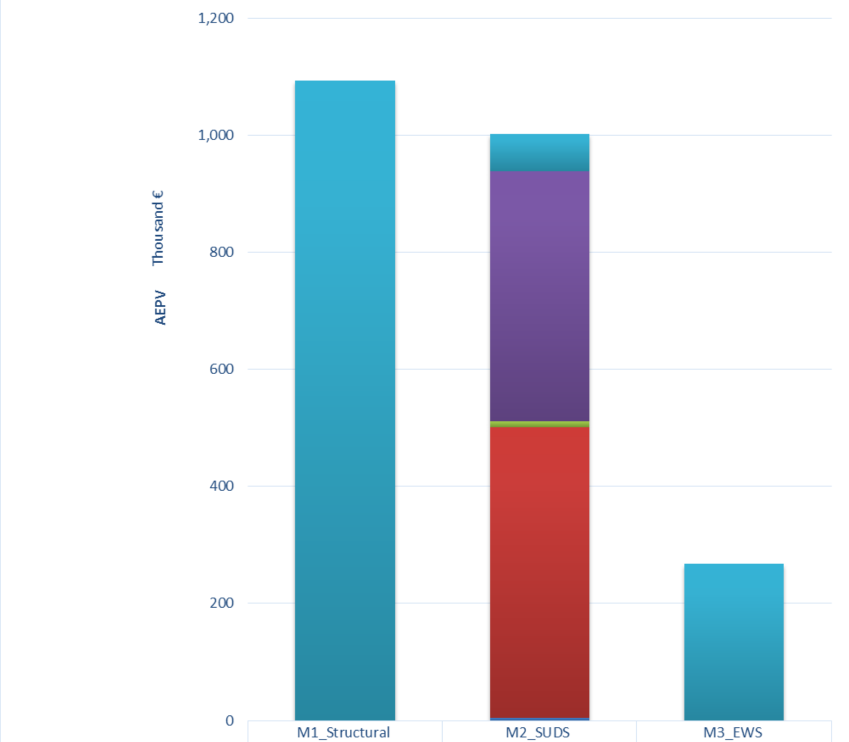
**Table 8.19 Summary of CBA NPV results for PRC and FRC**

| Adaptation Scenario | Climate Scenario | Baseline/BAU [€] | M1_Structural [€] | M2_SUDS [€] | M3_EWS [€] |
|---|---|---|---|---|---|
| EAD | FRC | 98,614,832 | 40,701,814 | 95,389,707 | 76,217,460 |
| | PRC | 75,766,995 | 30,647,391 | 73,639,995 | 50,008,508 |
| Benefits | FRC | | 57,913,019 | 52,254,902 | 22,397,372 |
| | PRC | | 45,119,604 | 51,156,777 | 25,758,486 |
| Costs | FRC | | 142,196,160 | 47,566,921 | 3,734,311 |
| | PRC | | 142,196,160 | 47,566,921 | 3,780,243 |
| Net Benefits | FRC | | -53,440,292 | 4,687,982 | 18,663,062 |
| | PRC | | -66,233,706 | 3,589,856 | 22,024,176 |

In addition, results are presented in terms of NPV for each proposed measures scenario under both rainfall conditions (PRC and FRC) in Figure 8.8.


**Figure 8.8: Results of CBA. NPV for the three scenarios under both rainfall conditions (Euros)**

Finally, the breakdown of the estimated benefits is available in Figure 8.9, which illustrates the source of benefits from each scenario.




| | M1_Structural | M2_SUDS | M3_EWS |
|---|---|---|---|
| Benefits - EAD change | 1,092,536 | 63,579 | 268,579 |
| Benefits - Aesthetic | | 426,226 | |
| Benefits - UHI effect | | 10,528 | |
| Benefits - Habitat creation | | 497,264 | |
| Benefits - Air Q improvements | | 3,902 | |

**Figure 8.9: Benefit sources for the three adaptation scenarios**

Structural and EWS are composed only from expected avoided damage, while SUDS benefits are dominated by benefits from ecosystem services improvements.

### *8.4.2 CSO Framework*

#### 8.4.2.1. Risk and Damages Analysis Results

**Table 8.20** shows the result of the risk and impact indicators analysed for the scenarios of the CSO framework. Results are presented in absolute terms and percentage variation with respect to baseline.

**Table 8.20: Risks and impacts from CSO as a function of the different adaptation measures.**

| | Unit | Baseline (=BAU) | Structural measures | SUDS | EWS |
|---|---|---|---|---|---|
| Mean time duration of insufficient bathing water quality | days | 3.3 | 1.5 | 3.1 | =BAU |
| Percentage of bathing season time with insufficient bathing water quality | % | 3.6 | 1.6 | 3.3 | =BAU |
| Mean number of sea water pollution events | - | 5.1 | 2.4 | 5.0 | =BAU |
| Red flag day per bathing season (Jun 1st- Sep 1st) | days | 5.3 ** | 2.4 | 5.0 | not estimated |
| Annual CSO volume from wet weather periods *** | $m^3$/year | 1 612 832 | 871 857 | 1 556 219 | =BAU |
| Reduction of annual wet weather CSO volume | % | | 46 | 4 | 0 |
| Annual volume to WWTP* | m3/year | | +740 975 | -10 496 | =BAU |
| * From simulation of 2006 and 2007 summer seasons and then annual extrapolation<br>** Based on observed red flag days due to rain and CSO events during the bathing seasons of 2015, 2016 and 2017<br>*** Simple linear annual extrapolation of bathing season results | | | | | |

The results show that structural measures are the most effective reducing the percentage of time with insufficient bathing water quality (from 3.6% to 1.6%) during bathing season and the annual CSO volume (from 1,612,832 $m^3$/y to 871,857 $m^3$/y). However, they significantly increase the volume to be treated and pumped to the WWTP. The EWS does not reduce any of the analysed indicators, however it is expected to reduce the risk of red flag days per bathing season, although it was not calculated due to the lack of a model that can measure how the EWS can bring efficiency to the existing bathing water quality protocol. The SUDS slightly reduce the percentage of bathing season time with insufficient bathing water quality, the red flag days, the annual CSO volume and the volume sent to the WWTP. In this case the structural measures were explicitly designed to reduce CSO whereas SUDS no. Also, much higher investment costs are allocated for SUDS compared to structural measures.

##### 8.3.4.2.1 Indirect Damages Results

The estimated environmental damage unit cost of discharges estimated is **0.78 EUR/$m^3$**. The results for the expected discharge volumes under each scenario are presented in Table 8.21.

**Table 8.21: Results of estimated environmental damages for CSO framework**

| Scenario | Annual CSO Volume | Estimated Annual Costs |
|---|---|---|
| Baseline | 1,612,832 $m^3$/y | **1,262,216 €/y** |
| Structural | 871,857 $m^3$/y | **682,322 €/y** |
| SUDS | 1,556,219 $m^3$/y | **1,217,910 €/y** |

The estimated daily welfare loss of a red flag (bathing forbidden) is of 30,144 €/day. The results for the expected red flag days under each scenario are presented in Table 8.22.

**Table 8.22: Results of estimated welfare loss for CSO framework**

| Scenario | Annual number of red flag days | Estimated Annual Costs |
|---|---|---|
| Baseline | 5.3 days | **159,764 €/y** |
| Structural | 2.4 days | **72,346 €/y** |
| SUDS | 5 days | **150,721 €/y** |

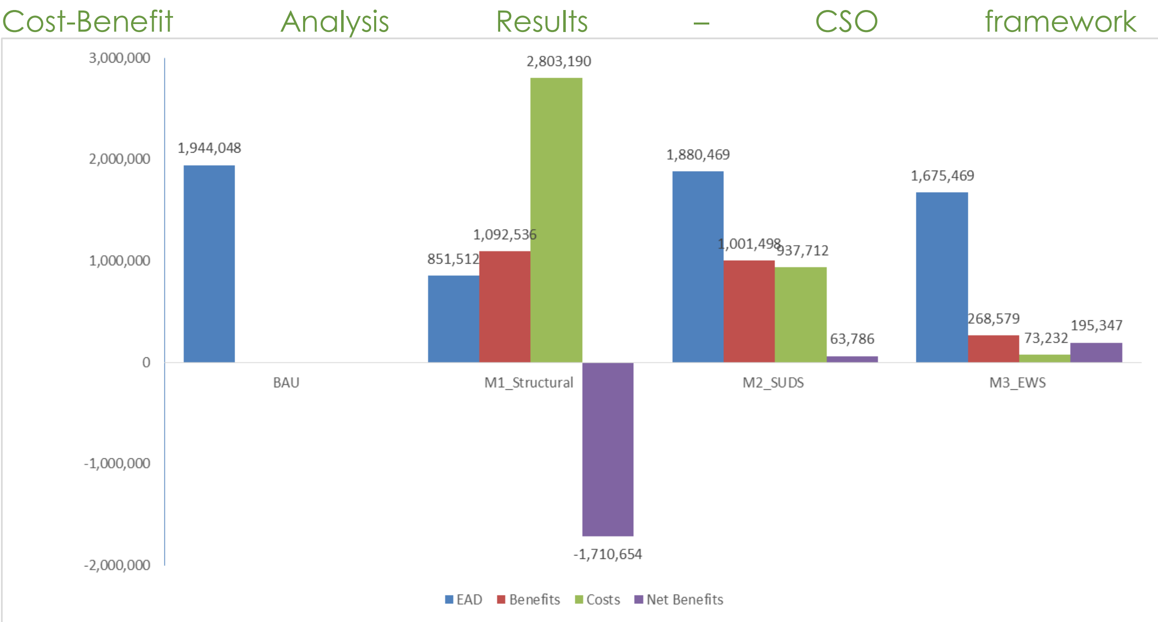



**Figure 8.7: Results CBA for floods framework under future rainfall conditions. Annual Equivalent Present Value (Euros/year)**

Results of the CBA for the CSO framework are in presented in annual-equivalent present values (AEPV). The figure provides a complete overview of financial, economic and risks assessment results, as it includes the damages indicator, costs and net benefits, to illustrate the final results of the scenarios considering all variables.

The results show an advantage on net benefits of SUDS over structural measures. Although investment costs are lower in this framework, structural measures still do not compensate the reduction of estimated damage. In the case of SUDS measures, the reduction of damages is lower compared to the expected for structural measures, but the benefits almost double, whereas the annualized costs are similar for both alternatives.

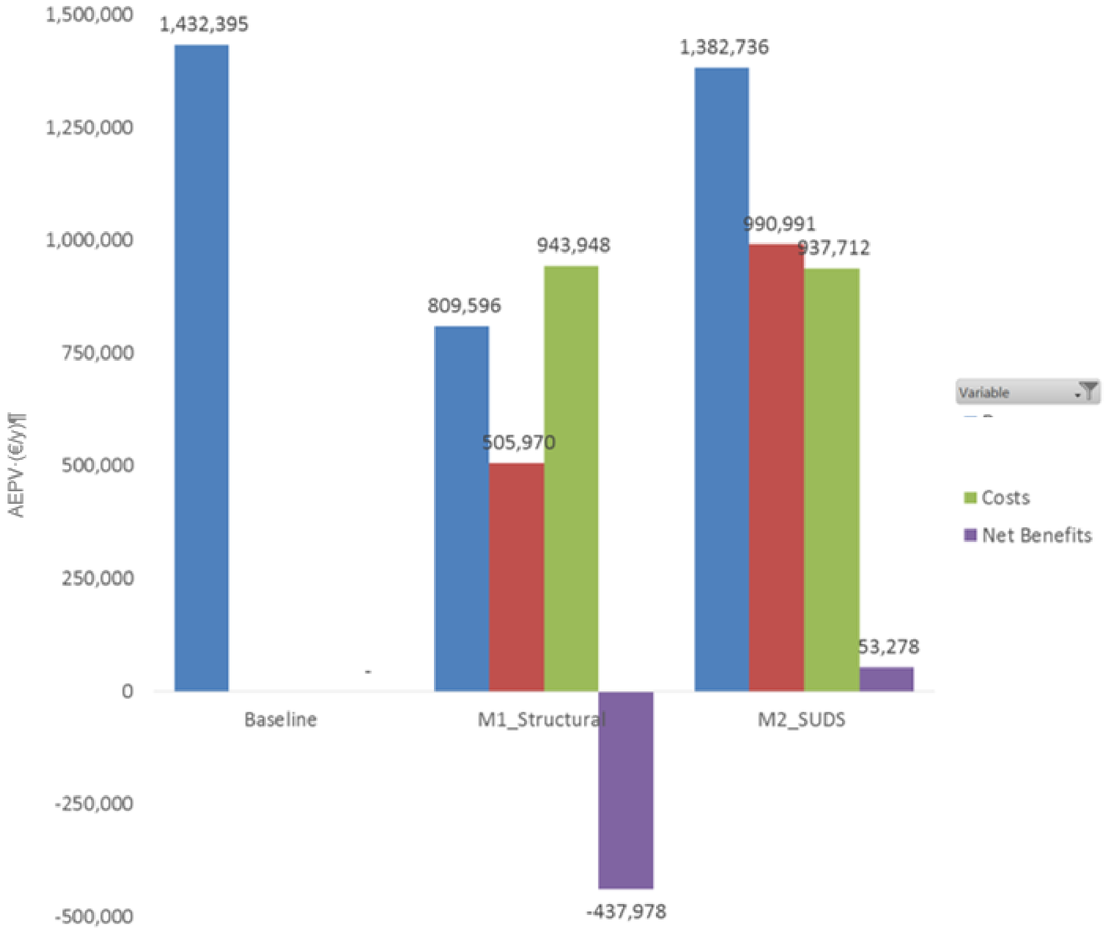
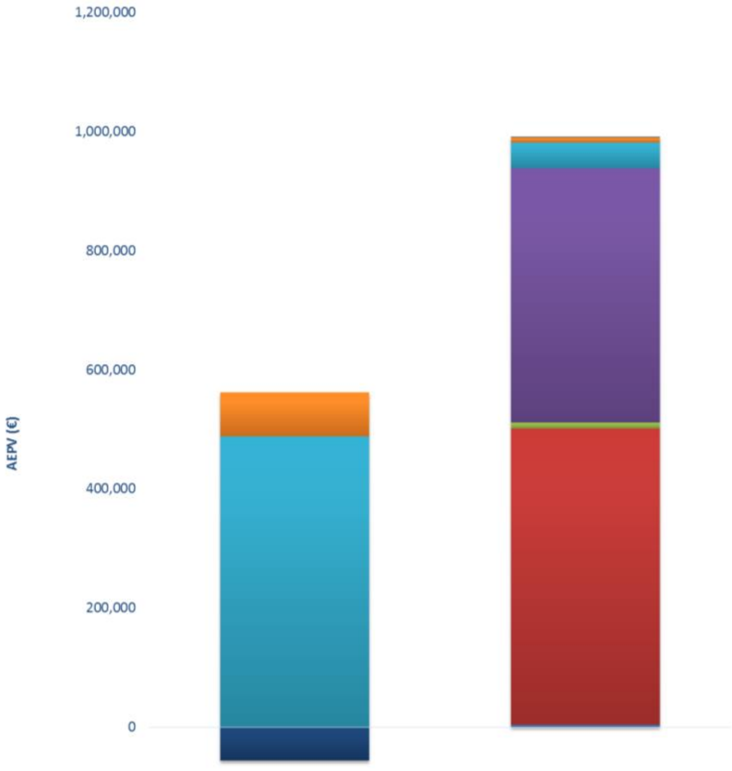



**Figure 8.10: CBA for CSO framework (AEPV)**


**Figure 8.11: Results CBA for floods framework under future rainfall conditions. Annual Equivalent Present Value (Euros/year)**




| | M1_Structural | M2_SUDS |
|---|---|---|
| Benefits - WWTP costs | -56,178 | 923 |
| Benefits - Beach closure avoided costs | 73,642 | 8,840 |
| Benefits - Avoided environmental damage | 488,507 | 43,308 |
| Benefits - Aesthetic | | 426,226 |
| Benefits - UHI effect | | 10,528 |
| Benefits - Habitat creation | | 497,264 |
| Benefits - Air Q improvements | | 3,902 |

**Figure 8.12: Breakdown of net benefits of CBA results for CSO framework (AEPV)**

Figure 8.12 illustrates the categorisation of benefit sources of the two adaptation scenarios. While the avoided environmental damage dominates the total of benefits in the structural scenario, there is a negative part originated from the increase in the water sent to the treatment plant. In the case of the SUDS scenario, similarly to the floods framework, the majority of benefits are coming from the increase in ecosystem services provided by green areas. Moreover, although proportionally very small, there are benefits from the reduction of water sent to the WWTP.

#### 8.3.4.2.2 Indirect Intangible Damages Analysis Results

Survey results provide, on the one hand, information to the City Council regarding the effectiveness of current informative measures to prevent negative impacts on human health; and on the other hand, potential economic losses of coastal businesses, from behavioural changes derived from a red flag at the beach. Comparative analysis between Badalona and Barcelona is shown when appropriated to illustrate differences in behaviour. The case of Barcelona is different, as users are mostly non-residents and the flag directive is less restrictive towards CSO events, due to differences in the discharge casuistry.

Interviews to business owners support the latter findings, except for the restaurant sector. In the following paragraphs the analysis of the results can be found together with related recommendations to decision-makers.

The total of respondents go to the beach for swimming, in addition to other complementary activities (e.g. practice sports, eat out or sunbath). Thus, it can be assumed that, during the bathing season, the prohibition to swim affects all users negatively.

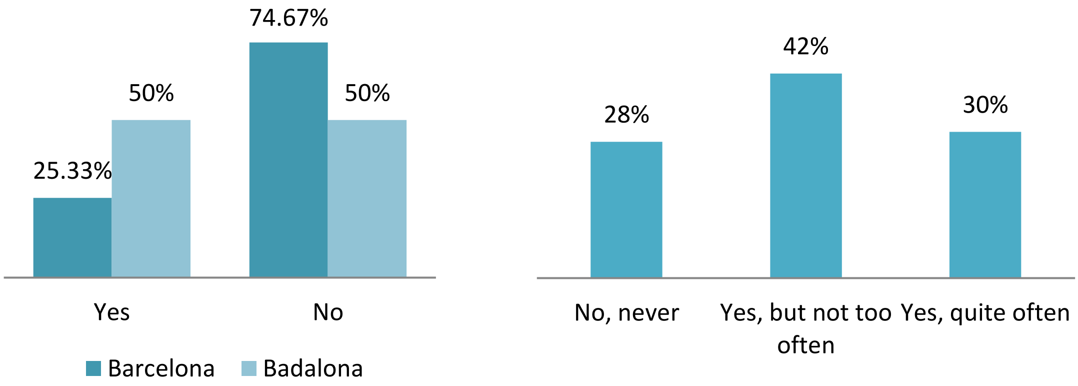



**Figure 8.13: (left) Comparative results of knowledge of CSO events at the beach, (right) Users' expeirence of beach closure/red flag from a CSO spill in Badalona**

When asked about the knowledge of relationship between red flag and CSO event, respondents in Badalona seem more aware of the occurrence of these events. Regarding the users' experience of beach closure due to a CSO event in Badalona, the 72% of affirmative answers show the wide acknowledge of this issue in the city.

The following question, which asks about the habit of checking the flag status before going, 62% always or sometimes do check, the majority of them use apps or social media to do so. Related to that, when they were asked what they do if they find that there is a red flag before going (Figure 8.14), it shows that more than half (58.3%) change their plans. That could be interpreted as potential benefits of coastal business that are missed.

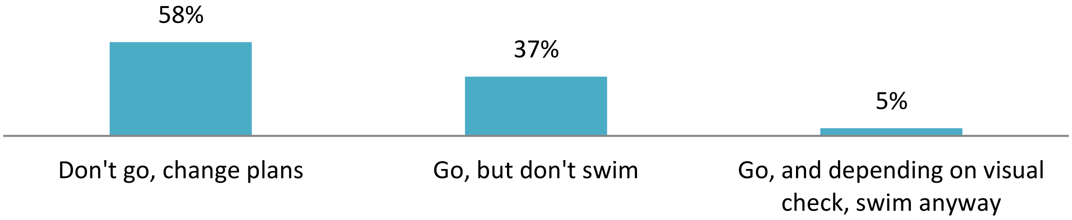



**Figure 8.14: Behaviour if user knows there is a red flag at the beach before going**

The question relative to the responsibilities of CSO events also shows strong differences between Badalona and Barcelona. While in Barcelona only 20% pointed the city council as responsible, in Badalona 40% assigned the responsibility to them. The answers follows the insight that in Badalona citizens are more aware of the issues related to CSO. However, it is worth mentioning that older respondents agree on the improvements in the water quality compared to the past.

The owners of coastal business presented high level of knowledge about CSP events and sewer functioning, and clearly showed that they are negatively affected by those events, although they were not able to estimate a monetary value. The water sport business, due to the direct contact of themselves and their customers with the water, showed higher concerns about these events, to the level of counting with internal water quality evaluation processes. Both water sports and fishermen demonstrated concerns about the environmental impact on the marine ecosystem, while restaurant owners focused more on the impact on the image that CSO discharge could have on them. During all interviews, it was revealed, the demands to stakeholders to focus on avoiding the occurrence of discharges, instead of preventing the consequences on health with informative measures; as well as improvements in communicati9on channels with them.

### 8.4.3 Results derived from the social justice questionnaires

In addition to the comprehensive quantitative assessments as presented above, also an so called “social justice analysis” has been conducted, based on questionnaires about the adaptation measures explored for Badalona. The original questionnaire can be found in Annex I, the answered questionnaires for the Badalona case in Annex II. The results from the qualitative analysis are presented in this section below.

*Social justice analysis – Natural based solutions*

Apart from main aim, to reduce the risk of bad water quality at the beach side due to CSO, the side effects of the natural based solutions enhancing the social justice for the society as a whole (egalitarian principle), due to the fact that just positive effects are enhanced and the negative effects are minimized regardless of social status in society. For the general public in Badalona, and also for the tourists, the main side effects are enhanced public amenity, enhanced health benefits (due to the improvement of air quality), an increase of ecosystems services and reduction of heat island effect. As a result of tourists in the city there is a positive economic impact for the inhabitants and the municipality. Likewise the reputational gain due to less CSO-events and enhanced public amenity has positive effect for the sewer system manager in almost the same manner as for the municipality. The negative effects are reduced, since there are almost exclusively monetary burden payed by Badalona’s City Council.

*Social justice analysis – Early warning system*

The measure Early Warning System for Flooding and for CSOs has the main aim to prevent direct damages on citizens and on beaches. The measure has no significant positive or negative side effects. The only appreciable side effect is perhaps that the costs for the implementation and upkeep of the measure would be assumingly payed by the Badalona City Council. This could have negative side effects later on in terms of social justice, because of a possible cost distribution from the city to the citizens.

That means most likely the egalitarian principle would apply to the Early Warning Systems, because it tries to minimize the negative effects, but an Early Warning System is not enhancing to maximize the positive effects. The main aim of the measure benefits the general public, but also the municipality and tourist (in general all people to be affiliated with the region Badalona).

*Social justice analysis – Inlets increase*

Apart from main aim, the reduction of flooding and combined sewer overflows (CSOs) events, the side effects of increasing the amount of inlets in Badalona don't enhancing the social justice for the society as a whole. Instead the deontological principle ("polluters pays") applies, since the final users of the sewer system's service are paying for its proper performance, despite the measure will benefit all Badalona's inhabitants equally. Also, a tax increase is conceivable to cover the increased cost of the measure. This in turn usually leads, depending on which taxes are increased, to greater social injustice, To compensate this social injustice and minimize the economic negative side effects, social benefits for socially disadvantaged groups would be possible. However, since the municipality pays in advance, the municipality has to defray the monetary burden first. Apart from increase the taxes and potentially increase social injustice, some private construction companies and some European subsidies could be requested to contribute to the funding of new developments.

The main positive effect for the general public are decreasing the risk of bather's who are coming in contact with polluted waters (health impact, less CSO-events). For the sewer system manager and the municipality the positive side effects are mainly a reputational gain due to less CSO-events and an increase the social perception (trust) in municipality's efficiency. The beach services/businesses economically benefit from less interruptions in visitors traffic due to less times with beaches closed due to CSO.

Another possible negative effect for the public could be the construction sites in the city that arise when more inlets are built. But on the other hand this might raise employment in the local construction business.

## 8.5. Conclusions and outlook

The results from the CBA and the risks and impacts assessment can be useful to support the decision-making process. For instance, measures can be ranked by different indicators, such as net benefits, costs, welfare benefits or just risk reduction.

Regarding the effectiveness of the adaptation measures for **urban floods risk reduction** it can be concluded that the structural measures are the ones reducing the most the flood risk (for pedestrians, vehicles and for monetized damages). Particularly, they can almost eliminate the high risk area derived from 10-year design rainfalls. Secondly, the EWS also significantly reduces flood risk. In this case the risk reduction is rather uncertain and conservative assumptions were made when simulating the EWS impacts on high risk areas. Finally, the proposed SUDS are the least flood risk reducing measures. This is mainly because the implementation of SUDS only affect 2% of the actual impervious area of Badalona whereas flood structural measures were designed to avoid floods for a 10 year design storm implying much higher investment costs

Results from the CBA show the net socio-economic benefits for each of the adaptation measure. The net benefits can be used as an indicator to rank and prioritize the different adaptation measures. The EWS is the most beneficial measure of the present analysis. Indeed, the EWS can significantly reduce flood vulnerability (not hazard), expected annual damage (EAD) and risks with minor investment requirements. SUDS are the second most beneficial measure. Despite the fact that the SUDS have limited capability to reduce flood hazard (not vulnerability), EAD and risk, they provide a number of improvements on ecosystem services which affect positively the citizens (i.e., $CO_2$ reduction, urban heat island effect reduction, aesthetic values of buildings and habitat creation). The structural measures proposed are the least convenient from a socio-economic point of view because the flood EAD reduction is not high enough to compensate the high investment costs required for the infrastructure. Note that, this CBA of structural measures do not include intangible damages due to flood, however the conclusions are likely not to change. Implementing all the structural measures from a Master Drainage Plan (that design measures for 10 year design storms) seems to have negative socio-economic net benefits. However, results of strategically selected structural measures might lead to positive benefits. Hence, further analysis of efficiency and effectiveness is recommended to understand a possible positive socio-economic results from the partial implementation of structural measures.

Regarding the effectiveness of the adaptation measures for CSO risk reduction it can be concluded that:

The structural measures (CSO detention tanks) are the ones reducing the most the annual wet weather CSO volume (46% reduction) and thus the percentage of bathing season time with insufficient bathing water quality (from 3.6% in the BAU scenario to 1.6% with detention tanks). SUDS measures only reduce by 4% the annual CSO volume.

The CBA results show that SUDS are the most beneficial measures in terms of net benefit. They involve high socio-economic benefits mainly derived from the ecosystem services improvements they bring (air quality, habitat creation, etc.), although the welfare increase due to reduction of beach closure is higher with structural measures. Even considering that, structural measures provide negative net benefits meaning that the investment and operational costs are not compensated by their damage reduction.

For future work, it is recommended to analyse more SUDS measures in terms of implementation area and possible measures that might deliver higher risk reduction results. Similarly, it is recommended to study the efficiency of EWS in its capability to improve the bathing closure protocol, as it can potentially reduce red flag hours, by providing more precise information regarding insufficient bathing water quality following CSO events.

The qualitative assessment of CSO's indirect intangible damages gives an insight to decision-makers regarding the view of citizens and affected parties about CSO spills. It also provides information about the most effective informative channels to prevent people from bathing in poor water quality situations, e.g. whether beachgoers understand available informative measures and comply with swim prohibitions.

# 9 BIBLIOGRAPHY

Adger, W. N. 2006. Vulnerability. In: Global Environmental Change, 16(3) 268-281.

Ajuntament de Badalona (2012). Anàlisis de la demanda: Hàbits de consum a la platja.

aus der Beek, T. (Coordination); Alves, E.; Becker, R.; Bruggeman, A.; Fortunato, A.; Freire, P.; Gragne, A.; van Huijgevoort, M.H.J. ; Iacovides, A.; Iacovides, I.; Kristvik, E.; Locatelli, L.; Lorza, P.; Mouskoundis, M.; Muthanna, T.; Nottebohm, M.; Novo, E.; Oliveira, M.; Rijpkema, S.; Rodrigues, M.; Rodrigues, R.; Russo, B.; Scheibel, M.; Sunyer, D.; Teneketzi, E.; Vayanou, P.; Viseu, T.; Voortman B.R.; Witte F. (2018). D3.4 - Model results for water and land use scenarios completed and analysed. Deliverable 3.4 of Project BINGO, June.

aus der Beek, T., Alphen, H.-J., Alves, E., Bruggeman, A., Camera, C., Fohrmann, R., Fortunato, A., Freire, F., Iacovides, A., Iacovides, I., Kristvik, E., Kübeck, C., Lorza, P., Muthanna, T., Novo , E., Rocha, F., Rodrigues, M., Rodrigues, R., Russo, B., Sánchez, P., Scheibel, M., Spek, T., Witte, F. and Zoumides, C. (2016) Characterization of the catchments and the water systems, Deliverable 3.1, BINGO - Bringing innovation to ongoing water management – a better future under climate change assessment, p. 89.

aus der Beek, T., Becker, R., Bruggemann, A. et al. (2019) Optimized water resources models as a support to management strategies, BINGO Deliverable 3.6.

Baur, A., Fritsch, P., Hoch, W., Merkl, G., Rautenberg, J., Weiß, M. and Wricke, B. (2019) Mutschmann/Stimmelmayr Taschenbuch der Wasserversorgung (Translation: Handbook of water supply), Springer Viweg, Wiesbaden.

BCN 2015. Guia de terrats vius i cobertes verdes. Ajuntament de Barcelona

Bruggeman, A., Zoumides, C., Camera, C. 2015. The effect of climate change on crop production in Cyprus – The Cyprus green-blue water model and scenario modelling. AGWATER Scientific Report 8. The Cyprus Institute, Nicosia, Cyprus.

Bundesamt, S. (2008) Klassifikation der Wirtschaftszweige mit Erläuterungen, Wiesbaden.

Caney, S. 2005. Cosmopolitan Justice, Responsibility, and Global Climate Change, in: Leiden Journal of International Law, 18: 747-775.

Caney, S. 2005. Cosmopolitan Justice, Responsibility, and Global Climate Change, in: Leiden Journal of International Law, 18: 747-775.

Carrera, J., Standardi L., Bosello F., Myslak, J. (2013). Research Papers Issue RP0202: Assessing direct and indirect economic impacts of a flood event through the integration of spatial and computable general equilibrium modelling.

Census of Agriculture (2010). Census of Agriculture – 2010. Statistical Service of Cyprus

Charalambous, K., A. Bruggeman, A. M.A. Lange. 2012. Assessing the urban water balance: The Urban Water Flow Model and its application in Cyprus. Water Science and Technology, 66 (3): 635-643, https://doi.org/ 10.2166/wst.2012.188

Christou, A., Dalias, P., Neocleous, D., 2017. Spatial and temporal variations of evapotranspiration and net water requirements of typical Mediterranean crops in the island of Cyprus, The Journal of Agricultural Science 155, 1311-1323.

Cook, K.S. 1987. Toward a more interdisciplinary research agenda: The potential contributions of sociology, in: Social Justice Research, 1(1): 5018.

Cook, K.S. 1987. Toward a more interdisciplinary research agenda: The potential contributions of sociology, in: Social Justice Research, 1(1): 5018.

CyStat, 2014. Census of agriculture 2010. Agricultural statistics, Series 1, Report No. 8. Printing Office of the Republic of Cyprus, Nicosia, Cyprus.

de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., Dong, W., Ford, J., Fuss, S., Hourcade, J.-C., Ley, D., Mechnler, R., Newman, P., Revokatova, A., Schultz, S., Steg, L. and Sugiyama, T. (2018) Strengthening and Implementing the Global Response. Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. (eds).

De Jong, J. J., Van Raffe J. K. 2016. Normenboek Natuur, Bos en Landschap. Wageningen.

DIN-4124 (2012) DIN 4124 Baugruben und Gräben - Böschungen, Verbau, Arbeitsraumbreiten (Translation: Excavations and trenches – Slopes, planking and strutting breadths of working spaces), Berlin.

Djuma, H., Bruggeman, A., Camera, C., Eliades, M., Kostarelos, K. (2017). The impact of a check dam on groundwater recharge and sedimentation in an ephemeral stream. Water, 9(10), 813.

DVGW (2008) Arbeitsblatt W 410 - Wasserbedarf - Kennwerte und Einflussgrößen, DVGW, Bonn.

DVWK (1985) Ökonomische Bewertung von Hochwasserschutzwirkungen, Deutscher Verband für Wasserwirtschaft und Kulturbau e.V. (DVWK), Bonn.

DWA (2012) Leitlinien zur Durchführung dynamischer Kostenvergleichsrechnungen (KVR Leitlinien) (translation: Guidelines to conduct dynamic cost comparisons).

DWD (2018) KOSTRA-DWD Rasterdaten. Wetterdienst, D. (ed).

EconAdapt. Chiabai, A.; Hunt, A.; Galarraga, I.; Lago, M.; Rouillard, J.; Sainz de Murieta, E.; Tepes, A.; Troeltzsch, J.; Watkiss, P. (205). Using cost and benefits to assess adaptation options. Deliverable 3.1A.

European Commission, Directorate-General Regional Policy (2010). Ex post evaluation of cohesion policy interventions 2000-2006 financed by the Cohesion Fund (including former ISPA). Work Package C – Cost benefit analysis of environment projects.

European Commission. 2008. Guide to Cost Benefit Analysis of Investment Projects. http://ec.europa.eu/regional_policy/sources/docgener/guides/cost/guide2008_en.pdf

eurostat (2019) Comparative price levels for investment.

exchange-rates.org (2019) Exchange rates between NOK and EUR for 2019.

FEMA. 2009. Benefit-Cost Analysis Re-engineering. http://www.bchelpline.com/bcatoolkit/resource_files/methodology/ProjectCostGuidance.pdf

Giannakis, E., Bruggeman, A., Zoumides, C., Charalambous, K., Camera, C. (2016). Pedieos River Basin Adaptation Plan - Part I & II.

Hammond, M. J., Chen, A. S., Djordjević, S., Butler, D., & Mark, O. (2015). Urban flood impact assessment: A state-of-the-art review. Urban Water Journal, 12(1), 14–29

Hanssen-Bauer, I., Førland, E.J., Haddeland, I., Hisdal, H., Mayer, S., Nesje, A., Nilsen, J.E.Ø., Sandven, S., Sandø, A.B., Sorteberg, A. and Ådlandsvik, B. (2015) Klima i Norge 2100 (The Climate in Norway 2100), Report NCCS no 2/2015, Miljødirektoratet (Norwegian Environment Agency), Norway.

Hoegh-Guldber, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K.L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S.I., Thomas, A., Warren, R. and Zhou, G. (2018) Impacts of 1.5°C Global Warmung on Natural and Human Systems. Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. (eds), pp. 175-311.

Hydrotec (2018-2019) Hydrologische Modellierung des Mirker Bachs, Hydrotec Ingenieurgesellschaft für Wasser und Umwelt mbH, Aachen.

ISO 31000 (2018) ISO 31000: Risk management - Guidelines, Switzerland.

Koti, J., Hein, A., Interwies, E., Wencki, K. and Görlitz, S. (2017) MS22-report: Economic and social impacts of measures determined. Suitable assessment methods for the evaluation of adaption strategies and/or measures to climate change (BINGO T5.2-Toolbox), BINGO.

Kowalewski, J. 2009. Methodology of the input-output analysis, HWWI Research Paper, No. 1-25, HWWI Institute of International Economics, Hamburg.

Kristvik, E. and Muthanna, T.M. (2017) Seasonal variations in climate and the performance of stormwater collection systems. 14th IWA/IAHR International Conference on Urban Drainage September 12th 2017, Prague, Czech Republic.

Low, N. and B. Gleeson 1998. Justice, Society and Nature, Routledge: London.

Low, N. and B. Gleeson 1998. Justice, Society and Nature, Routledge: London.

Matzinger, A., Riechel, M., Remy, C., Schwarzmüller, H., Rouault, P., Schmidt, M., Offermann, M., Strehl, C., Nickel, D., Sieker, H., Pallasch, M., Köhler, M., Kaiser, D., Möller, C., Büter, B., Leßmann, D., von Tils, R., Säumel, I., Pille, L., Winkler, A., Bartel, H., Heise, S., Heinzmann, B., Joswig, K., Rehfeld-Klein, M. and Reichmann, B. (2017) Zielorientierte Planung von Maßnahmen der Regenwasserbewirtschaftung - Ergebnisse des Projektes KURAS (Translation: Goal-oriented planning of stormwater management - Results of the KURAS project), p. 137.

Miller, D. 1999. The principles of Social Justice. Harvard University Press: Cambridge.

Miller, D. 1999. The principles of Social Justice. Harvard University Press: Cambridge.

OECD (2018), Cost-Benefit Analysis and the Environment: Further Developments and Policy Use, OECD. Publishing, Paris. http://dx.doi.org/10.1787/9789264085169-en

R+I Alliance project SW1002. I+D Project. Suez Environment. Internal report.

Rocha, F. (coordination); Adriana Bruggeman, Albert Pérez, Alberto Freitas, Ana Margarida Luís, André Fortunato, Basílio Martins, Beniamino Russo, Clemens Strehl, Christos Zoumides, David Suñer, Eduardo Martínez, Elias Giannakis., Esther Suárez, Erle Kristvik, Fabian Vollmer, Henk-Jan van Alphen, Josep Montes, Juliane Koti, Luca Locatelli, Marc Scheibel , Marta Rodrigues, Paula Freire, Paula Lorza, Pedro Brito, Teun Spek, Tone Muthann (2018). Estimated level of risk of each event and each scenario at the six research sites. D4.4 of Project BINGO, August.

Rocha, F. (coordination); Alphen, H-J. Van; Brito, P.; Bruggeman, A.; Freitas A.; Fortunato, A., Freire, P.; Giannakis, E.; Huijgevoort, M.H.J.; Koti, J.; Kristvik, E.; Locatelli, L.; Lorza, P.; Luís, A. M..; .; Martínez, E., Martins, B.; Muthanna, T.; Novo, E.; Rodrigues, M.; Rodrigues, M.; Russo, B.; Strehl, C.; Scheibel, M.; Spek, T.; Sunyer, D., Vollmer, F.; Zoumides, C. (2018). D4.3 Risk Analysis - Likelihood and consequences of each extreme weather event at the six research sites. Deliverable 4.3 of Project BINGO, August.

Rocha, F., Bruggeman, A., Freitas, A., Margarida, L., Fortunato, A., Martins, B., Russo, B., Strehl, C., Zoumides, C., Sunyer, D., Martínez, E., Giannakis, E., Novo, E., Kristvik, E., Vollmer, F., van Alphen, H.-J., Koti, J., Locatelli, L., Scheibel, M., van Huijgevoort, M., Rodrigues, M., Freire, P., Lorza, P., Brito, P., Rodrigues, R., Spek, T. and Muthanna, T. (2018a) D4.3: Risk Analysis - Likelihood and consequences of each extreme weather event at the six research sites, BINGO.

Rocha, F., Viseu, T., Bruggeman, A., Pérez, A., Freitas, A., Margarida, L., Fortunato, A., Martins, B., Russo, B., Strehl, C., Zoumides, C., Sunyer, D., Martínez, E., Giannakis, E., Suárez, E., Kristvik, E., Vollmer, F., van Alphen, H.-J., Montes, J., Koti, J., Locatelli, L., Scheibel, M., Rodrigues, M., Freire, P., Lorza, P., Brito, P., Spek, T. and Muthanna, T. (2018b) D4.4: Estimated level of risk of each event and each scenario at the six research sites, BINGO.

Rocha, F.; Viseu, T.; Barbosa, A.E. (coordination); Alphen, H-J. Van; Alves, E.; Beek, T aus der.; Bruggeman, A.; Fortunato, A.; Freire, P.; Giannakis, E.; Görlitz, S.; Hein, A.; Iacovides, A.; Iacovides, I.; Interwies, E.; Koti, J.; lorza, P.; Mälzer, H.-J.; Martínez, M.; Muthanna, T.; Novo, E.; Oliveira, M.; Rodrigues, M.; Russo, B.; Sánchez, P.; Sægrov, S.; Scheibel, M.; Spek, T.; Sunyer, D.; Zoumides, C. (2017). D4.1 - Context for risk assessment at the six research sites, including criteria to be used in risk assessment. Deliverable 4.1 (2nd version) of BINGO Project, March 2017.

Romero-Jordán, D.; del Río, P; Peñasco, C. (2014). En Household electricity demand in Spanish regions. Public policy implications.

Roy, J., Tschakert, P., Waisman, H., Abdul halim, S., Antwi-Agyei, P., Dasgupta, P., Hayward, B., Kanninen, M., Liverman, D., Okereke, C., Pinho, P.F., Riahi, K. and Suarez Rodriguez, A.G. (2018) Sustainable Development, Poverty Eradication and Reducing Inequalities. Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. (eds).

Russo, B., Sánches, P., Rocha, F., Viseu, T., Freitas, A., Luís, A., Fortunato, A., Villanueva, A., Martins, B., Strehl, C., Martínez, E., Alves, E., Bergsma, E., Kristvik, E., van Alphen, H.-J., Koti, J., Scheibel, M., Rodrigues, M., Freire, P., Lorza, P., Brito, P., Malgrat, P. and Munthanna, T. (2017) D4.2: Risk identification: Relevant hazards, risk sources and factors, BINGO.

Sartori, D. (Lead Author); Catalano, G.; Genco, M.; Pancotti, C; Sirtori, E; Vignetti, S; Del Bo, C.; (2014). Guide to Cost-benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020.

Shue, H. 1999. Global environment and international inequality, in: International Affairs, 75: 531-545.

Shue, H. 1999. Global environment and international inequality, in: International Affairs, 75: 531-545.

Siakou, M., A. Bruggeman, C. Zoumides and M. Eliades. 2019. Monitoring and improving irrigation efficiency in an organic olive farm in Cyprus. Acta Horticultura (in press).

Statistical Institute of Catalonia (2019) Input-Output tables. [Online]. Available from: https://www.idescat.cat/estad/mioc?lang=es (Accessed 6 February 2019).

Statistical Institute of Catalonia (2019) Population growth. [Online]. Available from: http://www.idescat.cat/emex/?id=080193&lang=en (Accessed 8 April 2019).

Statistisches-Bundesamt (2008) Klassifikation der Wirtschaftszweige - Mit Erläuterungen (Translation: Classification of business sectors - with explanations), p. 828, Statistisches Bundesamt (destatis), Wiesbaden.

Statistisches-Bundesamt (2019) Preisindizes für die Bauwirtschaft (traslation: Price indices for construction works), Statistisches Bundesamt /Destatis).

Strehl, C., Offermann, M., Hein, A. and Matzinger, A. (2017) Economic analysis of urban drainage scenarios in Berlin. Czech Technical University in Prague, F.o.C.E. (ed), pp. 1889-1897.

Thieken, A., Ackermann, V., Elmer, F., Kreibich, H., Kuhlmann, B., Kunert, U., Seifert, J. (2008). 4 th International Symposium on Flood Defence: Managing Flood Risk, Reliability and Vulnerability METHODS FOR THE EVALUATION OF DIRECT AND INDIRECT FLOOD LOSSES, 1–10.

UN (2019) United Nations Treaty Collection: Paris Agreement, United Nations.

UNFCC (2015) Paris Agreement. Change, U.N.F.C.o.C. (ed), p. 25.

Van Alphen , H-J and Bergsma, Emmy (coordination); A. Bruggeman, J. Engelenburg, E. Giannakis, A. Hein (IWW), J. Hogendoorn (Vitens), J. Koti , E. Kristvik, P. Lorza, P. Malgrat, M. Martinez, T.M. Muthanna, M. Scheibel, T. Spek, E. Suárez, B. Verboom, C. Zoumides (2016). Report on the assessment of the current governance situation and recommendations for improvement at the research

Viseu, T., Rocha, F., Barbosa, A.E., Bruggeman, A., Fortunato, A., Hein, A., Iacovides, A., Russo, B., Zoumides, C., Sunyer, D., Interwies, E., Giannakis, E., Alves, E., Novo, E., Mälzer, H.-J., van Alphen, H.-J., Iacovides, I., Koti, J., Oliveira, M., Scheibel, M., Rodrigues, M., Martínez, M., Sánches, P., Freire, P., Lorza, P., Görliztz, S., Saegrov, S., Spek, T., aus der Beek, T. and Muthanna, T. (2016) D4.1: Context for risk assessment at the six research sites, including criteria to be used in risk assessment, BINGO.

WATECO, 2003. Guidance Document No 1: Economics and the Environment — The implementation Challenge of the Water Framework Directive. Produced by Working Group 2.6 — WATECO in the context of the Common Implementation Strategy for the Water Framework Directive. European Communities, 2003

Water Development Department (2011a). Sewerage System of Astromeritis-Peristerona-Akaki Complex. WDD, Wastewater and Reuse Division, Nicosia, August 2011.

Water Development Department (2017). Feasibility Study for Vasilikos to Western Nicosia Conveyor Supply Project. WDD, Nicosia, March 2010.

Water Development Department, 2006. Development of technical documentation for the collection and treatment of urban waste waters. Financial study, Group A, Nicosia area, Astromeritis, Akaki, Peristerona

Zensus (2011) Zensusdatenbank Zensus 2011 der Statistischen Ämter des Bundes und der Länder, Bayerisches Landesamt für Statistik.

Zoumides, C., Bruggeman, A., Zachariadis, T. and Pashiardis, S. (2013). Quantifying the poorly known role of groundwater in agriculture: the case of Cyprus. Water Resources Management 27, 2501-2514

## ANNEX I – Social justice questionnaire (empty version)

# BINGO WP5 – Social Justice Assessment Template

### Introduction

The aim of BINGO WP5 is to assess the current governance context at the six BINGO sites and to provide recommendations regarding the adaptation strategies. Within his work package, relevant adaptation measures have been identified by Communities of Practices (CoP's) at each research site, which have been assessed by the WP5-team in terms of their governance needs (T5.3) and socio-economic costs and benefits (T5.2) to facilitate the development of adaptation strategies (adaptation measures including an implementation plan) at the research sites. As a last step in the assessment of selected adaptation measures, an analysis of the impact of these measures on social justice will be made.

Social justice refers to "how the basic structure of a society distributes advantages and disadvantages to its members" (Miller 1999[18]: 17). These distributions are often based on, and legitimized through, "distributive" or "equity" principles (Cook 1987[19], Caney 2005[20]). Equity principles appeal to general conceptions of what is good and what is bad. Besides notions about fair distributions, they are closely related to considerations of vulnerability (Adger 2006[21]). Generally, the political-philosophical literature distinguishes between three general equity principles (Shue 1999[22], Low and Gleeson 1998[23]):

1) The deontological principle is based on Kant's notion that people are rational and act intentional, and can therefore be held responsible for their choices and actions. The "polluter pays" principle is an example of this principle.
2) The solidarity principle aims to neutralize "involuntarily inequalities" between people. Distributions follow Rawls' "maximin" principle which involves maximizing the well-being of those who are worst-off.
3) The egalitarian principle is based on Mill's and Benthams' utilitarian "greatest happiness principle". Distributions aim to maximize the positive effects and minimize the negative effects for society as a whole.

By mapping out distributions of burdens and benefits related to the selected adaptation measures at each BINGO site, insight will be gained into the possible impacts of the measures on social justice. To what extent and how can the distribution of burdens and benefits brought forward by the measures be legitimized (based on which equity principle)? What does the measure imply for existing vulnerabilities, are they reduced or strengthened? These insights can be used in the final development of adaptation strategies.

The next page lists a number of questions to support the social justice analysis. These questions should be answered for (a selection of) the measures analyzed in Task 5.2, which has identified the socio-economic impacts of the selected adaptation measures at each research site. By answering the questions, the distributions of the socio-economic impacts identified in T5.2 will be mapped out and assessed.

[18] Miller, D. (1999) The principles of Social Justice. Harvard University Press: Cambridge.
[19] Cook, K.S. (1987) Toward a more interdisciplinary research agenda: The potential contributions of sociology, Social Justice Research, 1(1): 5018.
[20] Caney, S. (2005) Cosmopolitan Justice, Responsibility, and Global Climate Change, Leiden Journal of International Law, 18: 747-775.
[21] Adger, W. N. (2006) Vulnerability. Global Environmental Change, 16(3) 268-281.
[22] Shue, H. (1999) Global environment and international inequality, International Affairs, 75: 531-545.
[23] Low, N. & B. Gleeson (1998) Justice, Society and Nature, Routledge: London.

**Assessment questions**

According to current rules and regulations:

1. How are costs for the implementation and upkeep of this measure shared between parties?

   Example: Flood protection measures (technical measures at private property)→ are these paid by the owner of the building/property, or by the general public? How is the upkeep/O&M paid for - privately or with public funds?

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   Example: Flood protection walls are built that disturb the quality of the landscape.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   Example: Flood protection walls that disturb the quality of the landscape are designed in an appealing way at higher costs.

4. If no: Who will carry the burden of the negative side-effects?

   Example: The inhabitants living nearby a measure with negative side-effects.

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   Example: Property owners living nearby flood protection walls benefit from reduced flood risks.

   NOTE to questions 6 and 7: If the quantitative analysis of measures within T5.2 so far (assessment of risk reduction effectiveness, MCA/MCDA approach to assess benefits of a measure) to your opinion neglects any decision relevant side effects of the measure, please answer question 8 and 9. Otherwise you may skip them

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   Note: Here benefits are asked for that have not been quantitatively assessed in the T5.2 socio-economic analysis so far (e.g. as planned as feedback in your T5.2 case-study template). A qualitative answer is sufficient.

7. Which actor(s) will enjoy these indirect benefits?

   Example: Property owners living nearby a restored river section benefit from an improved living quality (recreational benefits).

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   Note: Here equity principles described in the introduction page are asked (i.e. the deontological/solidarity/egalitarian principles).

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   Example: Inequalities could arise if people who are not affected by flood risks have to pay for measures protecting only few inhabitants.

# ANNEX II – Social justice questionnaires (answered)

## Germany (Wupperverband)

### Assessment questions

According to current rules and regulations:

### Measure: substitution with alternative water sources or water saving

1. How are costs for the implementation and upkeep of this measure shared between parties?

   Groundwater / bank filtration: Direct costs for water suppliers and resulting higher water prices for consumers

   Water saving: Potentially increased water prices due to lower water consumption, thus the reduced water supply and the increased prices may compensate each other

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   Water saving: Additional flushing demand of pipes might be necessary using fresh water (as layout of piping system was built for higher volume flows)

   Groundwater/bank filtrate: There might be an additional water softening necessary. This softening must be realized either by the water supplier or by the consumer.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   Water saving: Water suppliers have to flush the system. The costs might increase the water price for consumers.

   Groundwater/bank filtrate: Either water suppliers and/or consumers.

4. If no: Who will carry the burden of the negative side-effects?

   –

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   General public by increased water availability.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   No.

7. Which actor(s) will enjoy these indirect benefits?

   –

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   2) Solidarity principle

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

There might be a little increase of inequalities due to increasing water prices. As they increase in the same amount for everyone, especially poor people will be relatively more affected by the financial burden.

### Measure: reduction of low water elevation

1. How are costs for the implementation and upkeep of this measure shared between parties?

   Costs due to reduced energy generation: Wupperverband

   Costs due to reduced ecosystem services: general public

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   Here only indirect costs occur (cf. answers to question 1)

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   Energy generation: Supply of electrical energy by external supplier

4. If no: Who will carry the burden of the negative side-effects?

   See answers to question 1

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   Direct benefit: contractual partners. Indirect benefit: Public

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   No

7. Which actor(s) will enjoy these indirect benefits?

   -

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   2) Solidarity principle

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   No

### Measure: transition between reservoir catchments

1. How are costs for the implementation and upkeep of this measure shared between parties?

   Direct costs will probably be paid by the Wupperverband. This might lead to increased costs for the contractual partners. This in turn might lead to increased costs for the consumers.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

Potential negative effects on the landscape and on the environment. Decrease of property value for properties affected by the pipe/channel route.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   Compensation payments for land owners.

4. If no: Who will carry the burden of the negative side-effects?

   The property owners.

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   Contractual partners & general public.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   Potentially increased recreational value near properties.

7. Which actor(s) will enjoy these indirect benefits?

   Potentially land owners that benefit from increased recreational value near their property.

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   2) Solidarity principle

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   There might be a little increase of inequalities due to increasing water prices. As they increase in the same amount for everyone, especially poor people will be relatively more affected by the financial burden.

### Measure: technical protection measures for properties

1. How are costs for the implementation and upkeep of this measure shared between parties?

   Costs not clearly allocated. Potentially partly by property owners and partly by funding.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   Potential decrease of property value due to decrease of aesthetics and due to obvious flood risk.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   A mitigation might be reached by an appealing design of the measure.

4. If no: Who will carry the burden of the negative side-effects?

   The property owner will carry the burden.

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   The property owner.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   No.

7. Which actor(s) will enjoy these indirect benefits?

   -

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   1) Deontological principle

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   Especially poorer people suffer from high costs for protection measures which might lead to an increased inequality.

### Measure: retention basin

1. How are costs for the implementation and upkeep of this measure shared between parties?

   Wupperverband

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   Decrease of aesthetics. Negative environmental impacts. Loss of value of properties in the surrounding of the retention basin.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   *E.g. by an appealing design of the basin. Environmentally friendly construction of the basin ("green engineering").*

4. If no: Who will carry the burden of the negative side-effects?

   *Property owners in the surrounding of the basin.*

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   *Property owners downstream of the retention basin.*

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   -

7. Which actor(s) will enjoy these indirect benefits?

-

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *2) Solidarity principle*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   -

## Measure: alignment protection

1. How are costs for the implementation and upkeep of this measure shared between parties?

   Potentially paid by Wupperverband. (Other possibility: affected property owners)

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   Decrease of landscape aesthetics.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   Mitigation by an appealing design of the alignment protection.

4. If no: Who will carry the burden of the negative side-effects?

   Affected property owners.

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   Affected property owners.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   -

7. Which actor(s) will enjoy these indirect benefits?

   -

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *If WV pays: 2) Solidarity principle*

   *If affected property owners pay: 1) Deontological principle*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   If WV pays: no

   If affected property owners pay: High costs for poorer people might increase social inequalities.

## The Netherlands (Veluwe)

MEASURE A: Landuse change

1. How are costs for the implementation and upkeep of this measure shared between parties?

   *Without some form of compensation all the costs are for the pine forest owners. This amounts to loss of production capacity and a relating loss in land value. However, this measure is only possible if compensation is given (for instance by the province) or a price is paid for the amount of water that is infiltrated above the current rates.*

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   *Specific wildlife and plant ecology related to pine species is destroyed. Heather, grass, sand and broadleaf wildlife and plant ecology will return. In the transition period, there will be low biodiversity. Also there will be a major change in the landscape after the transition is done.*

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   *The only mitigation tools are information and time. This is the experience in projects with a smaller scale with the same measure.*

4. If no: Who will carry the burden of the negative side-effects?

   *The inhabitants and tourists who are used to and appreciate the old landscape: wildlife and plants dependent on pine forests. During the transition tourist entrepreneurs may have less customers due to increased foresting activities on their lands.*

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   *Public water supply and Industry who can continue to use good quality groundwater for their production. The general public in the region who have their drinking water source secured for the future.*

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   *The landscape becomes more open and divers and more robust, with better soil condition and increased biodiversity (except during the transition period)*

7. Which actor(s) will enjoy these indirect benefits?

   *People who like divers, open landscapes instead of pine forests.*

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *Solidarity principle, since land owners are compensated for their loss through public means.*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   *This measure does not have notable impact on existing social inequalities.*

MEASURE B: Surface water infiltration

1. How are costs for the implementation and upkeep of this measure shared between parties?

   *The costs will be paid by the main beneficiary, the public water supply company. However, this will be translated into an increase in the drinking water price for all customers.*

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   *For this project, infrastructure needs to be built underground and at different location above ground. This can have an effect on local spatial quality. The measure will also require extra energy. If this must be provided by sustainable energy space will be needed for solar panels or windmills.*

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   *This can be mostly mitigated by designing and constructing the infrastructure in such a way that damages to the environment are minimal and the visible structure blend in into the natural environment.*

4. If no: Who will carry the burden of the negative side-effects?

   *Mostly people living or recreating nearby the infrastructure.*

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   *The measure will benefit the general public with a sustainable drinking water source without negative side effects to nature and aquatic ecology.*

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   *It is possible to connect this measure to forest fire mitigation/prevention, since the infiltration pipe ensures the constant availability of water.*

7. Which actor(s) will enjoy these indirect benefits?

   *Nature conservation agencies, tourism entrepreneurs, people living and recreating on and near the Veluwe.*

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *Solidarity principle, since the cost will be spread over a large part of the population.*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   *The measure has no notable influence on existing inequalities.*

MEASURE C: Limit sprinkler irrigation

1. How are costs for the implementation and upkeep of this measure shared between parties?

   *Without any form of compensation all the costs are for the farmers. Loss of production capacity and a relating loss in land value. Measure only possible if compensation is given in land exchange and/or soil quality improvement are implemented. Compensation is given by regional or national government, who can use taxation to acquire the necessary means.*

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   *No.*

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

4. If no: Who will carry the burden of the negative side-effects?

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   *The direct benefits are mostly for the natural environment, since more water is available during dry periods. The actors affected are land owners and people who live and recreate in those areas.*

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   *No*

7. Which actor(s) will enjoy these indirect benefits?

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *Solidarity principle: farmers are compensated for their loss in revenue (or transition costs) from public funds.*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   *There is no notable effect on existing social inequalities.*

## Portugal (Targus)

## Measure: Rehabilitation and modernization of transport and irrigation system

1. How are costs for the implementation and upkeep of this measure shared between parties?

ARBVS is the responsible for paying the costs of rehabilitation. It can apply to funds or support the measures by its direct funds (the less expensive measures) based of Taxes of conservation and exploitation that all farmers pay.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

3. No negative side effects If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

4. If no: Who will carry the burden of the negative side-effects?

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   Farmers of Sorraia Valley and the Irrigators Association (ARBVS)
   DGADR (the Agricultural Authority)

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   Yes:

   Assure agriculture sustainability in the region, agro-industry and rural employment. Contributes to the national PT PIB (PT GDP)

   Put in evidence costs of adaptation measures. It will maybe help future water allocation strategy based on efficiency of water use.

7. Which actor(s) will enjoy these indirect benefits?

Rural population. Regional Society, government, local tourism, etc.

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   The 3 principles

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

## Measure: Tagus water resources management model

1. How are costs for the implementation and upkeep of this measure shared between parties?

The Water Authority pays for the measure but all water uses pay a water resources tax, so by the end of the day, everybody pays.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

No negative side effects.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

4. If no: Who will carry the burden of the negative side-effects?

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   All water users sharing Tagus river and Zêzere river water resources.
   The Water Authority. DGADR (the Agricultural Authority)

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   Yes: WRM improvement, water resources deficit reduction, reduction of exposure (risk reduction) of water related sectoral activities; promotes CC adaptation, support decision making, improve general resilience.

7. Which actor(s) will enjoy these indirect benefits?

All the stakeholders, government

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   The 3 principles

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

## Cyprus (Peristerona Watershed)

MEASURE 1.1: Irrigation scheduling technologies

1. How are costs for the implementation and upkeep of this measure shared between parties?

   *Example: Flood protection measures (technical measures at private property)→ are these paid by the owner of the building/property, or by the general public? How is the upkeep/O&M paid for – privately or with public funds?*

   *Farmers bear the cost of installing and operating irrigation scheduling technologies. However, the uptake of these technologies can be subsidized by the Rural Development Programme measures.*

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   *Example: Flood protection walls are built that disturb the quality of the landscape.*

   *No*

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   *Example: Flood protection walls that disturb the quality of the landscape are designed in an appealing way at higher costs.*

   -

4. If no: Who will carry the burden of the negative side-effects?

   *Example: The inhabitants living nearby a measure with negative side-effects.*

   *There are no negative side-effects*

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   *Example: Property owners living nearby flood protection walls benefit from reduced flood risks.*

   *Farmers will benefit from the implementation of the measure; increasing the irrigation water efficiency can: (a) reduce water and pumping costs, (b) reduce costs for fertilizers and other agricultural chemicals.*

   *The uptake of irrigation scheduling technologies can result in water savings (10-20%) and reduce nutrient leaching, thus improving the quantitative and qualitative status of groundwater.*

*NOTE to questions 6 and 7: If the quantitative analysis of measures within T5.2 so far (assessment of risk reduction effectiveness, MCA/MCDA approach to assess benefits of a* *measure) to your opinion neglects any decision relevant side effects of the measure, please answer question 6 and 7. Otherwise you may skip them.*

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   *Note: Here benefits are asked for that have not been quantitatively assessed in the T5.2 socio-economic analysis so far (e.g. as planned as feedback in your T5.2 case-study template). A qualitative answer is sufficient.*

7. Which actor(s) will enjoy these indirect benefits?

   *Example: Property owners living nearby a restored river section benefit from an improved living quality (recreational benefits).*

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *Note: Here equity principles described in the introduction page are asked (i.e. the deontological/solidarity/egalitarian principles).*

   *The solidarity principle: the cost assessment conducted in Task 5.2 revealed the need of prioritizing the subsidization of irrigation scheduling technologies (through Rural Development Programme measures and schemes) for farmers not having access to recycled water, that is the most affordable irrigation water supply source, in terms of: (a) not disrupting the competition between farmers with and without access to recycled water, (b) improving groundwater resources protection and management, that is a public good.*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   *Example: Inequalities could arise if people who are not affected by flood risks have to pay for measures protecting only few inhabitants.*

   *Inequalities could arise between farmers with and without access to recycled water if the irrigation scheduling technologies will not be subsidized*

MEASURE 1.2: Use of treated sewage water for irrigation

1. How are costs for the implementation and upkeep of this measure shared between parties?

   *Example: Flood protection measures (technical measures at private property)→ are these paid by the owner of the building/property, or by the general public? How is the upkeep/O&M paid for – privately or with public funds?*

   *Communities bear the cost of the construction of the pipeline treated sewage water supply network for irrigation as well as the farmers who pay on top of water charge a premium for the recycled water (i.e., 0.05 €/m³)[24] to pay off the construction and maintenance cost.*

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   *Example: Flood protection walls are built that disturb the quality of the landscape.*

   *The long-term impacts of emerging contaminants such as pharmaceuticals, which are present in the treated sewage water, on soils, groundwater, ecosystems and human health are not known.*

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   *Example: Flood protection walls that disturb the quality of the landscape are designed in an appealing way at higher costs.*

   *None, academia developing research proposals funded by EU*

4. If no: Who will carry the burden of the negative side-effects?

   *Example: The inhabitants living nearby a measure with negative side-effects.*

   *Next generations*

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   *Example: Property owners living nearby flood protection walls benefit from reduced flood risks.*

   *Farmers having access to recycled water. The use of treated sewage water for irrigation can alleviate the pressures on groundwater resources and increase the water availability for domestic uses.*

*NOTE to questions 6 and 7: If the quantitative analysis of measures within T5.2 so far (assessment of risk reduction effectiveness, MCA/MCDA approach to assess benefits of a*

[24] The sewerage system of the Astromeritis - Peristerona – Akaki Complex buys the recycled water from the constructor at a rate of 0.07€/m3 and resell it to farmers (after an agreement with the district authority) at a rate of 0.12€/m3.

*measure) to your opinion neglects any decision relevant side effects of the measure, please answer question 6 and 7. Otherwise you may skip them.*

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   *Note: Here benefits are asked for that have not been quantitatively assessed in the T5.2 socio-economic analysis so far (e.g. as planned as feedback in your T5.2 case-study template). A qualitative answer is sufficient.*

7. Which actor(s) will enjoy these indirect benefits?

   *Example: Property owners living nearby a restored river section benefit from an improved living quality (recreational benefits).*

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *Note: Here equity principles described in the introduction page are asked (i.e. the deontological/solidarity/egalitarian principles).*

   *The egalitarian principle: the objectives are: (a) to optimize the supply of the annual wastewater production for irrigation to satisfy the needs of more farmers, (b) to minimize the effects of treated sewage water, on soils, groundwater, ecosystems and human health through research and strict enforcement of the legislation.*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   *Example: Inequalities could arise if people who are not affected by flood risks have to pay for measures protecting only few inhabitants.*

   *Inequalities could arise between farmers with and without access to recycled water; the production cost will be higher for farmers not having access to recycled water than farmers with access to it.*

MEASURE 1.3: Water desalination

1. How are costs for the implementation and upkeep of this measure shared between parties?

   *Example: Flood protection measures (technical measures at private property)→ are these paid by the owner of the building/property, or by the general public? How is the upkeep/O&M paid for – privately or with public funds?*

   *State (i.e., tax payers) bears the cost of the expansion of the water distribution pipeline network up to the downstream communities of the Peristerona Watershed. Households will pay a higher price for the desalinated water to cover the operational and maintenance costs of the pipeline network. The water price for households will be more than 1 €/m³ including the selling water price of Water Development Department to community councils (0.82 €/m³)[25] and the operational costs of communities.*

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   *Example: Flood protection walls are built that disturb the quality of the landscape.*

   *Negative side-effects include the increase of greenhouse gas emissions due to the energy intensive desalination processes and the energy needed for pumping the water from the coast to Peristerona watershed, which could exacerbate climate change. Another negative side-effect is the disturbance cost of the construction of the pipeline. Additionally, the chemical discharges and byproducts of the desalination plants may negatively affect coastal water and marine life.*

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   *Example: Flood protection walls that disturb the quality of the landscape are designed in an appealing way at higher costs.*

   - *Research towards the mitigation of the negative effects of the seawater desalination process*
   - *Optimization of water supply and demand (i.e., in dry years more desalinated water, in wet years less desalinated water)*

4. If no: Who will carry the burden of the negative side-effects?

   *Example: The inhabitants living nearby a measure with negative side-effects.*

   *Environment, current and future generations*

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

[25] *This price includes the environmental cost, that is, 0.05 €/m3*

*Example: Property owners living nearby flood protection walls benefit from reduced flood risks.*

*The measure ensures a reliable and continuous potable water supply for the households of the downstream communities of Peristerona Watershed.*

*NOTE to questions 6 and 7: If the quantitative analysis of measures within T5.2 so far (assessment of risk reduction effectiveness, MCA/MCDA approach to assess benefits of a measure) to your opinion neglects any decision relevant side effects of the measure, please answer question 6 and 7. Otherwise you may skip them.*

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   *Note: Here benefits are asked for that have not been quantitatively assessed in the T5.2 socio-economic analysis so far (e.g. as planned as feedback in your T5.2 case-study template). A qualitative answer is sufficient.*

7. Which actor(s) will enjoy these indirect benefits?

   *Example: Property owners living nearby a restored river section benefit from an improved living quality (recreational benefits).*

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *Note: Here equity principles described in the introduction page are asked (i.e. the deontological/solidarity/egalitarian principles).*

   *The deontological principle: The households of the downstream communities of the Peristerona Watershed will pay a higher price for the desalinated water but on the other hand the measure secures the domestic water supply in those communities.*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   *Example: Inequalities could arise if people who are not affected by flood risks have to pay for measures protecting only few inhabitants.*

   *Inequalities could arise between the households in the upstream and downstream communities of the Peristerona Watershed. Upstream communities abstract groundwater for domestic water supply, thus households will have lower water charges compared to the households in the downstream communities using desalinated water.*

MEASURE 1.4: Groundwater recharge systems

1. How are costs for the implementation and upkeep of this measure shared between parties?

   *Example: Flood protection measures (technical measures at private property)→ are these paid by the owner of the building/property, or by the general public? How is the upkeep/O&M paid for – privately or with public funds?*

   *Downstream communities in the Peristerona Watershed bear the cost of the maintenance of check dams along the Peristerona River.*

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   *Example: Flood protection walls are built that disturb the quality of the landscape.*

   –

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   *Example: Flood protection walls that disturb the quality of the landscape are designed in an appealing way at higher costs.*

   –

4. If no: Who will carry the burden of the negative side-effects?

   *Example: The inhabitants living nearby a measure with negative side-effects.*

   –

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   *Example: Property owners living nearby flood protection walls benefit from reduced flood risks.*

   *The check dams slow down the river flow and improve groundwater recharge and water quality, thus increasing water availability for domestic water supply and irrigation.*

   *NOTE to questions 6 and 7: If the quantitative analysis of measures within T5.2 so far (assessment of risk reduction effectiveness, MCA/MCDA approach to assess benefits of a measure) to your opinion neglects any decision relevant side effects of the measure, please answer question 6 and 7. Otherwise you may skip them.*

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   *Note: Here benefits are asked for that have not been quantitatively assessed in the T5.2 socio-economic analysis so far (e.g. as planned as feedback in your T5.2 case-study template). A qualitative answer is sufficient.*

7. Which actor(s) will enjoy these indirect benefits?

   *Example: Property owners living nearby a restored river section benefit from an improved living quality (recreational benefits).*

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   *Note: Here equity principles described in the introduction page are asked (i.e. the deontological/solidarity/egalitarian principles).*

   *The egalitarian principle: the proper maintenance of the check dams will improve groundwater recharge, i.e., improve the provision of a public good.*

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   *Example: Inequalities could arise if people who are not affected by flood risks have to pay for measures protecting only few inhabitants.*

   *The measure reduces existing inequalities between the upstream and downstream communities of the Peristerona Watershed as it increases the groundwater recharge and subsequently the water availability for the downstream communities.*

## Norway (Bergen)

## Measure: SUDS

In Norway, stormwater is commonly managed following a three-step approach: 1) Retain and infiltrate (frequent events), 2) detain and delay (medium extreme events, typically T=20yr), and 3) Secure safe flood paths (extreme events). Sustainable urban drainage systems (SUDS) refers to a wide range of techniques used for stormwater management are typically based on the philosophy of replicating the natural, pre-development conditions (Fletcher *et al.*, 2015). Due to their reliance on nature-based processes (i.e. evapotranspiration, infiltration) SUDS in Norway are designed for handling the frequent to medium extreme events (Step 1-2).

In the Bergen case, we focus on a sub-group of SUDS such that only 'blue-green' SUDS, i.e. type of SUDS that are vegetated and surface-based are considered. We also focus on SuDS that are meant for at-site volume control, i.e. SuDS measures that handles stormwater locally, at-site through retention or detention.

1. How are costs for the implementation and upkeep of this measure shared between parties?

   The owner of the measure is responsible for implementation and maintenance of the measure. If the measure is implemented by the municipality, the measure will be part of the municipal drainage system and followingly the costs are municipal. In Bergen, the Agency for Water and Sewerage Works (AWSW) manage the drainage system and the cost will fall within their budget. The AWSW is fully financed by water and sewerage fees paid by the public. Norwegian municipalities are increasingly encouraging and demanding blue-green solutions when processing new building proposals and developments. Depending on the municipality, private developers may be imposed to manage stormwater at-site through SuDS. The developer will then bear the cost of implementation and the owner will bear the cost of maintenance.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   SUDS require surface area – a scarce resource in built-up environment. Thus, a decision to implement SUDS will in many cases mean that other needs, wishes and proposals for the same area is given less priority.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   Many SUDS may be designed and categorized as multi-functional (e.g. recreational areas can be designed as open, dry detention basins, etc). If such solutions are chosen several needs can be met. Local governance can help ensure such solutions. The Norwegian municipality Oslo has defined stormwater strategy that developers must follow. In this strategy, it is clearly stated that multifunctional SUDS are expected and preferred to traditional solutions (The City of Oslo, 2013).

4. If no: Who will carry the burden of the negative side-effects?

   Land-use stakeholders (both private and municipal).

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   The public is the main beneficiary.

   Since blue-green SuDS are not the traditional measures used for stormwater management in Norway, the market for pre-fabricated SUDS solutions and relevant consultancy services has potential to grow. Thus, increased demand for SUDS may incur economic revenue and development of solutions for new and established actors and suppliers.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   In addition to at-site volume control, the NOU 2015:16 report states that blue-green SUDS may incur positive side-effect such as pollution control, noise reduction, $CO_2$- capturing, better air quality and biodiversity. In addition, it is expected the green environment resulting of some SUDS (e.g. open rivers and creeks, dams, and open, vegetated dry basins) invite to recreational activities that are positive for mental and physical health. Traces of natural elements (such as running water or water mirrors) can have positive effects on children's learning and development.

7. Which actor(s) will enjoy these indirect benefits?

   The public.

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   The deontological - due to SUDS being based on local stormwater management (at-site control → 'the polluter pays')

   The Solidarity - due to the many positive effect SUDS can have for the public if designed as multi-functional solutions and/or located in places where the public can enjoy them.

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   Reduce existing social inequalities when designed for the public.

References:

Fletcher, T. D. *et al.* (2015) 'SUDS, LID, BMPs, WSUD and more - The evolution and application of terminology surrounding urban drainage', *Urban Water Journal*, 12(7), pp. 525-542. doi: 10.1080/1573062X.2014.916314.

NOU 2015:16. *Overvann i byer og tettsteder - som problem og ressurs* [*Norwgian public investigations 2015:16. Stormwater in urban areas - problem and resource*]. Departmentenes sikkerhets- og serviceorganisasjon Informasjonsforvaltning. 2015.

The City of Oslo. *Strategi for overvannshåndtering i Oslo 2013-2030 [Strategy for stormwater management in Oslo];* Oslo, Norway, 2013.

## Measure: Road as emergency flood way

In Norway, stormwater is commonly managed following a three-step approach: 1) Retain and infiltrate (frequent events), 2) detain and delay (medium extreme events, typically T=20yr), and 3) Secure safe flood paths (extreme events). Using roads to route stormwater to recipients is a measure used in Norway during the most extreme precipitation events (step 3). It is an emergency solution aimed at securing safe paths for the water to flow during events that are so extreme and rare that it is not possible, nor economically feasible, to design retention or detention measures for. In urban, built-up areas, existing road network is sometimes the only available space for routing extreme runoff.

Because stormwater has traditionally been managed along with sewage in piped systems governed by Norwegian municipalities, the administrative and legal responsibility for stormwater, and open, surface-based measures for handling stormwater, is unclear. To address this, an Official Norwegian Report (NOU 2015:16) was issued in 2015 by a committee constituted by the Norwegian Government. The recommendations and perceptions of the committee is basis for the answers provided in this questionnaire.

1. How are costs for the implementation and upkeep of this measure shared between parties?

   NOU 2015:16 states that the actor responsible for implementing and financing this measure should also be considered the owner of the facility. It follows from this, that the owner of sewage systems (including open, surface-based solutions) is responsible for the uptake and maintenance of the facility according to the Norwegian Pollution Control Act §24. This also applies when the measure is implemented at property that is not owned by the responsible actor.

   NOU 2015:16 recommends that Norwegian municipalities are responsible for regulating floods paths for leading stormwater safely to recipients. Because roads have multiple functionality, preparing roads for emergency flood ways should be part of interdisciplinary, municipal zoning planning where all stakeholders have the opportunity to object (NOU 2015). Relevant stakeholders are neighbors, local associations, road owners and civil protection authorities. Hence, if the municipality is considered the owner of the measure, the municipality is also responsible for the costs for implementation and maintenance. If, however, the road owner (private, municipality, county or country) ensure implementation, the road owner is also considered the owner of the measure, with associated responsibilities and costs.

   It is natural that that the municipal Agency for Water and Sewerage works (AWS) takes a leading role in the planning and implementation of this measure and will thus be carrying a large portion of the costs. The services provided by the AWS is fully financed through public fees. Thus, the public is, indirectly, sharing the costs.

   Norway lacks guidelines and design recommendations in order to safely use roads as emergency flood ways. In order to be able to implement, such guidelines must be in place. NOU 2015:16 suggests that the Norwegian Road Authority provide the investigations and evaluations necessary to develop guidelines. The estimated cost of this work is 10-15 MNOK (NOU 2015:16).

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   The following negative side-effects are mentioned in NOU 2015:16:

   The measure might cause damaging effects such as clogged drains/intakes, erosion, fractures in the road and reduced life expectancy of the road cover. Furthermore, the measure can cause negative effects for road users (pedestrians, cyclists and drivers) that can lead to accidents such as; reduced friction and stability due to water velocity and depth, aquaplaning, reduced visibility, and traffic jams

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   Damaging effects would depend on the flow velocities occurring during an extreme event, the length of road used for routing and the specific local design of constructions made to adapt the road for flood routing. These effects may be mitigated if guidelines and regulations as described in Q1 for securing a proper design exists. As stated above, the NOU 2015:16 recommends that the Norwegian Road Authority provides this.

   For mitigating accidents caused by other negative side-effects, warning systems should be in place to minimize traffic and exposure to the associated risks. According to Skrede (2018), cars parked in roads used for emergency flood routing are prone to damages if flow velocity is high and friction reduced. A system for temporal parking restrictions when extreme events are forecasted is proposed (Skrede, 2018).

4. If no: Who will carry the burden of the negative side-effects?

   Measure owner (assumed municipality), the road owner, pedestrians, cyclists and drivers.

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   This measure benefits the public. The idea is to route the water in a controlled manner during very extreme events, rather than letting the water flow freely and uncontrolled and potentially cause accidents and large material damages. Avoiding flooding of private property will be a benefit for private property owners and insurance agencies and will help maintaining the reputation and image of the municipality. It is also assumed that the overall costs of the municipality will be reduced as the measure involves adding functionality to existing infrastructure (road) rather than constructing or upgrading storm sewers.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   The low level of physical intervention (minimum digging required) is a social benefit as implementation will be faster and noise pollution reduced compared to traditional measures (buried) for stormwater management.

7. Which actor(s) will enjoy these indirect benefits?

   The public.

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   Using roads as emergency flood ways applies to rainfall events so extreme that the adaptation measure has to be ‘system-level’. Thus, the aim is that the measure benefits the whole system, i.e. the society and the egalitarian principle thus applies.

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

The measure is supposed to benefit the society as a whole, and everyone equally benefit from the measure. Thus, the measure strengthens social equalities.

References

NOU 2015:16. *Overvann i byer og tettsteder – som problem og ressurs* [*Norwgian public investigations 2015:16. Stormwater in urban areas – problem and resource*]. Departmentenes sikkerhets- og serviceorganisasjon Informasjonsforvaltning. 2015.

Skrede, T. I. *The applicability of urban streets as temporary open floodways – A case study from Bergen, Norway*. Master's thesis. Norwegian University of Science and Technology. 2018.

### Measure: Separation of sewer system

1. How are costs for the implementation and upkeep of this measure shared between parties?

   The sewer system is owned by the municipality and governed on behalf of the municipality by the municipal Agency for Water and Sewerage Works (AWSW). AWSW is responsible for planning and initiating of the measure but the maintenance is performed by the municipal owned company Bergen Vann (Bergen Water) upon request from AWSW. Thus, AWSW is also responsible for all the costs related to the measure.

   The sewers routing water from private property onto the municipal network is usually owned by the property owner. If separation of the municipal sewers is implemented separation it may be necessary to separate private sewers as well. According to the Norwegian Pollution Control Act §22 the municipality has the authority to request separation of private sewers if the municipality itself is separating the municipal network. In such case, the private owner is responsible for implementation and is also bearing the cost.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   Implementation of the measure entails the use of two separate sewers instead of one combined sewer. This will likely raise the need for constructing new trenches (Vista Analyse, 2015). Temporary, negative side-effects occur manly the construction work related to new sewers and trenches. Examples of such negative side-effects are noise and lowered mobility for pedestrians, bikers and drivers.

   Furthermore, separation of private sewers (as described in 1) cause extra costs and inconveniences for private owners.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   The contractor responsible for the construction work is responsible for mitigating the negative side-effects. With regards to noise, choice of equipment will impact the noise level. Proper logistical plans can countervail the lowered mobility.

4. If no: Who will carry the burden of the negative side-effects?

   The public.

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   The public.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   Besides mitigating CSO spills to receiving water bodies, separating the sewer system has several positive side-effects. Sewage and stormwater have different treatment needs and separation will decrease the load on treatment facilities. It will also decrease the load on pumping stations, and thus, operation and maintenance costs. Furthermore, separating the sewers will reduce the risk of flooded basements during extreme precipitation and combined sewers reaching their capacities. Another possible positive side-effect is that separation opens up for the possibility to uograde the capacity of the storm sewer such that climate change and increased area of impermeable pavements may be accounted for.

7. Which actor(s) will enjoy these indirect benefits?

   The public.

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   For separation of the municipal sewer system, the egalitarian and solidarity principle due to the measure being a system-level measure.

   For private owners being requested to separate their private sewers due to the municipal system being separated, the deontological ('polluter-pays') principle applies.

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   Because separation is a system-level measure where the aim is to provide the same service (safe transportation of sewage and stormwater) to all inhabitants it strengthens social equalities.

## References

Vista Analyse. *Kostnader og nytte ved overvannstiltak [Cost-benefit of stormwater measures].* Vista Analyse AS, Report 2015/02. Oslo, Norway, 2015.

## Spain (Badalona)

## Measure: Early Warning System

1. How are costs for the implementation and upkeep of this measure shared between parties?

   The costs for the implementation and upkeep of the measure would be assumed by the Badalona City Council given that it is a measure (service) for the municipality.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   No

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   -

4. If no: Who will carry the burden of the negative side-effects?

   -

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   The measure will benefit the general public (Badalona's citizens).

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   Regarding the Early Warning System for Flooding the measure can contribute to the anticipation of preventive measures and thus to prevent direct damages on citizens (loss of lives and related health problems), vehicles, buildings and other urban assets.

   Regarding the Early Warning System for CSOs the measure can contribute to the anticipation of preventive measures and thus to prevent direct damages on Badalona's beaches and its related uses.

7. Which actor(s) will enjoy these indirect benefits?

   The general public (Badalona's citizens) and the Badalona City Council.

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   None

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   None

## Measure: Inlets increase and overall increase of the drainage and retention capacity of the network

1. How are costs for the implementation and upkeep of this measure shared between parties?

   The costs for the implementation and upkeep of the measure would be assumed by the Badalona City Council given that it is a measure for the municipality. Also some private construction companies could be requested to contribute to the funding of new developments. Maybe some European subsidies (e.g. FEDER funds or similar) could be requested to contribute to its funding.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   In case all or part of this important measure was implemented, the City Council should increase municipal taxes to cover these additional costs. This will affect the economy of citizens.

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   Some social aids (bonuses) could be provided for vulnerable groups to pay these extra costs.

4. If no: Who will carry the burden of the negative side-effects?

   -

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   The measure will benefit the general public given that it will contribute to the reduction of flooding and combined sewer overflows (CSOs) events. It will also benefit the managers of the sewer system given that due to the enlargement of the current sewer system it will be collapsed less frequently.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   The lower occurrence of CSOs episodes will decrease the risk of bather's contact with polluted water (health impact) and will allow users of the Badalona's beaches to enjoy more their associated services. Also other sectors related to beach's services/businesses (tourism, fishing, restaurant and other leisure sectors) will directly benefit (economic benefits) from the "normal" status of the beach.

   Also the lower occurrence of flooding and CSOs episodes will increase the social perception (trust) in municipality's efficiency.

7. Which actor(s) will enjoy these indirect benefits?

   The general public (users of Badalona's beaches) for the first one and the Badalona City Council for the second one.

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

The deontological principle, given that the final users of the sewer system's service are paying for its proper performance (also for the causes of climate change that are forcing these measures)

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   The measure will benefit all the Badalona's inhabitants equally.

## Measure: Nature Based Solutions

1. How are costs for the implementation and upkeep of this measure shared between parties?

   The costs for the implementation and upkeep of the measure would be assumed by the Badalona City Council given that it is a measure for the municipality. Maybe some European subsidies (e.g. FEDER funds or similar) could be requested to contribute to its funding.

2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?

   No

3. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?

   -

4. If no: Who will carry the burden of the negative side-effects?

   -

5. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?

   The measure will benefit the general public given that it will contribute to the reduction of flooding and combined sewer overflows (CSOs) events. It will also benefit the managers of the sewer system given that due to the on-source retention/detention/filtration of the stormwater performed by the sustainable urban drainage systems (nature based solutions) the sewer system will be collapsed less frequently.

6. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?

   Yes. Additional social co-benefits include:

   -enhanced public amenity

   -enhanced health benefits (due to the improvement of air quality)

   -increase of ecosystems services

   -reduction of heat island effect

   -job creation

7. Which actor(s) will enjoy these indirect benefits?

   Also the general public (Badalona's inhabitants).

8. Considering the answers to the questions above, which equity principles do you recognize in these distributions?

   The egalitarian principle, given that this measure maximize the positive effects and minimize the negative effects for the society as a whole

9. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

   The measure will benefit all the Badalona's inhabitants equally.

# ANNEX III – Supplementary material from cases

**Example template for the pairwise comparison of criteria in the German case study in Wuppertal to commit weighting factors**

BINGO
a better future under
CLIMATE CHANGE

**Paarvergleich der Kriterien**

| Nr. | Kriterium | | Nr. | Kriterium | Wert |
|---|---|---|---|---|---|
| 1 | Image | wichtiger als | 2 | Sensible Objekte (Kindergarten, Altersheim, Polizei) | |
| | | | 3 | Personenschäden | |
| | | | 4 | Rettungswege / Mobilität | |
| | | | 5 | Denkmäler | |
| | | | 6 | Einschränkung Stadtentwicklung | |
| | | | 7 | Stadtbild | |
| | | | 8 | Ökologie | |
| | | | 9 | Mikroklima | |

| Optionen: |
|---|
| 2 = Ja |
| 1 = Unentschlossen |
| 0 = Nein |

| Nr. | Kriterium | | Nr. | Kriterium | Wert |
|---|---|---|---|---|---|
| 2 | Sensible Objekte (Kindergarten, Altersheim, Polizei) | wichtiger als | 3 | Personenschäden | |
| | | | 4 | Rettungswege / Mobilität | |
| | | | 5 | Denkmäler | |
| | | | 6 | Einschränkung Stadtentwicklung | |
| | | | 7 | Stadtbild | |
| | | | 8 | Ökologie | |
| | | | 9 | Mikroklima | |

| Nr. | Kriterium | | Nr. | Kriteirum | Wert |
|---|---|---|---|---|---|
| 3 | Personenschäden | wichtiger als | 4 | Rettungswege / Mobilität | |
| | | | 5 | Denkmäler | |
| | | | 6 | Einschränkung Stadtentwicklung | |
| | | | 7 | Stadtbild | |
| | | | 8 | Ökologie | |
| | | | 9 | Mikroklima | |

## Decision support table to adapt the sewer system and city quarter of Damsgård, Bergen to climate change (in relation to CSO risks)

| Subcatch-ment number [FID_Nr.] | Area subcatch-ment [m²] | Area public property [m²] | *Normal-ized score public property-* | Area public property [%] | Area buildings [m²] | Area buildings [%] | Area roads [m²] | Area roads [%] | Area natural / non-build-up [m²] | Area natural / non-build-up [%] | CSO reduction volume [10^6 litre] | *Normal-ized score of CSO reduction volume [%]* | *Combined normal-ized score* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 2760.04 | 2671.91 | *0.10* | 96.81% | 508.74 | 18.43% | 448.60 | 16.25% | 1802.70 | 65.31% | 0.11 | *0.05* | 0.07 |
| 1 | 2593.42 | 1439.25 | *0.05* | 55.50% | 735.96 | 28.38% | 327.94 | 12.65% | 1529.52 | 58.98% | 0.11 | *0.05* | 0.05 |
| 2 | 4668.46 | 0.00 | *0.00* | 0.00% | 1059.70 | 22.70% | 920.33 | 19.71% | 2688.43 | 57.59% | 0.01 | *0.01* | 0.00 |
| 3 | 2626.45 | 0.00 | *0.00* | 0.00% | 816.77 | 31.10% | 29.48 | 1.12% | 1780.19 | 67.78% | 0.01 | *0.00* | 0.00 |
| 4 | 4065.45 | 0.00 | *0.00* | 0.00% | 1119.44 | 27.54% | 582.28 | 14.32% | 2363.73 | 58.14% | 0.01 | *0.01* | 0.00 |
| 5 | 3039.51 | 0.00 | *0.00* | 0.00% | 908.83 | 29.90% | 831.50 | 27.36% | 1299.19 | 42.74% | 0.01 | *0.00* | 0.00 |
| 6 | 1685.15 | 100.79 | *0.00* | 5.98% | 201.76 | 11.97% | 235.07 | 13.95% | 1248.32 | 74.08% | 0.01 | *0.00* | 0.00 |
| 7 | 3273.36 | 710.93 | *0.03* | 21.72% | 453.74 | 13.86% | 660.93 | 20.19% | 2158.69 | 65.95% | 0.01 | *0.00* | 0.01 |
| 8 | 718.76 | 291.94 | *0.01* | 40.62% | 2.28 | 0.32% | 343.90 | 47.85% | 372.57 | 51.84% | 0.00 | *0.00* | 0.01 |
| 9 | 1881.24 | 10.18 | *0.00* | 0.54% | 435.41 | 23.14% | 3.17 | 0.17% | 1442.66 | 76.69% | 0.01 | *0.00* | 0.00 |
| 10 | 1523.35 | 2.38 | *0.00* | 0.16% | 395.99 | 25.99% | 1.14 | 0.08% | 1126.22 | 73.93% | 0.00 | *0.00* | 0.00 |
| 11 | 2305.65 | 0.00 | *0.00* | 0.00% | 584.44 | 25.35% | 252.26 | 10.94% | 1468.95 | 63.71% | 0.01 | *0.00* | 0.00 |
| 12 | 6445.01 | 1935.60 | *0.07* | 30.03% | 2109.52 | 32.73% | 1439.80 | 22.34% | 2895.69 | 44.93% | 0.02 | *0.01* | 0.04 |
| 13 | 1651.26 | 0.00 | *0.00* | 0.00% | 718.26 | 43.50% | 17.11 | 1.04% | 915.89 | 55.47% | 0.01 | *0.00* | 0.00 |
| 14 | 2005.05 | 99.43 | *0.00* | 4.96% | 553.92 | 27.63% | 603.40 | 30.09% | 847.73 | 42.28% | 0.01 | *0.00* | 0.00 |
| 15 | 1733.08 | 428.05 | *0.02* | 24.70% | 313.70 | 18.10% | 152.83 | 8.82% | 1266.55 | 73.08% | 0.01 | *0.00* | 0.01 |
| 16 | 2226.59 | 0.00 | *0.00* | 0.00% | 803.26 | 36.08% | 123.63 | 5.55% | 1299.70 | 58.37% | 0.01 | *0.00* | 0.00 |
| 17 | 3218.04 | 406.75 | *0.01* | 12.64% | 633.15 | 19.68% | 559.32 | 17.38% | 2025.56 | 62.94% | 0.01 | *0.00* | 0.01 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 762.42 | 216.69 | *0.01* | 28.42% | 147.13 | 19.30% | 0.00 | 0.00% | 615.29 | 80.70% | 0.00 | *0.00* | 0.00 |
| 19 | 2730.28 | 1121.49 | *0.04* | 41.08% | 694.37 | 25.43% | 126.73 | 4.64% | 1909.18 | 69.93% | 0.01 | *0.00* | 0.02 |
| 20 | 4156.64 | 2365.27 | *0.09* | 56.90% | 688.88 | 16.57% | 293.48 | 7.06% | 3174.28 | 76.37% | 0.01 | *0.01* | 0.05 |
| 21 | 2249.89 | 964.17 | *0.03* | 42.85% | 523.63 | 23.27% | 183.77 | 8.17% | 1542.49 | 68.56% | 0.01 | *0.00* | 0.02 |
| 22 | 5857.57 | 3230.29 | *0.12* | 55.15% | 1390.01 | 23.73% | 1176.94 | 20.09% | 3290.63 | 56.18% | 0.02 | *0.01* | 0.06 |
| 23 | 4961.98 | 2595.31 | *0.09* | 52.30% | 1743.37 | 35.13% | 1077.39 | 21.71% | 2141.21 | 43.15% | 0.16 | *0.07* | 0.08 |
| 24 | 2269.56 | 511.06 | *0.02* | 22.52% | 493.35 | 21.74% | 229.46 | 10.11% | 1546.75 | 68.15% | 0.06 | *0.03* | 0.02 |
| 25 | 1250.03 | 649.44 | *0.02* | 51.95% | 402.53 | 32.20% | 558.14 | 44.65% | 289.36 | 23.15% | 0.02 | *0.01* | 0.02 |
| 26 | 4908.63 | 0.00 | *0.00* | 0.00% | 1202.66 | 24.50% | 471.32 | 9.60% | 3234.65 | 65.90% | 0.01 | *0.01* | 0.00 |
| 27 | 3039.89 | 10.07 | *0.00* | 0.33% | 389.23 | 12.80% | 540.95 | 17.80% | 2109.71 | 69.40% | 0.09 | *0.04* | 0.02 |
| 28 | 2707.83 | 0.00 | *0.00* | 0.00% | 686.10 | 25.34% | 255.49 | 9.44% | 1766.23 | 65.23% | 0.01 | *0.00* | 0.00 |
| 29 | 3122.01 | 5.30 | *0.00* | 0.17% | 987.76 | 31.64% | 301.50 | 9.66% | 1832.74 | 58.70% | 0.10 | *0.04* | 0.02 |
| 30 | 2392.67 | 93.13 | *0.00* | 3.89% | 540.34 | 22.58% | 436.89 | 18.26% | 1415.44 | 59.16% | 0.06 | *0.02* | 0.01 |
| 31 | 3646.40 | 307.24 | *0.01* | 8.43% | 647.78 | 17.77% | 290.88 | 7.98% | 2707.74 | 74.26% | 0.09 | *0.04* | 0.03 |
| 32 | 6458.47 | 397.03 | *0.01* | 6.15% | 1400.35 | 21.68% | 731.80 | 11.33% | 4326.31 | 66.99% | 0.12 | *0.05* | 0.03 |
| 33 | 2593.58 | 950.35 | *0.03* | 36.64% | 503.28 | 19.40% | 433.76 | 16.72% | 1656.54 | 63.87% | 0.08 | *0.03* | 0.03 |
| 34 | 6337.53 | 694.90 | *0.03* | 10.96% | 1018.81 | 16.08% | 937.59 | 14.79% | 4381.14 | 69.13% | 0.13 | *0.06* | 0.04 |
| 35 | 4101.01 | 652.50 | *0.02* | 15.91% | 684.01 | 16.68% | 276.60 | 6.74% | 3140.40 | 76.58% | 0.14 | *0.06* | 0.04 |
| 36 | 2384.55 | 1646.84 | *0.06* | 69.06% | 348.73 | 14.62% | 279.99 | 11.74% | 1755.83 | 73.63% | 0.01 | *0.00* | 0.03 |
| 37 | 3150.80 | 517.24 | *0.02* | 16.42% | 831.66 | 26.40% | 428.21 | 13.59% | 1890.93 | 60.01% | 0.10 | *0.04* | 0.03 |
| 38 | 3020.53 | 331.62 | *0.01* | 10.98% | 348.87 | 11.55% | 667.10 | 22.09% | 2004.55 | 66.36% | 0.07 | *0.03* | 0.02 |
| 39 | 4117.23 | 944.18 | *0.03* | 22.93% | 626.74 | 15.22% | 434.55 | 10.55% | 3055.94 | 74.22% | 0.12 | *0.05* | 0.04 |
| 40 | 10658.21 | 3614.37 | *0.13* | 33.91% | 2206.46 | 20.70% | 1969.95 | 18.48% | 6481.80 | 60.82% | 0.41 | *0.18* | 0.15 |
| 41 | 10047.44 | 1573.93 | *0.06* | 15.66% | 1792.43 | 17.84% | 1280.81 | 12.75% | 6974.20 | 69.41% | 0.26 | *0.11* | 0.08 |
| 42 | 3373.48 | 743.21 | *0.03* | 22.03% | 622.01 | 18.44% | 624.10 | 18.50% | 2127.37 | 63.06% | 0.10 | *0.04* | 0.04 |
| 43 | 4531.91 | 4048.81 | *0.15* | 89.34% | 1276.87 | 28.18% | 761.69 | 16.81% | 2493.35 | 55.02% | 0.03 | *0.01* | 0.08 |
| 44 | 2333.00 | 662.83 | *0.02* | 28.41% | 287.15 | 12.31% | 1080.28 | 46.30% | 965.57 | 41.39% | 0.01 | *0.00* | 0.01 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | 6031.75 | 1219.00 | *0.04* | 20.21% | 960.24 | 15.92% | 1234.14 | 20.46% | 3837.38 | 63.62% | 0.20 | *0.09* | 0.07 |
| 46 | 1990.15 | 512.43 | *0.02* | 25.75% | 570.75 | 28.68% | 0.00 | 0.00% | 1419.40 | 71.32% | 0.01 | *0.00* | 0.01 |
| 47 | 9113.41 | 4500.79 | *0.16* | 49.39% | 2410.65 | 26.45% | 1535.95 | 16.85% | 5166.82 | 56.69% | 0.03 | *0.01* | 0.09 |
| 48 | 3214.11 | 822.16 | *0.03* | 25.58% | 158.11 | 4.92% | 406.80 | 12.66% | 2649.20 | 82.42% | 0.01 | *0.00* | 0.02 |
| 49 | 2056.96 | 845.01 | *0.03* | 41.08% | 479.06 | 23.29% | 399.25 | 19.41% | 1178.65 | 57.30% | 0.01 | *0.00* | 0.02 |
| 50 | 1909.87 | 1743.64 | *0.06* | 91.30% | 85.42 | 4.47% | 377.45 | 19.76% | 1447.00 | 75.76% | 0.01 | *0.00* | 0.03 |
| 51 | 2897.52 | 2399.95 | *0.09* | 82.83% | 13.64 | 0.47% | 952.99 | 32.89% | 1930.89 | 66.64% | 0.00 | *0.00* | 0.04 |
| 52 | 2694.98 | 1158.40 | *0.04* | 42.98% | 1457.07 | 54.07% | 597.64 | 22.18% | 640.27 | 23.76% | 0.09 | *0.04* | 0.04 |
| 53 | 1533.57 | 56.02 | *0.00* | 3.65% | 389.85 | 25.42% | 103.13 | 6.72% | 1040.60 | 67.85% | 0.00 | *0.00* | 0.00 |
| 54 | 2829.54 | 2335.54 | *0.08* | 82.54% | 141.05 | 4.98% | 1688.77 | 59.68% | 999.72 | 35.33% | 0.10 | *0.04* | 0.06 |
| 55 | 12834.67 | 9329.37 | *0.34* | 72.69% | 990.33 | 7.72% | 706.75 | 5.51% | 11137.59 | 86.78% | 0.53 | *0.22* | 0.28 |
| 56 | 3422.06 | 787.83 | *0.03* | 23.02% | 0.00 | 0.00% | 748.03 | 21.86% | 2674.03 | 78.14% | 0.15 | *0.06* | 0.05 |
| 57 | 2846.25 | 803.42 | *0.03* | 28.23% | 436.92 | 15.35% | 370.81 | 13.03% | 2038.53 | 71.62% | 0.12 | *0.05* | 0.04 |
| 58 | 8228.19 | 6794.07 | *0.25* | 82.57% | 3084.16 | 37.48% | 374.32 | 4.55% | 4769.72 | 57.97% | 0.01 | *0.00* | 0.13 |
| 59 | 2345.66 | 2173.48 | *0.08* | 92.66% | 465.03 | 19.83% | 196.34 | 8.37% | 1684.29 | 71.80% | 0.00 | *0.00* | 0.04 |
| 60 | 4859.86 | 4631.96 | *0.17* | 95.31% | 915.09 | 18.83% | 1032.17 | 21.24% | 2912.61 | 59.93% | 0.21 | *0.09* | 0.13 |
| 61 | 2358.11 | 2289.98 | *0.08* | 97.11% | 377.16 | 15.99% | 389.88 | 16.53% | 1591.07 | 67.47% | 0.10 | *0.04* | 0.06 |
| 62 | 4324.59 | 2670.91 | *0.10* | 61.76% | 657.44 | 15.20% | 951.55 | 22.00% | 2715.60 | 62.79% | 0.00 | *0.00* | 0.05 |
| 63 | 7526.05 | 1548.83 | *0.06* | 20.58% | 2027.23 | 26.94% | 1126.13 | 14.96% | 4372.69 | 58.10% | 0.01 | *0.00* | 0.03 |
| 64 | 4802.98 | 1887.12 | *0.07* | 39.29% | 1594.39 | 33.20% | 2.76 | 0.06% | 3205.83 | 66.75% | 0.20 | *0.09* | 0.08 |
| 65 | 1573.56 | 1534.42 | *0.06* | 97.51% | 213.97 | 13.60% | 10.05 | 0.64% | 1349.53 | 85.76% | 0.00 | *0.00* | 0.03 |
| 66 | 3461.58 | 724.48 | *0.03* | 20.93% | 914.69 | 26.42% | 169.16 | 4.89% | 2377.73 | 68.69% | 0.00 | *0.00* | 0.01 |
| 67 | 4971.12 | 1532.64 | *0.06* | 30.83% | 1009.35 | 20.30% | 951.51 | 19.14% | 3010.27 | 60.56% | 0.01 | *0.00* | 0.03 |
| 68 | 4094.72 | 538.86 | *0.02* | 13.16% | 1107.01 | 27.04% | 956.45 | 23.36% | 2031.26 | 49.61% | 0.01 | *0.00* | 0.01 |
| 69 | 5169.39 | 2880.32 | *0.10* | 55.72% | 602.00 | 11.65% | 1540.79 | 29.81% | 3026.60 | 58.55% | 0.14 | *0.06* | 0.08 |
| 70 | 7515.85 | 1077.74 | *0.04* | 14.34% | 1269.13 | 16.89% | 920.44 | 12.25% | 5326.27 | 70.87% | 0.20 | *0.08* | 0.06 |
| 71 | 6918.68 | 6918.68 | *0.25* | 100.00% | 24.06 | 0.35% | 2336.27 | 33.77% | 4558.35 | 65.88% | 0.19 | *0.08* | 0.17 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | 3451.53 | 3451.53 | *0.12* | 100.00% | 0.00 | 0.00% | 913.46 | 26.47% | 2538.07 | 73.53% | 0.08 | *0.03* | 0.08 |
| 73 | 2416.65 | 1483.22 | *0.05* | 61.38% | 0.00 | 0.00% | 850.25 | 35.18% | 1566.39 | 64.82% | 0.06 | *0.03* | 0.04 |
| 74 | 1279.97 | 1279.97 | *0.05* | 100.00% | 0.00 | 0.00% | 768.72 | 60.06% | 511.25 | 39.94% | 0.02 | *0.01* | 0.03 |
| 75 | 5202.89 | 866.74 | *0.03* | 16.66% | 2222.18 | 42.71% | 376.76 | 7.24% | 2603.95 | 50.05% | 0.00 | *0.00* | 0.02 |
| 76 | 79788.24 | 27668.61 | *1.00* | 34.68% | 0.00 | 0.00% | 1059.56 | 1.33% | 78728.68 | 98.67% | 2.34 | *1.00* | 1.00 |
| 77 | 17543.60 | 5571.50 | *0.20* | 31.76% | 2.81 | 0.02% | 766.59 | 4.37% | 16774.20 | 95.61% | 0.72 | *0.31* | 0.26 |
| 78 | 4131.00 | 3886.42 | *0.14* | 94.08% | 163.29 | 3.95% | 2681.17 | 64.90% | 1286.54 | 31.14% | 0.14 | *0.06* | 0.10 |
| 79 | 2922.78 | 2922.78 | *0.11* | 100.00% | 10.50 | 0.36% | 2114.56 | 72.35% | 797.72 | 27.29% | 0.09 | *0.04* | 0.07 |
| 80 | 6302.49 | 6098.75 | *0.22* | 96.77% | 0.00 | 0.00% | 5968.62 | 94.70% | 333.87 | 5.30% | 0.14 | *0.06* | 0.14 |
| 81 | 1639.71 | 1613.06 | *0.06* | 98.37% | 0.00 | 0.00% | 1224.14 | 74.66% | 415.58 | 25.34% | 0.05 | *0.02* | 0.04 |
| 82 | 2104.07 | 1935.35 | *0.07* | 91.98% | 67.46 | 3.21% | 1710.93 | 81.32% | 325.68 | 15.48% | 0.06 | *0.03* | 0.05 |
| 83 | 4366.82 | 4311.70 | *0.16* | 98.74% | 10.01 | 0.23% | 788.05 | 18.05% | 3568.77 | 81.72% | 0.19 | *0.08* | 0.12 |
| 84 | 1560.76 | 1399.81 | *0.05* | 89.69% | 56.58 | 3.63% | 724.21 | 46.40% | 779.97 | 49.97% | 0.06 | *0.02* | 0.04 |
| 85 | 726.38 | 352.11 | *0.01* | 48.48% | 5.29 | 0.73% | 29.71 | 4.09% | 691.38 | 95.18% | 0.04 | *0.02* | 0.01 |
| 86 | 1401.35 | 757.46 | *0.03* | 54.05% | 4.78 | 0.34% | 374.81 | 26.75% | 1021.76 | 72.91% | 0.07 | *0.03* | 0.03 |
| 87 | 6063.01 | 4053.90 | *0.15* | 66.86% | 0.00 | 0.00% | 1807.71 | 29.82% | 4255.30 | 70.18% | 0.27 | *0.12* | 0.13 |
| 88 | 1764.37 | 1764.37 | *0.06* | 100.00% | 0.41 | 0.02% | 703.28 | 39.86% | 1060.68 | 60.12% | 0.07 | *0.03* | 0.05 |