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Climate action, environment, resource
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BINGO

Bringing INnovation to onGOing water management –

a better future under climate change

Grant Agreement n° 641739, Research and Innovation Action

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Contributor(s) [alphabetical]:	Henk-Jan van Alphen (KWR), Elsa Alves (LNEC), Tim aus der Beek (IWW), Adriana Bruggeman (CYI), Corrado Camera (CYI), Reinhard Fohrmann (IWW), André Fortunato (LNEC), Paula Freire (LNEC), Ayis Iacovides (IACO), Iacovos Iacovides (IACO), Erle Kristvik (NTNU), Christine Kübeck (IWW), Paula Lorza (WV), Tone Muthanna (NTNU), Emilia Novo (LNEC), Fernanda Rocha (LNEC), Marta Rodrigues (LNEC), Rui Rodrigues (LNEC), Beniamino Russo (AQUALOGY), Pablo Sánchez (AQUALOGY), Marc Scheibel (WV), Teun Spek (GLD), Flip Witte(KWR), Christos Zoumides (CYI)
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Changes with respect to the DoA

Not applicable

Dissemination and uptake

This report is confidential, only for members of the consortium (including the European Commission Services).

Short Summary of results (<250 words)

D3.1 – *Characterization of the catchments and the water systems* was developed by IWW, LNEC, NTNU, KWR, AQUALOGY, CYI, and all local partners within WP3 - Integrated analysis of the water cycle.
This deliverable evaluates the state of water resources (surface and groundwater, quantity and quality) at all six research sites. A consistent characterization of the catchments and surface, groundwater, and estuarine water bodies, including land use, pollution sources and anthropogenic water abstractions is included. It includes measured data, results from previous research, literature, knowledge. This deliverable serves as an overview of all six BINGO research sites.
According to the comments and suggestions made by the external EC reviewer, this report has been updated on November 15th 2016.

Evidence of accomplishment

This report.

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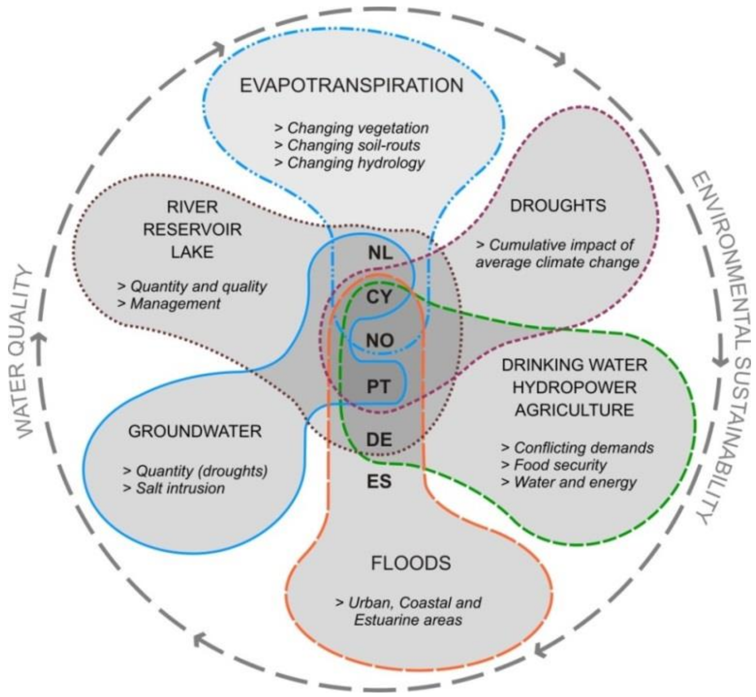
1. INTRODUCTION

This document is developed as part of the BINGO (Bringing INnovation to onGOing water management – a better future under climate change) project, which has received funding from the European Union's Horizon 2020 Research and Innovation programme, under the Grant Agreement number 641739. The Project website (www.projectbingo.eu) represents Deliverable 3.1 of Work Package 3 (WP3) – Integrated analysis of the water cycle. According to the comments and suggestions made by the external EC reviewer, this report has been updated on November 15th 2016.

2. BINGO Research Site Characterization

BINGO is built around six research sites that represent challenges in terms of water management options and approaches. They have been selected based on relevant criteria (areas with expected strong impacts from climate change, previous R&D knowledge, end users in need for solutions, high potential for innovation and replication, competing demands) and covering a representative range of conditions. The following chapters provide a characterization of the (geo-)hydrological systems at the BINGO research sites in Cyprus, Germany, the Netherlands, Norway, Portugal, and Spain, These sites are differently affected by global change, as shown in the figure below. Therefore, this document serves as overview and reference for research site dependent work within WP3.



Range of water systems, strategic uses, and key problems addressed at BINGO research sites

The figure above provides an overview of water and climate change related challenges at the six BINGO research sites. It also depicts the multidimensional overlaps and interactions between the sites:

Floods are in focus of BINGO research activities at five sites (except Netherlands). At the Spanish, Portuguese, and Norwegian site, urban flash floods are of interest, as they can cause infrastructure damage, pollution of water, and implications for tourism. In addition, floods at the Norwegian, Cypriot, and German site have effects on reservoir management. Floods at the Portuguese site also can have impacts on estuary water quality and quantity as well as for saltwater intrusion.

Groundwater is a BINGO research topic at three sites. Linkages between the Portuguese and Dutch site have been established, as both sites conduct advanced groundwater modelling. In addition, at the Cypriot site groundwater overexploitation is an important problem to be tackled, whereas the effects of climate change on groundwater levels will be analysed at all three sites. Furthermore, the hydrological models of the other three sites also include groundwater routines, which can benefit from these advanced studies.

Rivers, reservoirs, and lakes are a common BINGO research topic at five sites (except Spain). The effect of climate change on reservoirs for water use purposes will be studied at the Norwegian, German, and Cypriot site. At all five sites hydrological models will be applied and/or further developed for river (sub-)basins, whereas a close collaboration of knowledge exchange is foreseen.

Evapotranspiration is an important driver for droughts and therefore studied at four sites (except Norway and Spain). The Dutch and German site coordinate the use of identical lysimeters in order to measure climate change induced variations of evapotranspiration and to directly compare data and trends. At the Cypriot and German site, interactions on equipment for measuring river runoff and soil moisture have been initiated. At all four sites, the advanced measurements will help to realistically improve the evapotranspiration model routines in order to better assess the impact of climate change on runoff and groundwater generation.

Droughts are a major BINGO topic at two sites. The Portuguese and Cypriot site features long dry and hot periods, which can have large scale consequences for multiple sectors. In order to assess the local impacts of climate change on drought intensity, both sites are collaborating.

Drinking water, hydropower, and agriculture are in the focus of BINGO research at four sites (except Netherlands and Spain). To balance water demands during droughts, e.g. for irrigation and drinking water purposes, and to prepare for future conditions, the German, Portuguese, and Cypriot site refer to each other. Furthermore, at the Norwegian and German site, hydropower water use is being considered.

2.1. Northern Troodos, Cyprus

2.1.1. Location of the site

The Cyprus Research Site is located along the northern slopes of the Troodos Mountains in Cyprus. The Troodos is a fragment of a fully developed oceanic crust, consisting of plutonic, intrusive and volcanic rocks and chemical sediments. It was formed in the Upper Cretaceous (90 Ma) as a result of the collision of the Eurasian and African plates. The stratigraphy of the ophiolite shows a topographic inversion, related to the way the ophiolite was uplifted (diapirically) and later eroded (Geological Survey Department, 2016). Its highest point at Mount Olympus is 1950 m above sea level.

The Troodos Mountains form the water tower of the island, with many streams running down its steep slopes, in deeply incised valleys. The northern slopes are in the rain shadow of the mountains and are less endowed with water resources than the southern slopes. Investigations in the agro-ecological and hydrological processes along the northern slopes of the Troodos mountains could also present insights in the potential effects of climate change on the southern slopes.

The research focusses on two representative watersheds along the northern slopes of the Troodos mountains: the Pedieos and the Peristerona Watersheds (Figure 1). Both rivers flow across the buffer zone into the northern part of the island, inhabited by the Turkish Cypriot community. These watersheds cover 112 km² and 120 km^2, respectively.

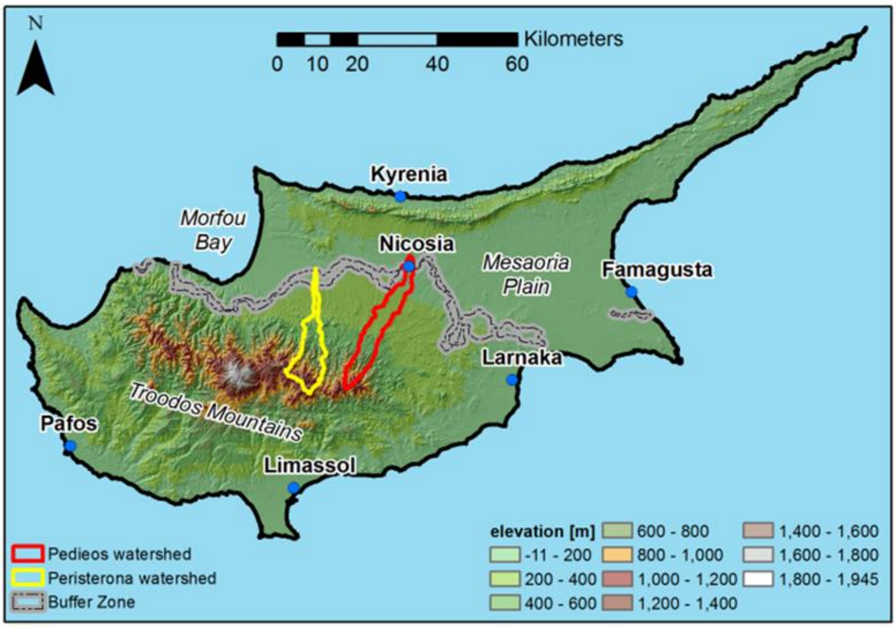


Figure 1. The Troodos mountains in Cyprus with the Peristerona and Pedieos Watersheds along the northern slopes

2.1.2. Local climate

Cyprus has a Mediterranean climate, with rain during the months October to May and very hot dry summers. December, January and February are the wettest months. The climate along the northern slopes of Troodos mountains is classified as semi-arid, while the mountains at higher elevations are classified as dry sub-humid (Bruggeman et al., 2015), according to the UNEP (United Nations Environment Programme) definition (Middleton and Thomas, 1997). The long-term average annual precipitation (1980-2010) was 754 mm at Polystypos (1100 m asl (above sea level)) in the mountains of Peristerona Watershed and 670 mm at Kionia (1200 m asl) in Pedieos Watershed. In the foothills, precipitation was 405 mm at Panagia Bridge (440 m asl) and 344 mm in Politiko (405 m asl). While precipitation was 270 mm at Peristerona (200 m asl) and 306 mm in Nicosia (160 m asl) in the plains. Average annual reference evapotranspiration, computed with the FAO Penman-Monteith equation (Allen et al., 1998), was 1278 mm in Agros (1015 m asl) in the mountains and 1384 mm in Nicosia in the plains (Figure 2).

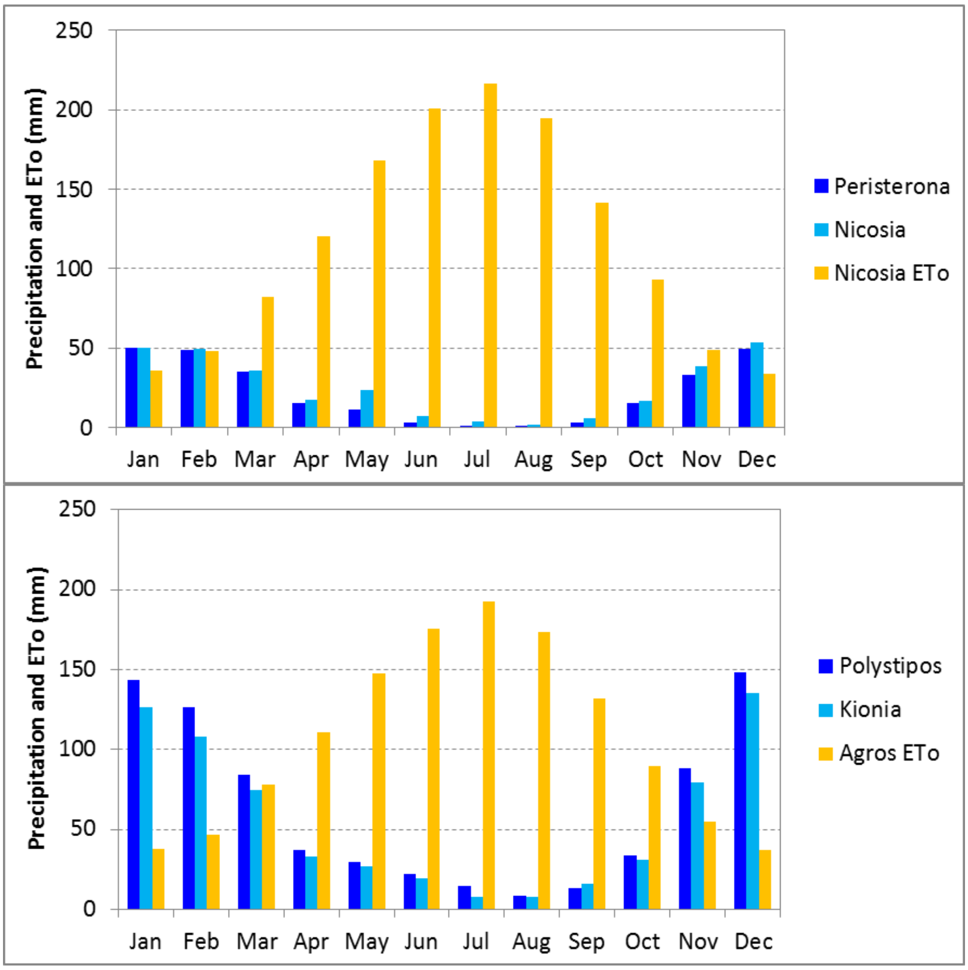


Figure 2. Longterm (1980-2010) monthly average precipitation and reference evapotranspiration (ETo) in the mountains (top) and in the plains (bottom)

Daily rainfall maxima during the period 1980-2010 were 196 mm in Kionia and 139 mm in Polystipos, both on 2 December 2001, and 157 mm in Panagia Bridge (18 Jan 2010). Average monthly daily minimum temperatures were 3 ^{0}C in Agros (1015 m asl) and 6 ^{0}C in Nicosia, during January. Daily maximum temperatures were 31 ^{0}C in Agros and 37 ^{0}C in Nicosia, in July and August (1980-2010).

2.1.3. Geo-hydrological descriptions

In the upstream and midstream areas of the Peristerona and Pedieos Watersheds the geology is dominated by the diabase and basal group formations, intrusive rocks of the Troodos ophiolitic sequence that form a heterogeneous fractured aquifer systems (Mederer, 2009). In the upstream areas of the Peristerona Watershed we also find gabbros and plagiogranates (plutonic rocks) with relatively high hydraulic conductivities. The Troodos foothills correspond to the transition area between the fractured diabase and basal group formations and the overlying, impermeable pillow lavas of the ophiolitic sequence. The Mesaoria aquifers in the plain are sedimentary formations, consisting of siltstones, calcarenites and marls (Nicosia formation) followed by the clastic deposits (gravels, sand and silt) of the Pleistone fanglomerate formation. These formations are overlain by the alluvium of the river valleys.

The Peristerona and the Pedieos Rivers are both ephemeral streams, which do 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 flow was 25.94 Mm^3 (2002). Total monthly flows for these years are presented in Figure 3.

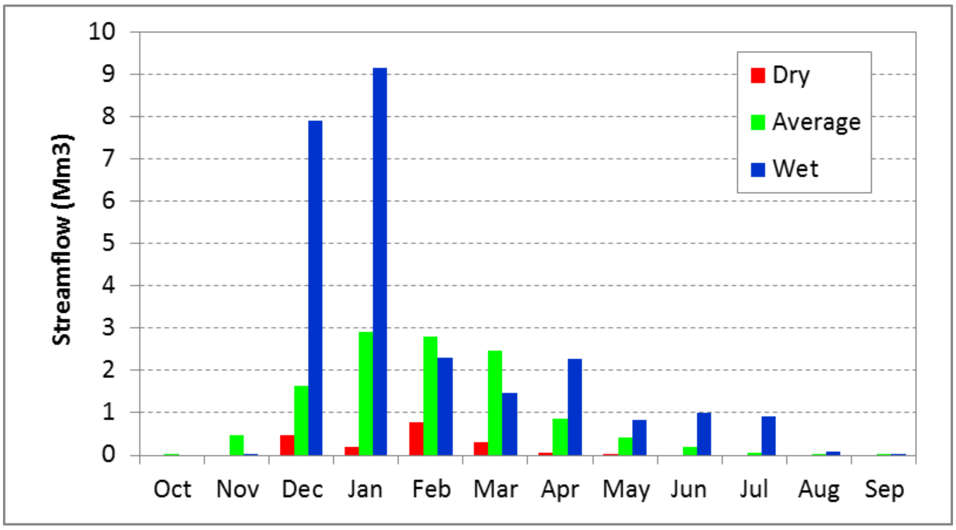


Figure 3. Total monthly streamflow at Panagia Bridge Station in Peristerona Watershed, driest (2007-2008) and wettest hydrologic year (2001-2002) and longterm average (1980-2010)

The streamflows from the Troodos mountains 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 both watersheds.

The downstream area of the Peristerona Watershed has been declared as a nitrate vulnerable area (MANRE, 2012). High nitrate concentrations have been observed in boreholes in the downstream area. Levels in excess of 50 ppm have been found in one of the boreholes. Intensive pig farms in the river valley most likely contribute to the high nitrate levels. In addition, up to recently the area did not have a domestic sewage network.

In the Pedieos Basin, streamflow is monitored by the Cyprus Water Development Department at two stations just upstream from the Tamassos dam. However, the weir at the western river branch is submerged when the dam reservoir is full and operation stopped in September 2001. Total annual flows of the two branches for the period 1982-2001 ranged between 0.95 Mm^3 (1998) and 12.87 Mm^3 (1992). The largest event in the past 40 years produced 3.1 Mm^3 of water in one day. This event occurred on 9 January 1989 and resulted from 57 mm rain over the upstream catchment on the preceding day and 108 mm on the day itself. Considering that there is always water in the reservoir in winter time, an enormous volume of water would have flown through the spillway of the dam.

The Mesaoria aquifer has been heavily exploited, resulting in a deterioration of groundwater quality. Georghiou and Pashalides (2007) analyzed the chemistry of groundwater samples from Nicosia and surrounding areas. The authors found a slight increase in boron levels between 1982-84 and 2002-03 and slightly higher levels in summer than in winter. The authors attributed the high boron levels (0.6 mg/L) to the marine origin of the geological formations, with the recent increase due to the overexploitation of groundwater resources and the pumping from deeper formations. The samples also showed high levels of other ions (e.g., Cl, SO_4) and had Electrical Conductivities ranging between 1.0 and 5.7 dS/m.

2.1.4. Land use

In the upstream area of Peristerona Watershed wsclerophylous vegetation exists, especially the Cyprus golden oak (Quercus alnifolia). These trees contribute to soil stabilization and prevent soil erosion due to their ability to colonize steep rocky hills (Loizides, 2011). The fractured volcanic formations in the steep sloping midstream areas are covered by state forests, which are dominated by Pinus brutia trees. This area forms part of the Adelphi forest, a Natura2000 site. Livestock grazing in state forests has been banned since British colonial rule in the late 19th century (Butzer and Harris, 2007). In the upstream and midstream areas of Peristerona Watershed agricultural lands are often located on terraces next to the streams, while the forested areas covers the steeper slopes above these lands.

According to the Census of Agriculture (Cystat, 2014a), agricultural cropland, including fallow, in the Peristerona Watershed's communities covered 3273 ha in 2010. In 2013, lands in good agricultural condition, which were submitted and qualified for Single Area Payment support, totaled 3546 ha (Cyprus Agricultural Payment Organization datasets). In the upstream areas the main crop is wine grapes, followed by almonds. Almost all crops are grown on dry stone wall bench terraces. However, the wine grapes are also grown on broader sloping terraces with shallow soils. The area covered with almonds and hazelnuts is much larger than the listed 118 ha, but many of these trees are no longer harvested and maintained.

In the foothills and downstream, both rainfed and irrigated crops can be found. 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.

The upstream area of the Pedieos Watershed, similarly to the Peristerona Watershed, is covered by Pinus brutia forests. This area is known as the Maheras Forest, an important Natura 2000 site (Department of Forestry, 2012). Smaller areas of sclerophyllous and shrub woodlands and few plots of rainfed cereals, irrigated fruit trees, greenhouses and livestock farms are also found in the upstream area. At the bottom of the foothills, the Tamassos dam captures and stores the runoff of the 45 km^2 upstream river basin in a 2.8 million m^3 reservoir. About half a dozen rural communities are located in the plains, downstream of the dam. Here barley, olives and irrigated vegetables are the most common crops. The river then flows into the urban agglomeration of the capital Nicosia and its adjacent municipalities.

2.1.5. Water use

The communities in the Peristerona Watershed rely on groundwater for domestic water supply. The permanent population in the communities in the upstream area totals 1227, while the population of the midstream and downstream areas numbers 3739 (Cystat, 2014b). Domestic water supplies are generally sufficient.

Agricultural water demand in the watershed is approximately 7 Mm^3, with almost half of this amount originating in Peristerona community (Bruggeman et al., 2015). Throughout the watershed there are diversions from the stream, which supply irrigation water to the fields by gravity through a system of open canals. Groundwater pumping is also common, especially in the alluvial river aquifer.

Figure 4. Streamflow diversion and groundwater pumping for irrigation in the Pedieos Watershed

In the Pedieos Watershed, the rural communities of Kampia, Psimolofou and Episkopio (and Kapedes, just outside the watershed) receive water from the Tamassos dam reservoir (interview with Pera Community leader, March 2014). Anthoupolis, Deftera and Ergates receive water from the seawater desalination plants supplied by the Nicosia Water Board (interview with Deftera Community Leaders, March 2014; Director of Nicosia Water Board, Cyprus Mail, 2013). However, some of the rural communities also pump groundwater for their domestic supply. The urban communities receive their water supply from the Nicosia Water Board. The water is predominantly sourced from the seawater desalination plants outside the basin, through the southern conveyor system. Irrigation is the largest user of water in the rural areas of Pedieos consuming on average 4.5 Mm^3/year (82%). Most irrigation water is pumped from groundwater. Treated sewage water from the Anthopouli treatment plant is also used for irrigation in some of the downstream areas.

2.1.6. Studies conducted in the past at the site

Le Coz et al. (2015) investigated the temporal and spatial transferability of model parameter values of a lumped four-parameter daily rainfall-runoff model for five northern Troodos watersheds. The temporal transferability analysis of the Peristerona Watershed showed that (i)for a decrease (about 25%) in the mean precipitation depth, the ability of the model to predict the runoff dynamics for low, medium and high flows becomes significantly poorer; and (ii) the predicted annual water budget is overestimated, up to 20%. Furthermore, high performance losses showed the poor spatial transferability of model parameters in this environment.

The history of flooding from the Pedieos River in the urban areas of Nicosia has been investigated by Charalambous et al. (in review). Historical records showed that responses to floods ranged from prayers and other religious rituals in the 14th century, to stormwater drainage networks and dam construction in the 20th and 21st century.

IACO Ltd (2006) conducted a flood modeling study for the design of the linear park and cycling path along the Pedieos River. The river segment where this linear park was envisaged, was found to have an active channel width of 25m on average (10 – 40m), while lacking suitable adjacent flood plains due to housing development. However, the active channel was found to present enough depth on average, rendering it suitable to accommodate flows of low frequency. Certain road crossings, mainly due to their design characteristics, i.e. Irish bridges, were found to be susceptible to flooding in high frequency events. In general, and since the linear park could only be placed within the active channel's width, an elevated pathway and bicycle lane of at least 3m higher than the active channel's bed elevation was recommended in order to mitigate estimated flood risks.

Flood modeling studies have been conducted by the Water Development Department as a requirement of the European Flood Directive (2007/60/EC). Flood hazard and flood risk maps and a flood management plan have been prepared for the flood sensitive areas (WDD, 2015).

Djuma et al (2014) have investigated erosion and surveyed sediment deposition at the first downstream recharge check dam in the Peristerona Watershed. They found an average erosion of 1 t ha^{-1} per year for the entire catchment area upstream of the first check dam, assuming a check-dam sediment trap efficiency of 15%.

Camera et al. (in review) used a Neyman-Scott Rectangular Pulses generator and 1 x 1 km^2 gridded dataset of Cyprus for 1980-2010 (Camera et al., 2014) to downscale three Regional Climate Models. The projections indicated a 1.5% to 12% decrease in the mean annual rainfall over Cyprus for 2020-2050 (A1B scenario), relative to 1980-2010.

2.1.7. Known water problems

As is common in semi-arid environments, in both watersheds agricultural water demand exceeds sustainable supply, especially in dry years (Zoumides et al., 2013). Droughts are a recurrent phenomenon and have especially strong negative effects on agriculture. In Peristerona Watershed, streamflow does not reach the downstream communities during dry years.

The Tamassos dam, which was completed in 2002, provides flood protection in the Pedieos Basin, by capturing the water of the steeply sloping upstream areas. However, due to increasing urbanisation, the downstream area is highly susceptible to floods. During heavy rainfall events runoff from the surrounding paved areas flows to the river. A total of 38 floods were recorded in urban Nicosia, from 1960 to 2012, of which three were caused by flooding from the river (I.A.CO Ltd, 2011). Natural vegetation that grows in the dry river bed impedes the flow of the water. Garbage and branches that are dragged along by the flood get trapped at the low road crossings over the river, causing water to spill over the road (Figure 5). The Water Development Department has identified the urban area along the Pedieos as an area of potentially significant flood risk, for the European Flood Directive (2007/60/EC).

The Flood Management Plant, which is currently under consultation, recommends the natural rehabilitation and improvement of waterways, including interventions to improve the hydraulic functioning of watercourses and to increase the discharge capacity. Alert mechanism for extreme weather and flooding (combination of thunderstorms and high reservoir level at Tamassos Dam) for the downstream Pedieos municipalities of Nicosia, Strovolos and Lakatamia are also suggested (WDD, 2015).

As mentioned previously, the downstream area of Pedieos has poor groundwater quality due to overexploitation. The downstream area of the Peristerona Watershed has been identified as a nitrate vulnerable area.

Figure 5. Flood event in the Pedieos Watershed (left: 31 May 2005, picture by I. Ioannou)

2.1.8. Outlook

The BINGO research will focus on improving our understanding of the hydrologic cycle in these two watersheds. Special attention is given to the water balance components of the Pinus brutia forests on the shallow and stony soils along the slopes. Field research is ongoing in a fenced site in the Pinus brutia forest at Agia-Marina-Xyliatou, on the edge of Peristerona Wateshed, in cooperation with the Department of Forests. Transpiration is measured with sapflow sensors in eight trees, and stem flow and throughfall is monitored for four trees. Soil moisture and meteorological parameters are also monitored. Streamflow will be measured at two locations along a stream stretch of the Peristerona River to improve the quantification of baseflow and groundwater recharge during wet and dry periods. In addition, soil moisture and meteorological parameters will be monitored in an irrigated olive orchard to assess irrigation water use efficiency.

Flood modelling will be conducted for the Pedieos Watershed with the HEC (Hydrologic Engineering Center) models, developed by the U.S. Army Corps of Engineers (http://www.hec.usace.army.mil/software/). Both the Hydrologic Modeling System (HEC-HMS) and the River Analysis System (HEC-RAS) will be used.

In addition, the Weather Research and Forecasting Model Hydrological modeling extension (WRF-Hydro) will be used. WRF-Hydro has modularized component model coupling interfaces for many terrestrial hydrological processes such as surface runoff, channel flow, lake/reservoir flow, sub-surface flow and land-atmosphere exchanges. It can be run as a stand-alone hydrological model, or coupled with atmospheric models (https://www.ral.ucar.edu/projects/wrf_hydro).

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2.2. Wupper River basin, Germany

2.2.1. Site Location

The Wupper River Basin lies in the state of North-Rhine Westphalia, Germany, with an area of 813 kilometres and a population of approximately 950,000 inhabitants. The Wupper is an upland river with a length of about 115 kilometres, rising in Marienheide-Börlinghausen (*Oberbergischer Kreis* district) and flowing into the Rhine River at the city of Leverkusen (see Figure 6). The Wupper River and its many tributaries form a river network of ca. 2,300 kilometres. The Große Dhünn Reservoir - the second largest drinking water reservoir in Germany - is located within the Dhünn River catchment area, one of the main tributaries of the Wupper River.

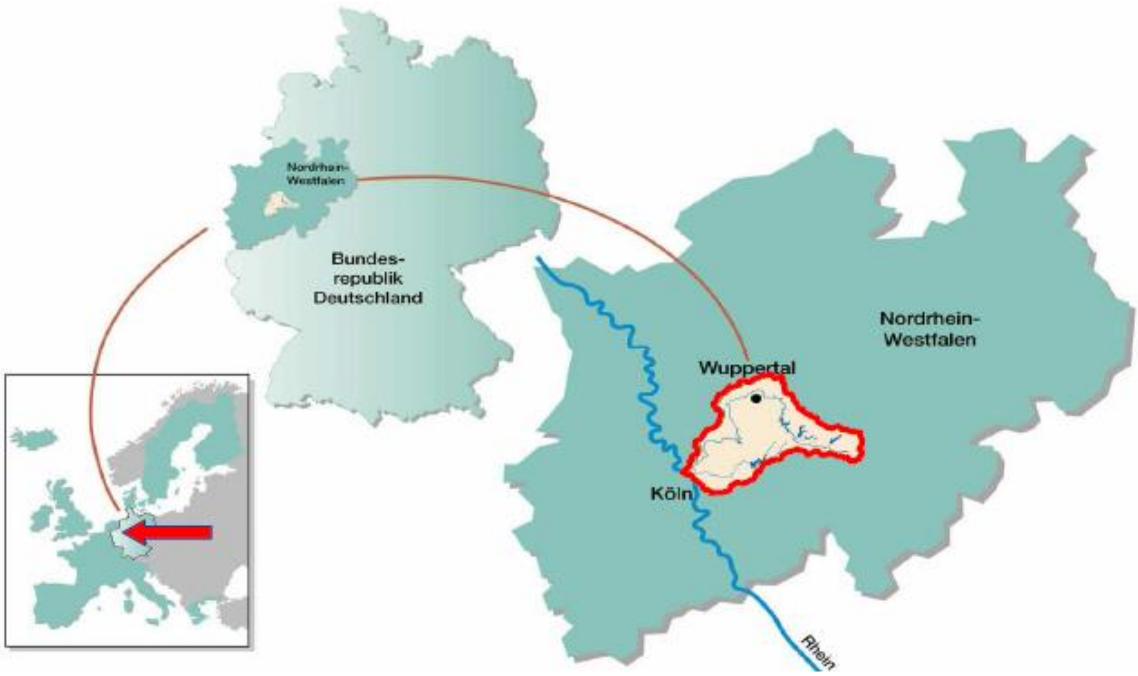


Figure 6. Location of the Wupper river basin, Germany

The Wupper Association[1] is responsible for water quantity management and quality of all water bodies within the Wupper River Basin. As a public body, the Wupper Association performs its tasks in the public interest and for the benefit of its association members: town councils, local and district authorities, municipal water suppliers, and effluent disposal businesses, trade, and industrial organisations in the catchment area of the Wupper River. Their contributions cover the costs of wastewater treatment with sewage sludge disposal, flood protection, managing water flow during dry periods (raising low water levels), water

[1] Wupperverband

supply provision, and maintenance and ecological development of rivers and streams. Close cooperation allows also for the identification of water management strategies.

The Wupper Association operates twelve reservoirs, eleven wastewater treatment plants, numerous storm water tanks, and flood control reservoirs (see Figure 7).

Figure 7. Main hydraulic structures and water bodies in the Wupper River Basin

2.2.2. Water use and related problems

In earlier centuries, the cool, clear, and oxygen-rich Wupper River provided an ideal environment for many species of fish, such as salmon and brown trout. The Wupper River and its tributaries have also served for human use since prehistoric times. Water power drove mills and forges and on the Wupper meadows, yarn bleachers kept their yarn moist with river water. Industrialisation continued with the growing number of dye works and other textile mills as well as metalworking plants.

In the end of the 19th century, a dramatic growth in industry and population took place in the Wupper River valley. As a result, waste and untreated sewage from businesses, factories, and households were discharged into the water bodies, turning the Wupper River into a sewer (it was known as one of the dirtiest rivers in Europe for a long time; even in the 1980s, the river was heavily polluted, particularly in the lower reaches between the city of Wuppertal and the confluence with the Rhine River).

In addition to environmental impacts caused by industrialization and population growth, the occurrence of floods and water shortages during dry periods affected towns and villages along the Wupper River, who were unable to solve all the water management problems by themselves. An organisation able to deal with all these difficulties from the source to the river mouth was necessary. Therefore, the Wupper Association was established in 1930 in order to assume responsibility for water management within the catchment area.

Over the past 20 years, the water quality of the Wupper River has been significantly improved through huge investments made by the Wupper Association, local authorities, and industrial companies. The water quality is currently so good that many species of fish have returned. Nevertheless, organic and thermal pollution prevails.

Nowadays, the influence on the water bodies is mainly related to the activities shown in Figure 8, which will be described in detail within the establishment of the context for risk management at Wupper River basin (see Deliverable 4.1).

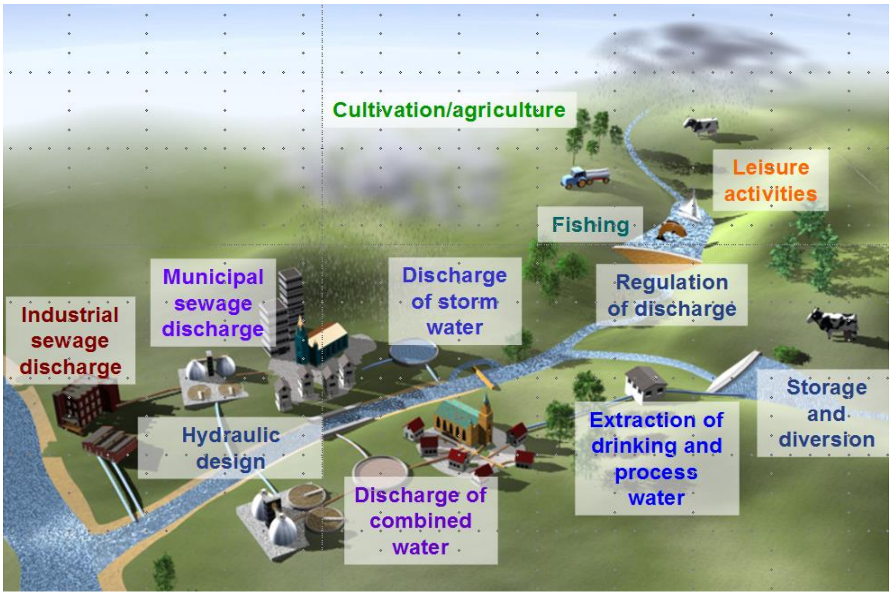


Figure 8. Main water use in the Wupper River Basin

2.2.3. Local climate

The Wupper River Basin has a wide range in the amount of Mean Annual Precipitation (MAP) of 775 to 1425 mm, as shown in Figure 9. On account of the higher rainfall amounts in the upper parts of the basin, the construction of large reservoirs for drinking and process water started towards the end of the 19th century.

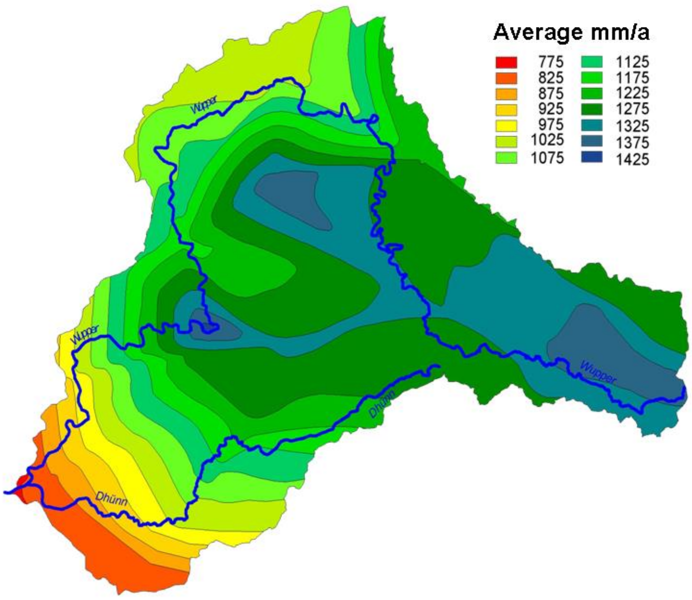


Figure 9. Spatial distribution of Mean Annual Precipitation (MAP) in the Wupper River Basin

The rain gauge in Wuppertal-Buchenhofen, maintained by the Wupper Association and the German Weather Service[2] (MAP of ca. 1425 mm per year), is popularly known as the *wettest* in Germany.

The mean discharge of the Wupper River is ca. 15.4 m³/s. At the end of the 19th century and the beginning of the 20th century, huge floods in the whole area (e.g., 1890, 1909, 1925, and 1946, see Figure 10) led to the implementation of more protection measures and the founding of the Wupper Association. Due to this initiative, the flood recurrence interval has been reduced.

[2] Deutsche Wetterdienst (DWD)

Figure 10. Floods in the city of Leichlingen, 1925

On the other hand, extreme dry periods have also taken place (see Figure 11), causing ecological impacts and problems for water dependent, industrial purposes. However, the reservoirs can currently retain enough water to prevent droughts for about two years.

Figure 11. Drought in the Dhünn River

2.2.4. Known problems related to climate change and weather extremes

Weather extremes have been well known in the last decades. Manifestation of extreme climate events in the Wupper River Basin ranges from dry periods in spring time (important for filling the reservoirs) to heavy convective rainfalls in summer time (triggering flash floods occurrence, see Figure 12), and the combination of snow melting and rainfall during the winter season (causing river floods). Heavy recent floods have been recorded for 2007, 2011, and 2013, for both winter and summer seasons (e.g., the 2007 and 2011 floods occurred in December and January, respectively, and the 2013 flood took place in June).

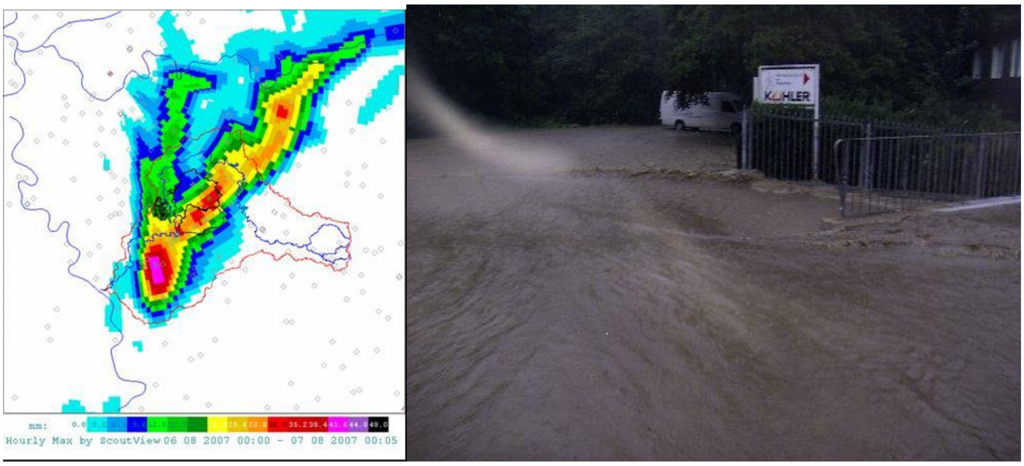


Figure 12. Flash flood occurrence along the Wupper River Basin

Monitoring of the mean temperature shows comparable results to other studies and reports (see Figure 13). There is a rising trend in temperature for the whole year as well as for summer and winter periods.

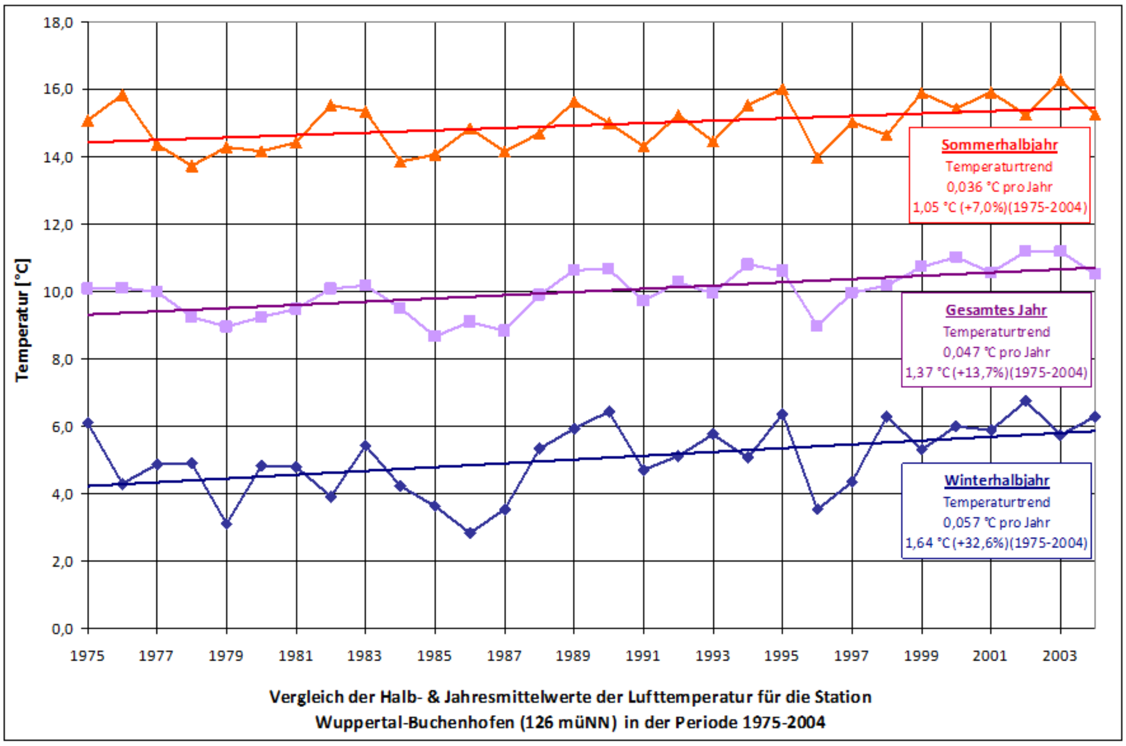
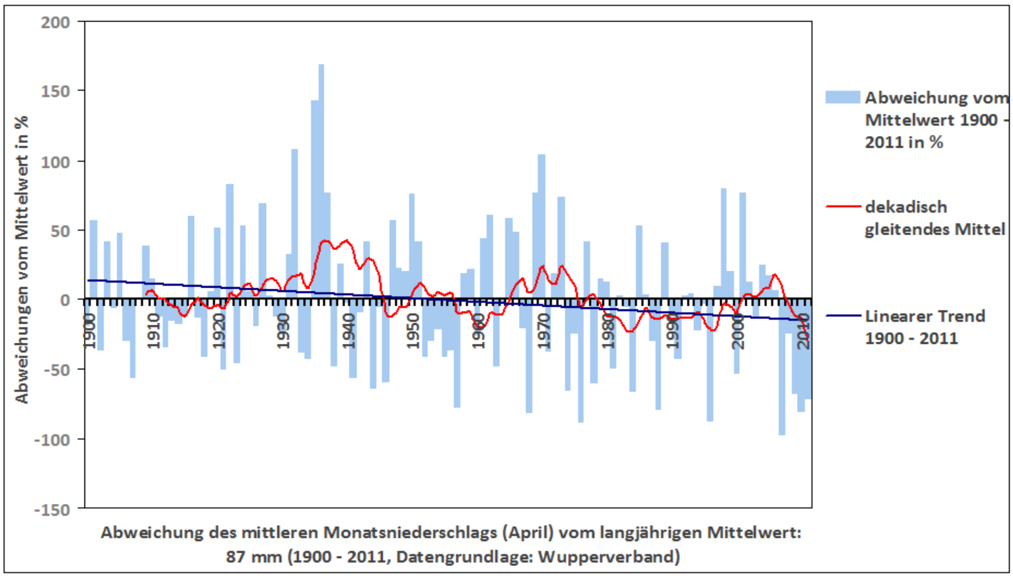


Figure 13. Air temperature trends for station Wuppertal-Buchenhofen in 1975-2004: annual (purple), summer (orange) and winter (blue)

Mean annual precipitation is relatively constant with respect to the weather normal distribution. However, the shifting of the rainy season has a negative impact for the water quality and quantity within the reservoirs. Figure 14 (top) presents the deviation from the mean monthly precipitation (in percentage) as well as the decadal moving average in April during the 20th century. The linear trend reflects a rainfall decreasing of about 25 mm for the spring period in the last decades leading to water stress. As a consequence, reservoirs are being filled up in June-July rather than in April-May, lacking the adequate temperature for ecological flow and affecting water quality. In contrast, Figure 14 (bottom) shows an increase in the linear trend of monthly precipitation in November of about 20 mm for the last 40 years.



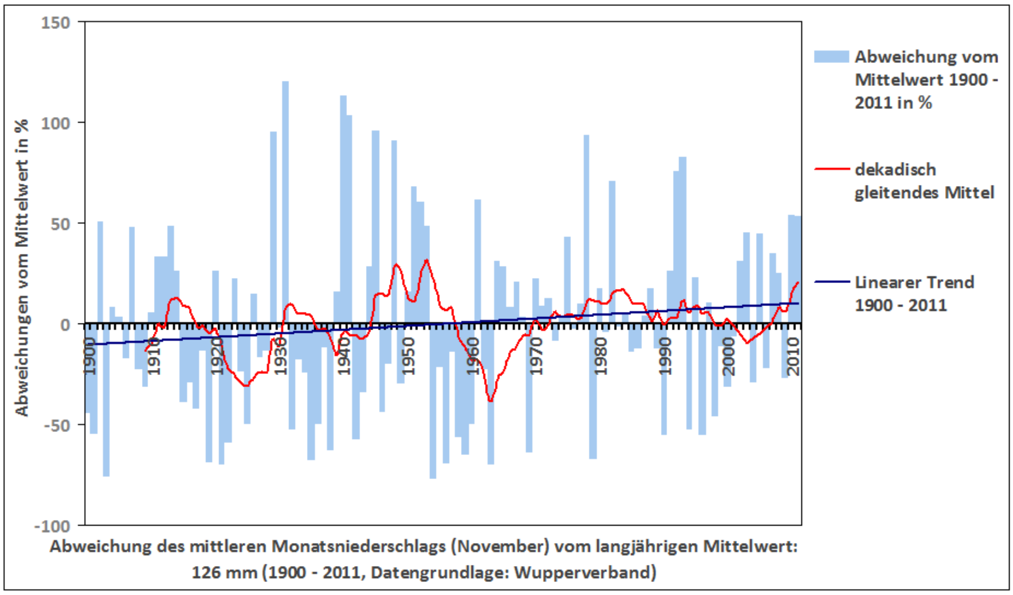


Figure 14. Distribution of mean monthly precipitation between 1900 and 2011: April (top) and November (bottom)

Flash floods occurrence caused by convective rainfall has increased in the last decade. Figure 15 shows an increment of events with more than 15 mm (warning threshold value from the German Weather Service).

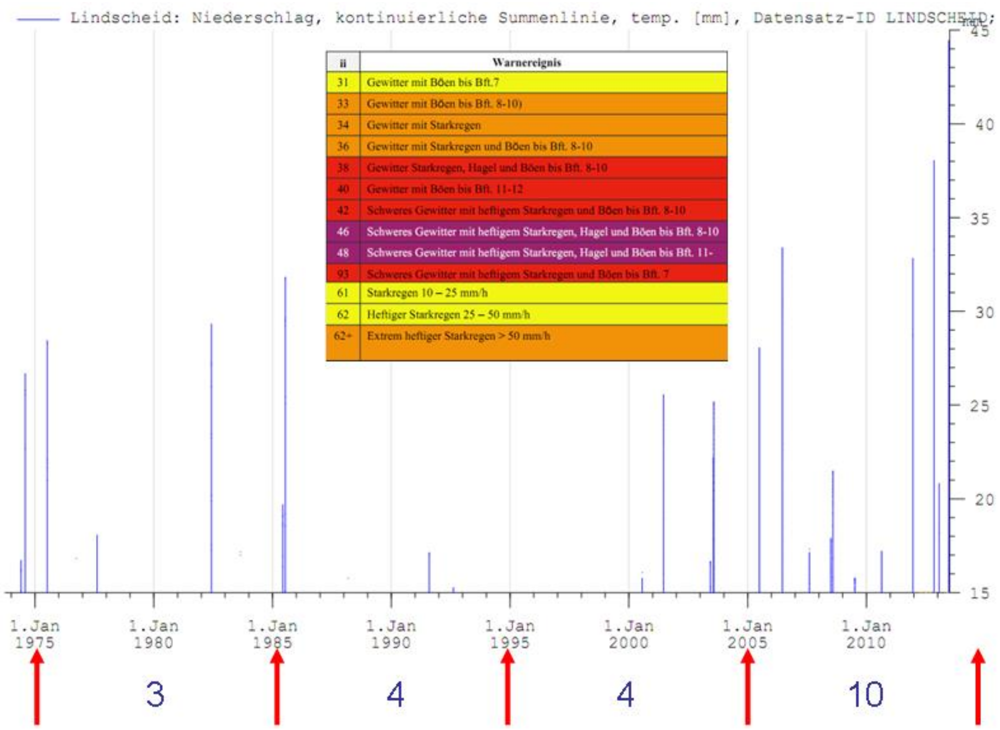


Figure 15. Increment of rainfall events with more than 15 mm between 1975 and 2010

2.2.5. (Geo-)hydrological description

The soil type within the Wupper River Basin is quite homogenous, as illustrated in Figure 16. Brown earth is the predominant soil type in the most upper layer of the catchment, followed by gley, luvisol, and alluvial soils. Table 1 presents the soil type and the percentage with respect to the total area of the catchment.

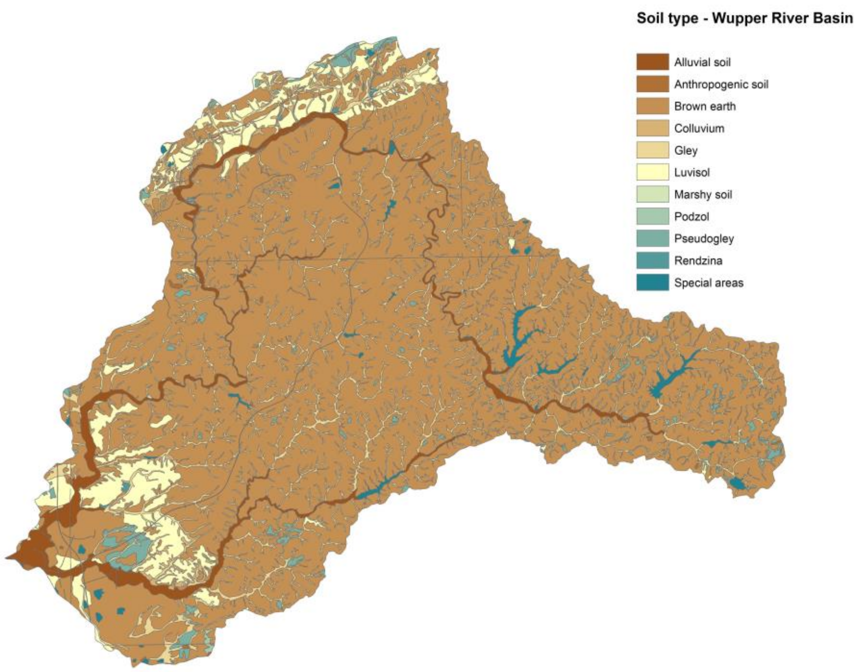


Figure 16. Soil types of the Wupper River Basin

Table 1: Soil types in the Wupper River Basin and percentage with respect to the total area

Soil type	Area [km²]	Percentage of total area [%]
Brown earth	611.2	75.3
Gley	73.4	9.0
Luvisol	52.4	6.4
Alluvial soil	33.5	4.1
Colluvium	15.9	2.0
Pseudogley	14.9	1.8
Special areas	8.3	1.0
Anthropogenic soil	1.0	0.1
Podzol	0.6	0.1
Rendzina	0.5	0.1
Marshy soil	0.2	0.0
Total	**811.9**	**100.0**

Figure 17 shows the topography of the watershed, with elevations ranging between ca. 700 m.a.s.l. in the source region of the Wupper and Dhünn Rivers (moderately hilly) and about 40 m.a.s.l. in the downstream area, as the terrain becomes flatter near the confluence with the Rhine River. In consequence, the Wupper River Basin presents short times of concentration in the upper catchment, critical for forecasting and measures during floods.

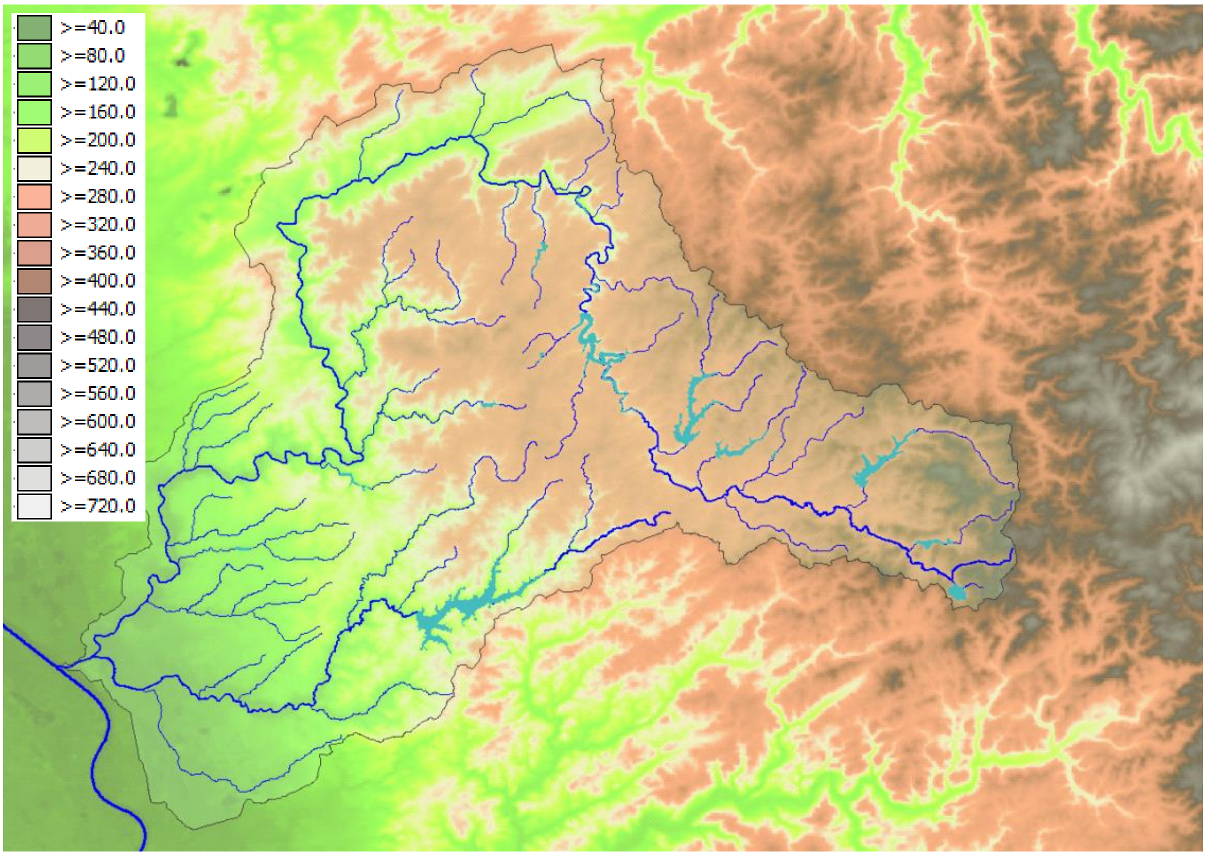


Figure 17. Topography of the Wupper River Basin

2.2.6. Land use

The land use within the Wupper River Basin can be described as partly urban with a high population density (see Figure 18, left) and partially rural, with forests, pasture, and horticulture as the predominant land cover units of the catchment (see Figure 18, right).

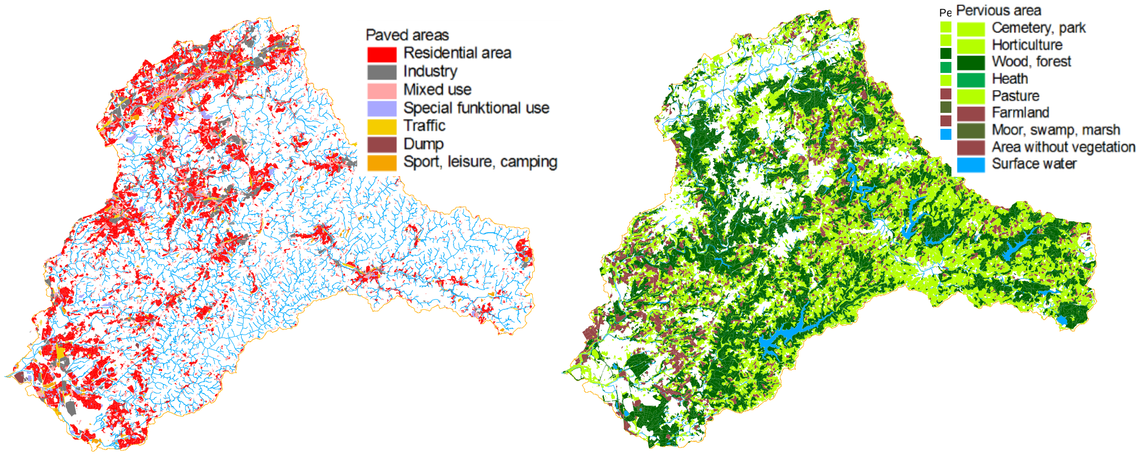


Figure 18. Land-use distribution of urban areas (left) and rural areas (right) within the Wupper basin

Table 2 presents the current land-use distribution within the basin. The actual trend for population is decreasing.

Table 2. Land-use within the Wupper River Basin

Land use	Part of total in percentage	Area [km²]
Wood, Forest	32.8	266.8
Pasture, Horticulture, Park, Cemetery	30.8	250.3
Paved area	25.3	205.6
Farmland	8.7	70.3
Surface water	2.0	15.9
Other	0.4	3.3
Total	**100.0**	**812.3**

2.2.7. Studies conducted in the past

The Wupper Association has been involved in a series of research projects (both national and international) run by the state, the German Ministry of Education and Research[3], and the European Union in order to develop new processes and technologies. However, the approaches have been mainly based on ecological issues, rain and wastewater treatment or flood protection; this is the first time that the Wupper Association is involved in an international research project with climate change as the main focus.

[3] Bundesministerium für Bildung und Forschung (BMBF)

DayWater

DayWater was an European research and development project carried out from 2002 to 2006. The Wupper Association was integrated into DayWater as one of the four Core End-users. The aim of the project was the development of an adaptive decision support system consisting of simulation models, assessment tools, databases, and guides, which considers the early involvement of all stakeholders in water management and their concerns. Partners were ENPC[4] (France), TAUW (Netherlands), Chalmers University of Technology (Sweden), Technical University (Denmark), National Technical University Athens (Greece), DHI HYDROINFORM (Czech Republic), IG Prof. F. Sieker mbH (Germany), LCPC[5] (France), and Lulea University of Technology (Sweden). The project activities included the development of an adaptive decision support system, integration of urban drainage with landscape planning, social and economic structures, risk analysis, and rain water management.

WASKlim (Wasserwirtschaftliche Anpassungsstrategien an den Klimawandel)

WASKlim[6] (Scherzer et al. 2012) was implemented in the frame of the Environmental Research Plan of the Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety[7] that supports the development process of the German strategy for adaptation to climate change. The initiative started in 2007 aiming at evaluating different strategies for climate change adaptation in three study areas in the states of Bavaria, North Rhine-Westphalia, and Sachsen-Anhalt. The upper reaches of the Wupper River (i.e., mountainous zone) corresponded to the research area within the state of North Rhine-Westphalia.

The project was implemented with the support of Universität der Bundeswehr München (Institute for Water Management[8]), UDATA[9] (Environmental protection and data analysis), among other partners. The methodology was based on the implementation of surface detailed numerical catchment models taking into account the range of uncertainty of climate change. Input hydro-meteorological data from 1971 and 2007 was provided by the Wupper Association, German Weather Service, and LANUV[10] NRW[11]. Different IPCC[12] (IPCC 2007)

[4] École des Ponts ParisTech
[5] Laboratoire central des ponts et chaussées
[6] Water management adaptation strategies to climate change
[7] Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB)
[8] Institut für Wasserwesen
[9] Umweltschutz und Datenanalyse
[10] North Rhine-Westphalia State Agency for Nature, Environment, and Consumer Protection (Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen)
[11] North Rhine-Westphalia (Nordrhein-Westfalen)
[12] Intergovernmental Panel on Climate Change

emission scenarios (i.e., A1B, B2, and A1) were simulated until 2100 using the statistical downscaling method WETTREG[13] and the dynamic regional climate model REMO.

The main results from the WETTREG approach indicated that from the three study areas, the Wupper catchment will be the most affected with the increment of the air temperature (it is expected that by the end of the 21st century, the air temperature will rise in comparison to the current state). According to the climate projections, the Wupper River Basin will be impacted by a steady to slightly increasing rainfall. The project was successfully concluded in 2009.

IMRA (Integrative flood risk governance approach for improvement of risk awareness and increased public participation)

IMRA (IMRA 2011) was implemented between 2010 and 2011 and was a research project in the framework of the 2nd ERA-Net[14] CRUE Research Funding Initiative. The followed approach was a) inventory of existing data, surveys, and discussions on risk perception; b) assessment of the performance of existing management systems; c) regional workshops d) communication and participation approaches; and e) adjustment of research and implementation strategy.

Under IMRA initiative, risk governance, risk communication, and participatory flood risk management were assessed for three study areas in Europe (Germany, Austria, and Italy). The Wupper River Basin was the German research region (selected because of being prone to winter floods and flash floods), where the Wupper Association participated actively as the responsible flood risk management authority.

One of the main findings was the low risk perception of the city of Leichlingen. Since the city is flood prone, many protection measures have been implemented. As a result, heavy floods do not occur as often, causing that the population is not as aware of its own risk as formerly.

REISE (Entwicklung eines risikobasierten Entscheidungshilfesystems zur Identifikation von Schutzmaßnahmen bei extremen Hochwasserereignissen)

REISE[15] (funded by BMBF) (Schüttrumpf et al. 2009) was a German project implemented from 2005 to 2009 by RWTH-IWW[16], gaiac,[17] and IfS[18] from the Aachen University and the

[13] Weather-based regionalization method (WETTerlagen-basierte REGionalisierung)
[14] European Research Area
[15] Development of a risk-based decision support system for the identification of protective measures in extreme flood events
[16] Institut of Hydraulic Engineering and Water Resources Management (Institut für Wasserbau und Wasserwirtschaft), RWTH Aachen
[17] Research Institute for Ecosystem Analysis and Assessment (Forschungsinstitut für Ökosystemanalyse und -bewertung e.V.)
[18] Institute for Sociology (Institut für Soziologie)

Institute of Hydrology, Water Resources Management, and Environmental Engineering[19] from the Ruhr-University Bochum[20], as part of the BMBF research cooperation *Risk management of extreme flood events – RIMAX*. The approach focused in three main areas: a) analysis, forecasting, and warning; b) information and communication; and c) safeguards and management. The objective was to develop a risk based decision support system for the assessment of flood management measures.

REISE targeted small and medium river basins and aimed at implementing instruments to evaluate economical, ecological, and psycho-social consequences of extreme events, as well as failure of protection measures. The integration of municipal decision processes and the communication and acceptance of risks from natural disasters and failure of protection measures supports the development of integrated flood management plans for river basins.

The created decision support system ProMaIDes[21] is a working tool for river basin analysis and improvement of flood protection for the wide range of possible flood events, starting from high frequency extreme events.

The essential characteristics and overall project results included:

- Using Multi-Attribute Decision-Methods for decision making
- Efficient, coupled 1D-2D hydraulic
- Monte Carlo-based analysis of the reliability or failure probability of measures for flood protection
- Monetary valuation for ecological damage and expenses on the basis of cost recovery with a time-lag function for soils and habitat protection
- Monetary evaluation of economic damage with the integration of uncertainty aspects
- Approaches to the evaluation of psycho-social consequences of flood events
- Assessment of consternation of people due to natural disasters
- Approaches to improve communication related to flood
- Comprehensive analysis of the hydrology of the Wupper River Basin and generation of flood peak discharge scenarios
- Strategies to improve the operation of the Wupper Reservoir

The main output was the development of the risk based decision support system for identification of protection measures in extreme flood events for the Wupper River Basin.

[19] Lehrstuhl für Hydrologie, Wasserwirtschaft und Umwelttechnik
[20] Ruhr-Universität Bochum (RUB)
[21] Protection Measures against Inundation Decision support

2.2.8. Planned activities within BINGO

The River Basin faces floods (including flash floods) and droughts. Both are interrelated with the operation of the reservoirs. The objective is to minimize flood impacts by improving the warning system and the reservoirs operation rules. The most import parameters in a flood forecast model are precipitation (an input variable), evapotranspiration and soil moisture (a state variable) (Marx 2007).

The spatial distribution of precipitation is currently determined with radar data (Hannesen 1998). Improving the quality of radar data contributes significantly to the performance of the forecast model (Gill et al. 2012). The accuracy of radar data can be enhanced if the dependence of the drop size distribution (DSD) on radar R-Z relation is known (Michaelides 2008). The drop size distribution will be assessed in this project with disdrometers and correlated to the radar reflectance (D'Adderio 2014; Jameson & Larson 2016; van de Beek 2013).

Soil moisture is fundamental for the determination of the excess precipitation (i.e., surface runoff) and consequently for flood forecasting. Spatially distributed soil moisture, currently derived from slope and soil types, will be calibrated / validated with a sensors network distributed in the pilot river basin.

Evapotranspiration is a major process for drought determination. In order to improve evapotranspiration models, a set of lysimeters will be also installed in the basin. A further process being currently investigated is sub-surface flow related to water losses within one catchment.

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2.3. Veluwe, The Netherlands

2.3.1 Location and local climate, site history and future importance

The Veluwe research site (ca. 1.250 km²) in the centre of the Netherlands (Figure 19) 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 is merely designated forests, heathlands and drift-sands.

Figure 19. Research site location Veluwe

The climate of the Veluwe research site is influenced by the North Sea and Atlantic Ocean. The predominant southwestern wind direction causes a maritime climate, with relatively cool summers (24h long-term average temperature of approximately 17°C) and moderate winters (24h long-term average temperature of approximately 3 °C). Occasionally easterly winds can cause more continental weather conditions. Current (1981-2010) precipitation is on average approximately 950 mm.y-1 and actual evapotranspiration 575 mm.y-1, resulting (in the absence of surface waters) in a daily groundwater recharge of ca. 1 mm per day (Verhagen e.a., 2014).

Villages and small cities have mainly developed at the fringe of the Veluwe, in the neighbourhood 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 17^{th}-19^{th} 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 19^{th} century.

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. Also the surrounding discharge area undergone 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 e.a. (2009), and ending with large scale drainage, land reclamation and groundwater abstractions in the 20^{th} century.

Nowadays, the Veluwe serves as an important area for nature and recreation. Moreover, its subsoil contains a large reservoir of fresh groundwater that is exploited for the production of drinking water (official capacity 110 Mm3yr-1, equivalent to the consumption need of two million people).

Nijssen e.a. (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 "Beleidsnota Drinkwater: 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. In Figure 20 possible reserve areas (in 3D) are presented. The total of the Veluwe research site is designated as reserve area.

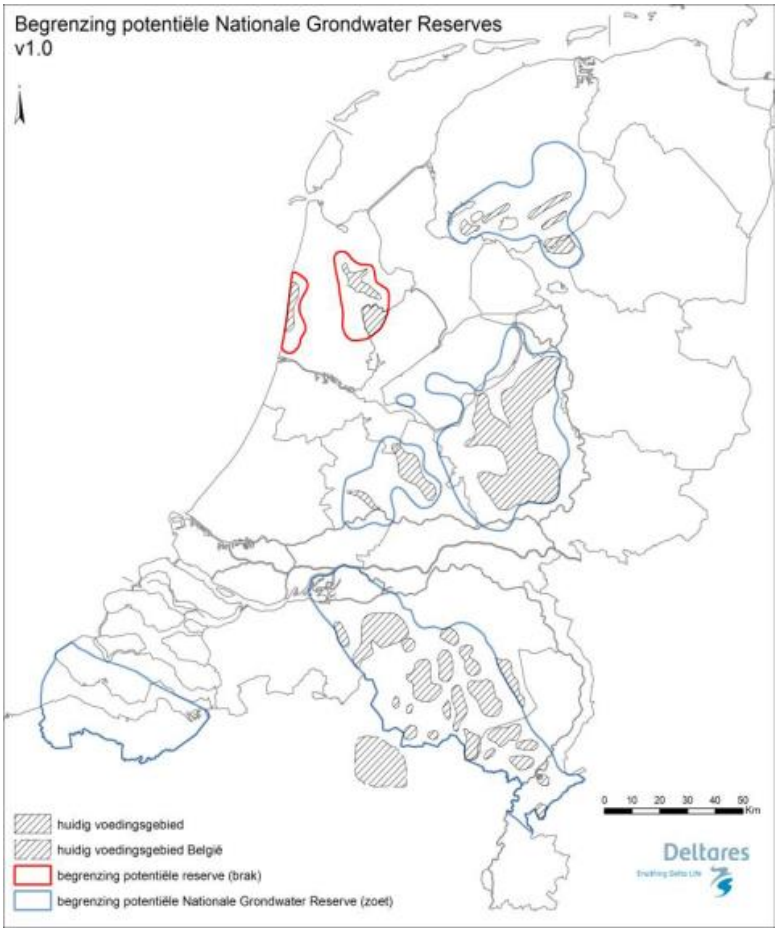

Figure 20. Potential national groundwater reserve areas by Boers (2015).

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 provincial government is responsible to prepare the Natura 2000 management plan. It is expected that the first management plan will come in to action in 2016.

The Veluwe is also a of the biggest tourist attractions in the Netherlands. The acting provincial government in cooperation with the tourist business will try to get Veluwe on first place again.

2.3.2 (Geo)hydrological description

The force of glaciers some 400.000 - 150.000 years ago formed the characteristics of the site. Deposits of Rhine and Meuse rivers were pushed aside by the onward creeping glaciers. At the end of the ice age the glaciers melted. They left behind ice pushed hills, dry stream valleys, sediment deposits on foothills and melt water-lake deposits. The main ingredient of the Veluwe is coarse, middle or fine sand. The unsaturated en saturated properties of water transport of this sand is one of the main characteristics of the Veluwe (see Figure 21). Another important feature is the size. 25 kilometers east-west and 40 kilometers north-south sandy hills without any surface water system. In the middle of this massive body of sand the groundwater level can rise 20 to 40 meters high. This high level is the driving force of the system. This system is sustained by the rainfall excess of the soil water balance. In this soil water balance the actual evapotranspiration is a very important therm.

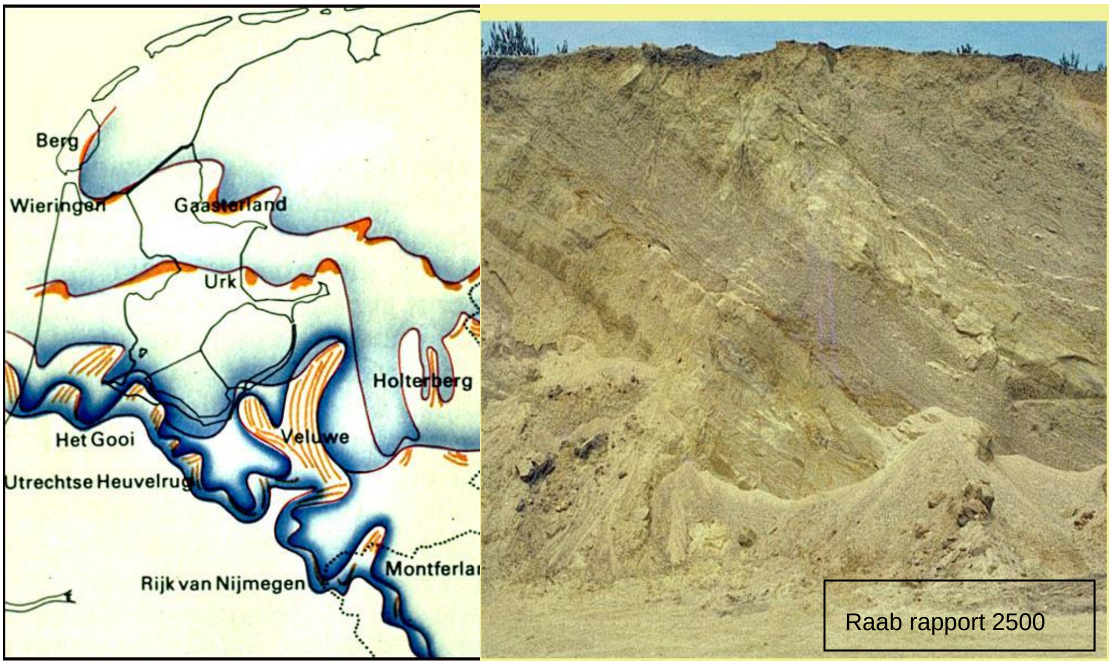

Figure 21. Example of glacier effect: horizontal layers pushed in an incline (Keunen 2013)

Conductivity in the incline areas is less, than in foothill deposits and non pushed layers in the deep. The thickness of the non pushed sandy layers increases from southeast to northwest (see Figure 23). As presented in Figure 22. Water transport through the groundwater system in the direction northwest is easier than for example east.

Figure 22. Schematic picture of the Veluwe with "incline" areas

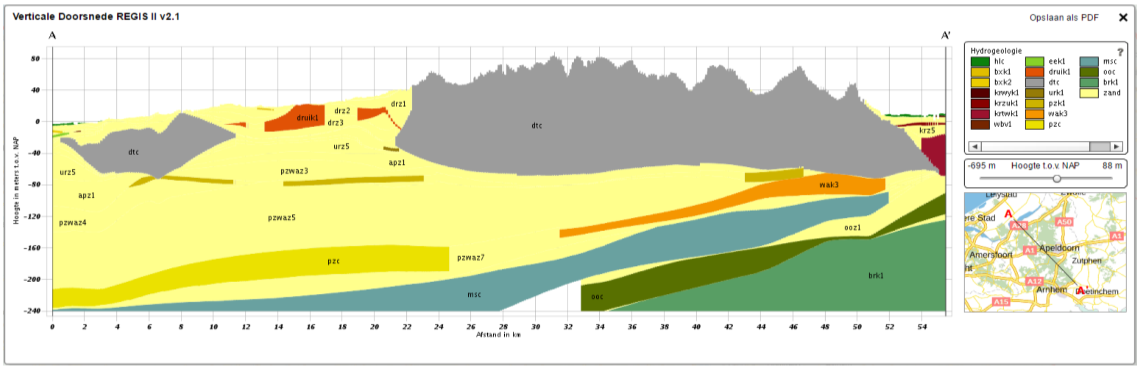

Figure 23. Profile southeast- northwest (https://www.dinoloket.nl/)

2.3.3 Present Land and water use

The land use for the research site Veluwe is mainly forest, with pine being the dominating tree species in the area. This is also the main land use that can potentially be changed. The broad-leafed forest, heather vegetation and sand areas are protected by European law, under the habitats directive (Council Directive 92/43/EEC). The research site is surrounded by residential areas and dairy farming mainly. In the West this is complemented with pig and poultry farming. The surrounding areas are envisaged to be affected by socio-economic change, while the research site itself will be more prone to climate change or changes in nature management policies. Figures 24 and 24a show the land and water use categories in the Veluwe research site.

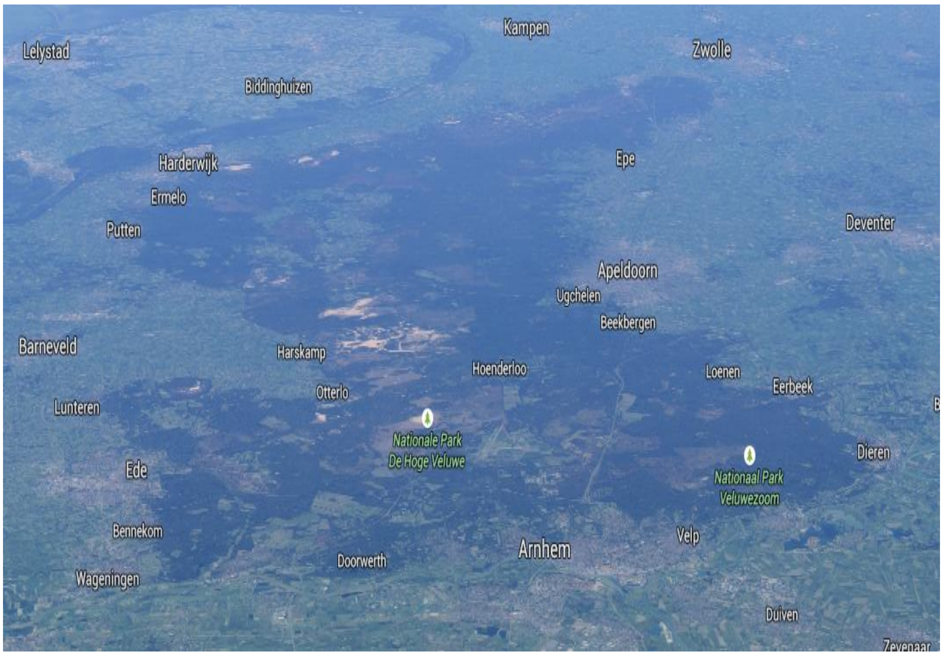

Figure 24. Present land use Veluwe (Google maps)

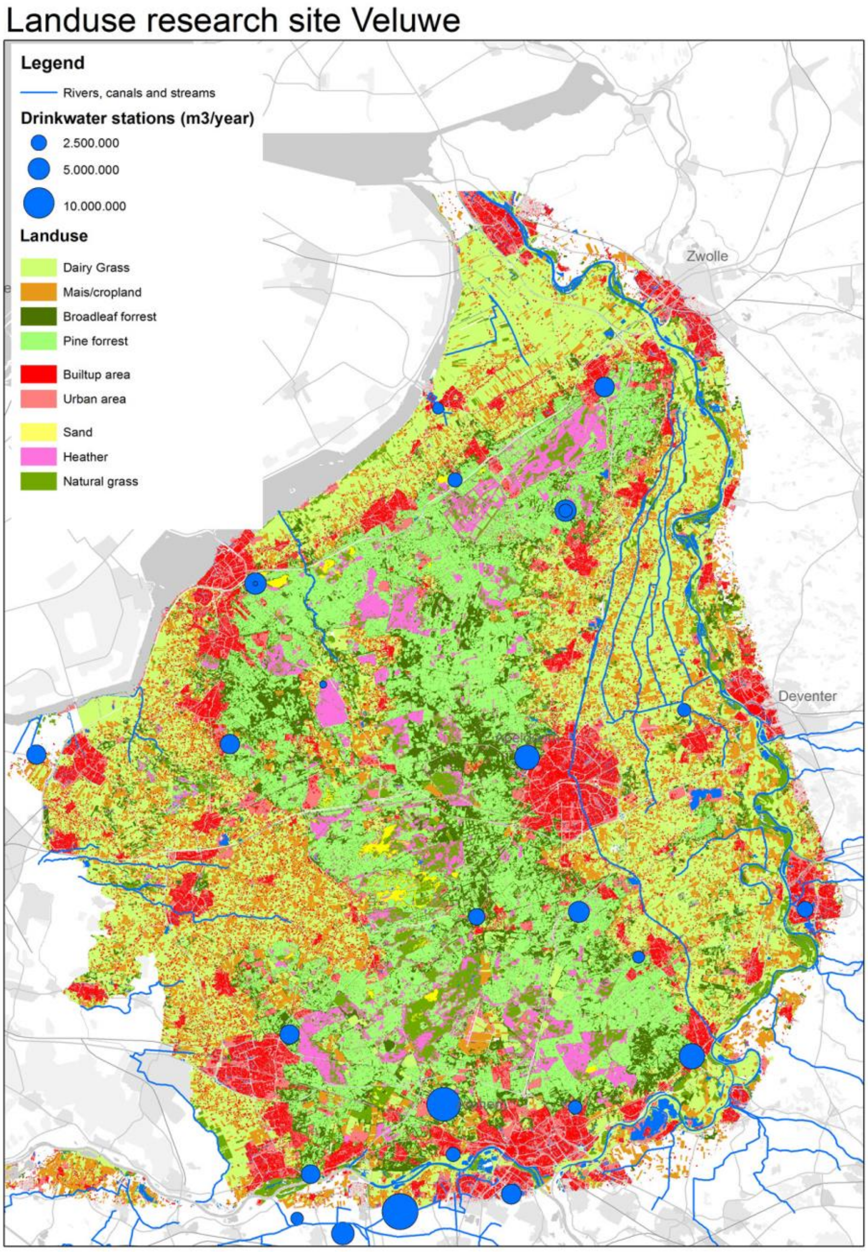

Figure 24a. Present land use Veluwe

2.3.4 Studies conducted

The first serious attempt to model the groundwater system of the Veluwe and its surrounding drainage area was carried out by Gehrels (1999). He used this model to study effects of e.g. groundwater abstraction and afforestation. In recent years, three regional authorities (province of Gelderland, drinking water company Vitens, water board Vallei & Eem) combined their efforts to develop a better model, called AZURE (www.azuremodel.nl). Of decisive importance to the accuracy of this model is a reliable estimation of the evapotranspiration demand by different vegetation types. Wageningen University measured evapotranspiration in a pine forest (Moors, 2012), Gehrels (1999) used tracers in groundwater and short-term eddy-correlation measurements to estimate evapotranspiration of different vegetation types, while KWR and Alterra recently started accurate measurements in a heather vegetation (Voortman et al, in preparation).

The groundwater of the Veluwe is a system that, because of its expanse and its large unsaturated zone, responds very slowly to changes in meteorological conditions as presented in Figure 25. Therefore it is advisable to study this system in a historical perspective.

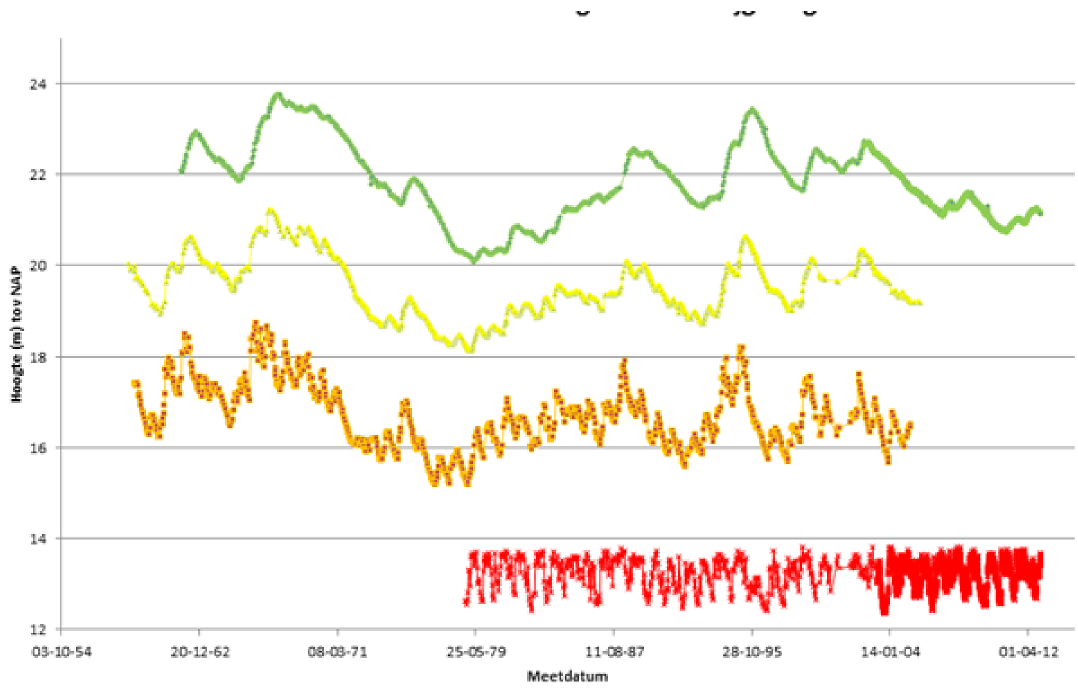

Figure 25. Measured groundwater heads form centre to the edge of the Veluwe (Helderman, 2013)

The green line centre, 10-12 km from surface water, yellow line 3-4 km from surface water, orange line 1 km from surface water, red line normal seasonal system in surface water system.

2.3.5 Known water problems and BINGO

Climate projections predict that precipitation shifts from summer to winter and that potential evapotranspiration in summer increases, meaning that dry spells will occur more frequently and intensively (KNMI, 2014). Moreover, under a warming climate the water quality of surface waters might degrade (Delpla e.a., 2009), especially during dry periods with low river discharge (Zwolsman en Van Bokhoven, 2007; Van Vliet en Zwolsman, 2008). As a consequence, it can be foreseen that the importance of the Veluwe for drinking water production will increase, which conflicts with the increasing need for fresh water for agriculture, recreation and groundwater depended habitats and aquatic ecology in small streams and the management of the natural vegetation on the Veluwe itself.

2.3.6 Outlook

The AZURE model will be used to assess how climate and landuse changes affect water resources of the Veluwe area and related functions. The sub-model MetaSWAP, to simulate actual evapotranspiration, will be updated based on field measurements with lysimeters installed in heather vegetation. Additionally the land use classes of AZURE will be updated to include more detailed dry natural vegetation classes. Because the Veluwe area consist of a large forested area, parallel to the modelling work, a large pot experiment (approximately 60 trees) will be performed to measure the transpiration and interception evaporation of common tree species of the Veluwe. These measurements will be related to pant traits and proxies (e.g. isotopes) to develop a framework to estimate transpiration and interception for forested areas. These measurements will be used to reassess the simulated evapotranspiration of forested areas of the AZURE model and improve our fundamental knowledge about the evapotranspiration response of natural vegetation to changing weather conditions.

Because the Veluwe area has a thick (10 m to 70 m) unsaturated zone, the system responds slowly to changing meteorological conditions. Therefore we will perform model simulations for historical conditions (from the 17th century), the recent past (1980-2015), the near future (2015-2025) and the far future (2050 to 2100).

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2.4. Bergen, Norway

2.4.1. Location

The city of Bergen is located at the west coast of Norway (60°N, 5°E) enclosed with high mountains and an open sea. Since the aims of the research work BINGO is going to undertake with regard to Bergen are twofold (i.e. analysis of climate change induced impacts on the stormwater and the recipients, and analysis of drought risk and availability of future water resource), two study sites have been selected (Figure 26). These are: (i) the Damsgård area – for the researches associated to stormwater, and (ii) Jordalsvannet, Svartediket, Sædalen and Espeland – for researches on availability and management of water resources in a changing climate.

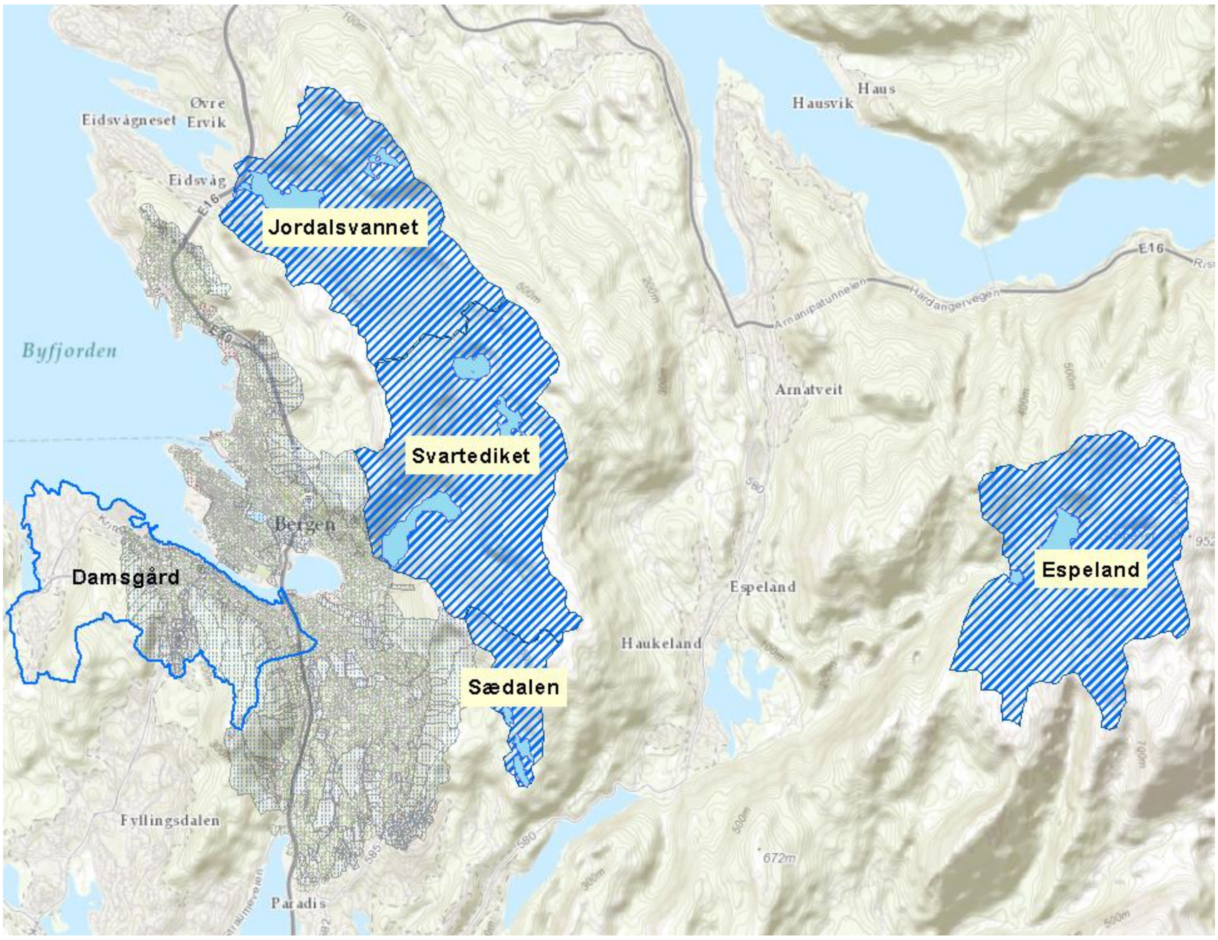

Figure 26. Study sites of the BINGO project in Bergen.

Damsgård is the study site for researches associated to stormwater management. Jordalsvannet, Svartediket, Sædalen and Espeland represent the drinking water resources of Bergen, and are sites for investigations related to drought risk and availability water resource in a changing climate.

2.4.2. Local climate

Bergen is renowned for its wet and mild climate. According to official numbers from the Norwegian Meteorological Institute (www.met.no), the 30 year normal (1960-1990) annual precipitation is 2485 mm. In 2015, the annual rainfall in Bergen was measured to 3101.7 mm, with an average temperature for 1.1°C above normal (Yr.no, 2015). The monthly average temperature is above 0°C throughout the year (Figure 27a) and the precipitation thus falls as rainfall. However, the mountainous area receives snowfall and snow accumulation occurs in the highlands. The rainiest season is fall and the driest month is May (Figure 27b)(Yr.no, 2015)”.

The large precipitation amounts over Bergen result from a combination of large-scale wind patterns and pronounced topography. At these latitudes, the prevailing wind patterns lead to dominance of winds from the west, exposing Bergen to winds coming in from the open sea. Low pressure systems from the Northern Sea provide the moist air, which is transported with the winds into the land. Further, the mountains surrounding the city cause the incoming air to release its moisture. As the air approaches the mountains it rises and cools. The cold air reaches saturation, vapor condensates and precipitation is released (Kolstad, 2015; Uib.no, 2009).

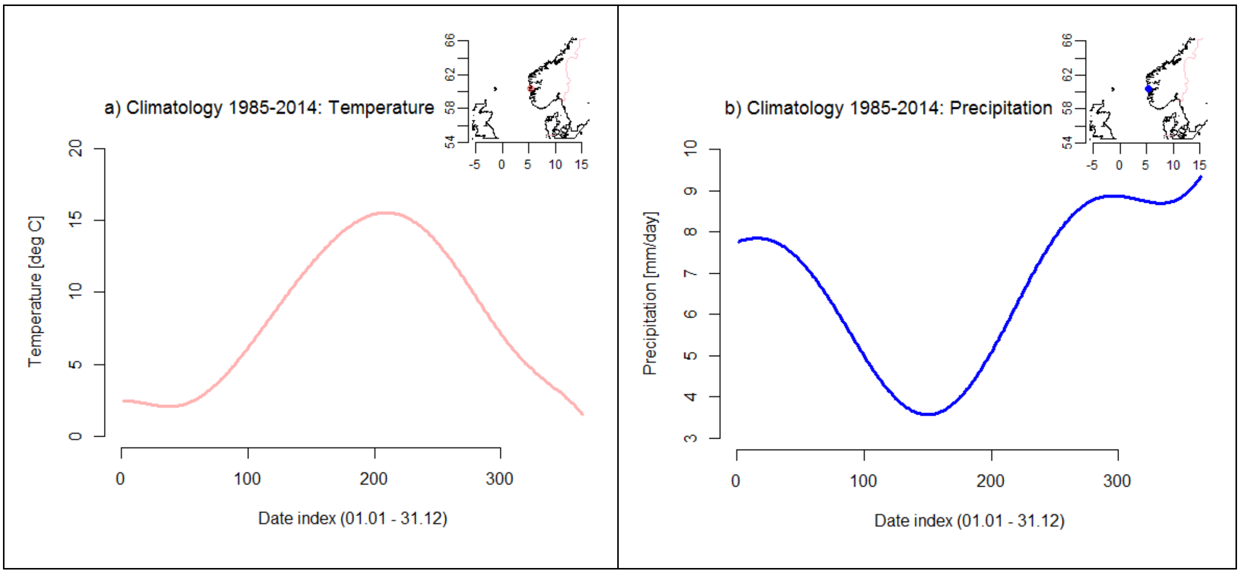

Figure 27. Climatology for temperature (a) and precipitation (b) at Florida Weather Station (Bergen city center) based on records from 1985-2014.

The municipality of Bergen extends from the ocean in the west to Gullfjellet (987 m above mean sea level; a.m.s.l.) in the east. In addition to Gullfjellet, several other mountains encircle the city. Not only does this pronounced topography influence the overall precipitation amounts, it also leads to large inter-city variations. In general, the precipitation amount and distance to mountains are correlated in such a way that the precipitation amount gets higher and higher as one gets closer to the mountains. Bergen is no different, and the precipitation amount increases from the east to the west. For instance, unofficial precipitation records from a station at Gullfjellet (located east of the city center) measured 5500 mm of precipitation in 2015, while a station at Øygarden (located northwest of the city center) recorded precipitation of 1900 mm for the same year. The difference in precipitation amounts was thus 3600 mm, while the linear distance between the spots is 20km (Kolstad, 2015). The further we move inland the higher the mountains in the Bergen region. The elevation gain pushes the moist air further up causing more precipitation is released and the weather fronts move inland. Explained by Erik Kolstad's chronicle (in Norwegian) (Kolstad, 2015).

In addition to large precipitation amounts, the precipitation often fall with high intensities, and Bergen has been hit by several extreme events over the past years. In January 2015, the county of Hordaland experienced wind with hurricane forced in certain places, due to the stormy weather "Nina". The most severe event in the recent years, however, was "Kristin" in 2005. During this storm, the extreme rainfall caused traffic jams, power outage, material damage, and a deadly avalanche of mud and stones, killing three people.

Contrary to this, Bergen has also experienced drought. In winter 2009/2010 the weather was both cold and dry. Due to the low temperatures, the precipitation falls as snow and the snowmelt would be delayed due to the length of the cold spell. This caused a drop in water levels in the drinking water reservoirs to unusually low levels and the inhabitants were urged to start preserving water.

Table 3. Catchment information of the drinking water reservoirs

Parameter	Svartediket	Jordalsvannet	Sædalen	Espeland
Area (km^2)	12.3	9.7	1.9	9
Lake area (%)	4.1	5.9	8.4	2.3
Elevation (m a.m.s.l.)	76 – 675	15 – 587	350 – 658	341 – 983
Specific runoff (l/s/km^2)	105	85	112	157

2.4.3. Hydrological descriptions

The Damsgård area has a size of around 8.3 km^2. The elevation of the study area ranges from sea level in the north to 468 m a.m.s.l. in the south. Information from nevina.nve.no reveal that the mean annual precipitation and temperature of the area are 2225 mm and 7.5 °C, respectively. Furthermore, the estimated mean specific runoff for the region is about 70 l/s/km^2.

Catchment information of the four drinking water reservoirs are summarized in Table 3. Riisnes and Kristvik (2015) report success in modelling the inflows into the drinking water reservoirs by transferring records from Haukåselva and Røykenes. They further describe that, season wise, the flow regime can be characterized as low-flow season during winter, moderate flow season between April and September, and high-flow season in autumn (i.e. October to the end of December).

2.4.4. Land use

The Damsgård area is located on the foot of a mountain. Built-up areas, including buildings and roads make up 48.3 % of the area. As can be seen in Figure 28, the built-up area most lies in the slope. About 44.5 % of the area is forest covered. This area lies in the mountainous part. Other land use units represented in the study area are open land (4.8 %), fresh water (1 %), and marsh land (0.4 %).

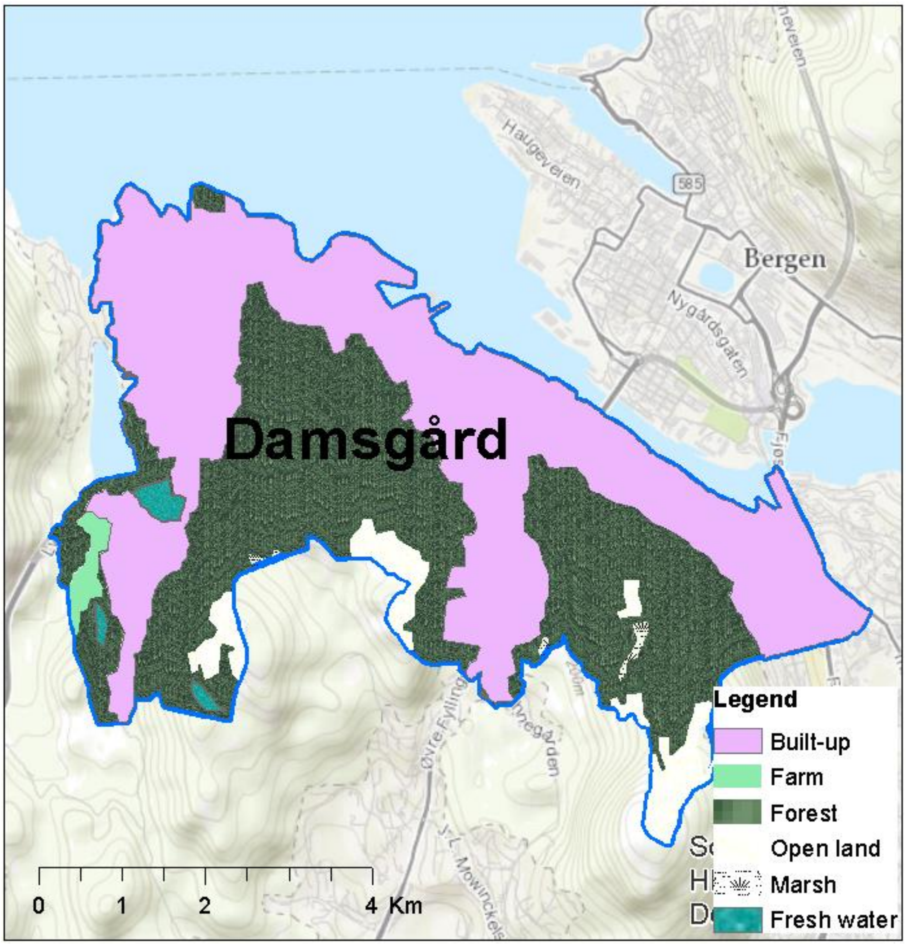

Figure 28. Land use map of the Damsgård area

Figure 29 summarizes the land use in the headwater areas of the drinking water reservoirs. The catchments are located in non-urban areas with a combination of wetlands, open-land and forested areas. Open-land, mountainous zones dominate the catchments.

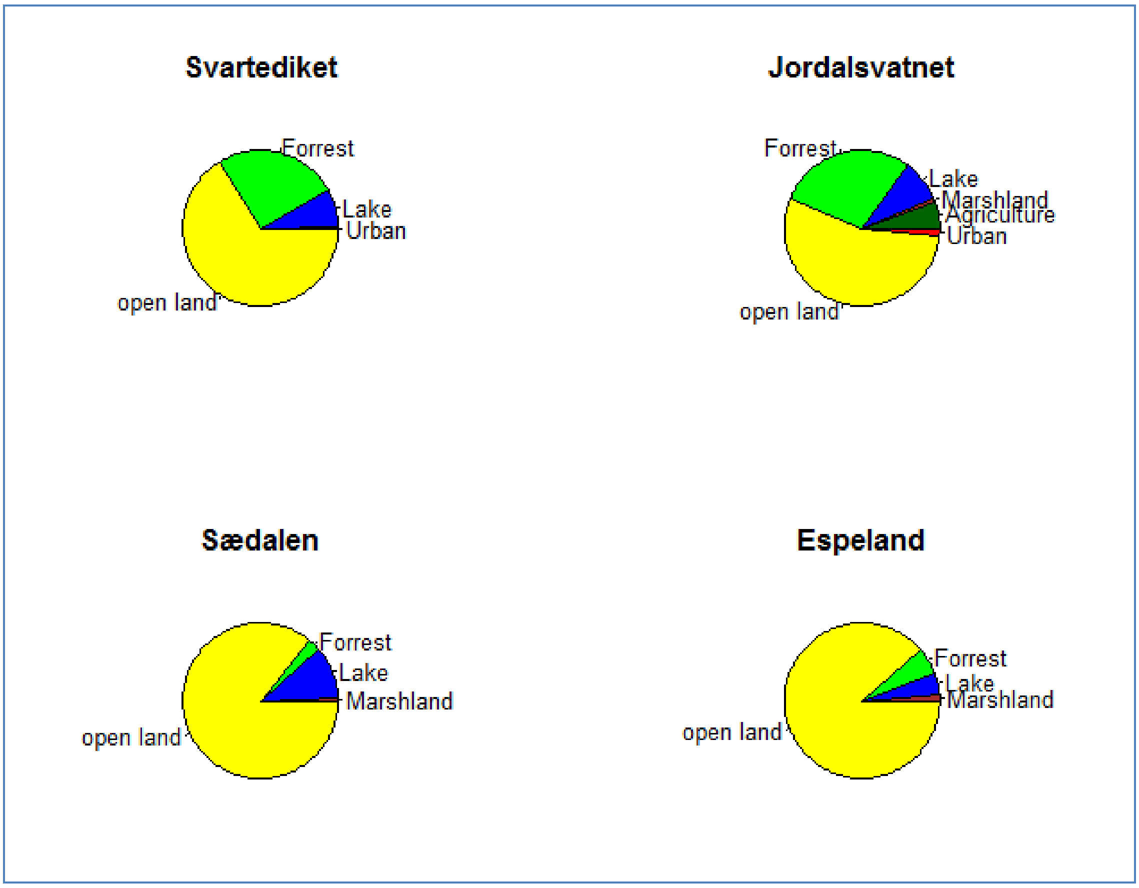

Figure 29. Distribution of different land use units in the catchments of the four drinking water reservoirs

2.4.5. Water use

An overview of the structure of Bergen Waterworks (BW) is presented in Figure 30. As indicated in the Figure, five major treatment plants produce drinking water to the city of Bergen (Svartediket, Jordalsvatnet, Sædalen, Espeland, and Kismul). The Figure also show the reservoirs connected to each treatment plant, the nature of the links between reservoirs (weir, regulated transfer), and minimum flows which need to be accounted for in a study of supply capacity. The total regulated storage volume of the reservoirs is 26.5 mil m^3 and approximately 37 mill. m^3 drinking water is produced every year (Bergen Vann, 2016). To ensure supply reliability, the threshold level is defined by the city of Bergen to 50 days of consumption. This is estimated to a volume of 5.5 mil m^3 (Kristivk & Riisnes, 2015).

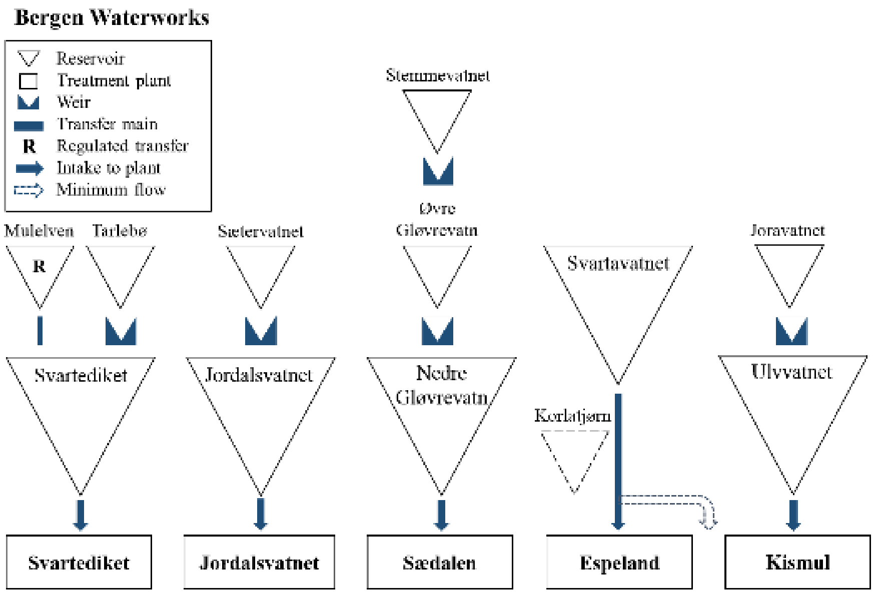

Figure 30. Bergen Waterworks

2.4.6. Past studies

To our knowledge, there have not been many studies conducted at the BINGO sites. An interesting research work is a master's thesis of Riisnes and Kristvik (2015). The work examines reliability of the drinking water sources utilized by Bergen Waterworks. They report that the municipal water supply system is vulnerable to droughts and seasonal changes in inflows. They also analyze the impact of climate change by projecting the changes in temperature and precipitation (IPCC AR5 emission scenarios RCP2.6, RCP4.5 and RCP8.5) employing empirical-statistical downscaling technique for downscaling Nor-ESM1-M. The study provides insights into how the different emission scenarios affect the maximum supply capacity of the water resources, and highlight the merits of controlling leakages in the water distribution networks as a mechanism for coping with the impact of climate change.

2.4.7. Known water problems

One of the important water problems in Bergen relates to the Drinking water resources. Due to the above mentioned water shortage experienced in 2010, there is a concern for the supply capacity of the existing drinking water system in Bergen. The water sources for drinking water purposes comprise of several reservoirs located in, and close to, Bergen. These reservoirs are relatively small in volume. As the reservoirs are quickly refilled from the steady and frequent precipitation loads (up to 300 days a year of rain), this is usually not a constraint. However, the incident in 2009/2010 showed that the reservoirs are in fact vulnerable to drought. This is a concern, as the Intergovernmental Panel on Climate Change (IPCC) projects not only increased temperature and more extreme precipitation events, but also more frequent dry spells and droughts of longer duration (IPCC, 2013). One of the research aspects of BINGO is therefore to study the supply capacity in Bergen under climate change. To do so, all catchments comprising the water supply in Bergen will be investigated. In the following section we present the catchments and the relevant background to do so. A pre-study to the BINGO project was conducted by Kristivk & Riisnes (2015) and most of the background provided here is covered in their report.

Bergen city is exposed to heavy precipitation loads. In the light of a changing climate, flash floods and storm water related challenges and the subsequent impacts on the stormwater system and recipients is of interest. The Damsgård area of Bergen, in particular, needs immense attention because of ongoing land use changes due to new developments and increasing population in the catchment. The area lies in the shadow of a mountain, which poses a challenge in the management of stormwater. The stormwater from this part of the city at the moment is released to the Pudde fjord directly but the municipality plans to monitor the water quality.

2.4.8. Outlook

The model framework for study site has been divided in two models, one for water resources and drinking water safty studies and one for sewer system and stormwater management modeling. For the former, the water resources, a HBV-model has been established, which will be further used for uncertainty analysis and climate change scenario development. Most likely this model will be further developed into an operational model for water level forecasting/projection (requested by Bergen municipality in the BINGO project description).

For the wastewater/combined system and stormwater management the model framework will be based on a SWMM or MikeUrban platform with auto calibrations using the statistical modeling software called R.

For the Damsgaard catchment a grid of rain gauges will be deployed in order to collect improved precipitation records for the catchment, and determine if there are systematic wind corrections across the catchment.

2.4.9. References

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2.5. Portugal

2.5.1. Geographical framework

The Tagus river basin has a total drainage area of 80600 km², 30% of which correspond to the downstream part in the Portuguese territory. The longitudinal east-to-west development in the centre of the Iberian peninsula of both the drainage basin and the Tagus river itself (660 km in Spain and 230 km in Portugal) stands as a climatic divide between the rainy northern Iberian territory and the southern dry part, where the rainfall regime is dictated by the scarce influence of the Atlantic moist north-westerly winds (Figure 31). This dual north-to-south feature is also felt inside the basin, especially in the Portuguese territory due to its latitudinal strip-wise development along the Atlantic coastline.

The significant north-to-south differences in the Portuguese side are well depicted by the two main tributaries of the Tagus basin with similar orders of magnitude for the drainage area: the Zêzere river, on the right hand side margin (with a drainage area of 5060 km^2), and; the Sorraia river on the left hand side margin (with a drainage area of 7730 km^2). Whilst the former has an average annual rainfall of 1090 mm and an average slope of 16.5%, the latter has an average annual rainfall of 690 mm and an average slope of 4.5%. Analogous differences occur at the land cover and human occupation level too: on the northern margin these numbers are 72% of forest cover, 26% of agricultural area and 55 inhabitants per km^2 for the Zêzere basin, while on the Sorraia basin, in the southern margin the corresponding values are 43% of forest cover, 56% of agricultural area and a density of 21 inhabitants per km².

Besides the asymmetry in the magnitude of rainfall and subsequent flows reaching the Tagus river from each margin there are also differences between the location and downstream influence of the interception of the two main tributaries with the Tagus stream body: the main tributary in the northern margin intercepts the Tagus river at approximately 120 km from the mouth, while the confluence of the Sorraia with the Tagus occurs close to the mouth immediately after these rivers expand into a large estuary. The area surrounding the Tagus estuary has a significant human occupation: 11 municipalities with 1.6 Million inhabitants bordering the estuary margins with its industries and port facilities, and; three municipalities hosting the headwaters of small watersheds draining directly to the estuary (like the Trancão basin) with 0.4 million inhabitants.

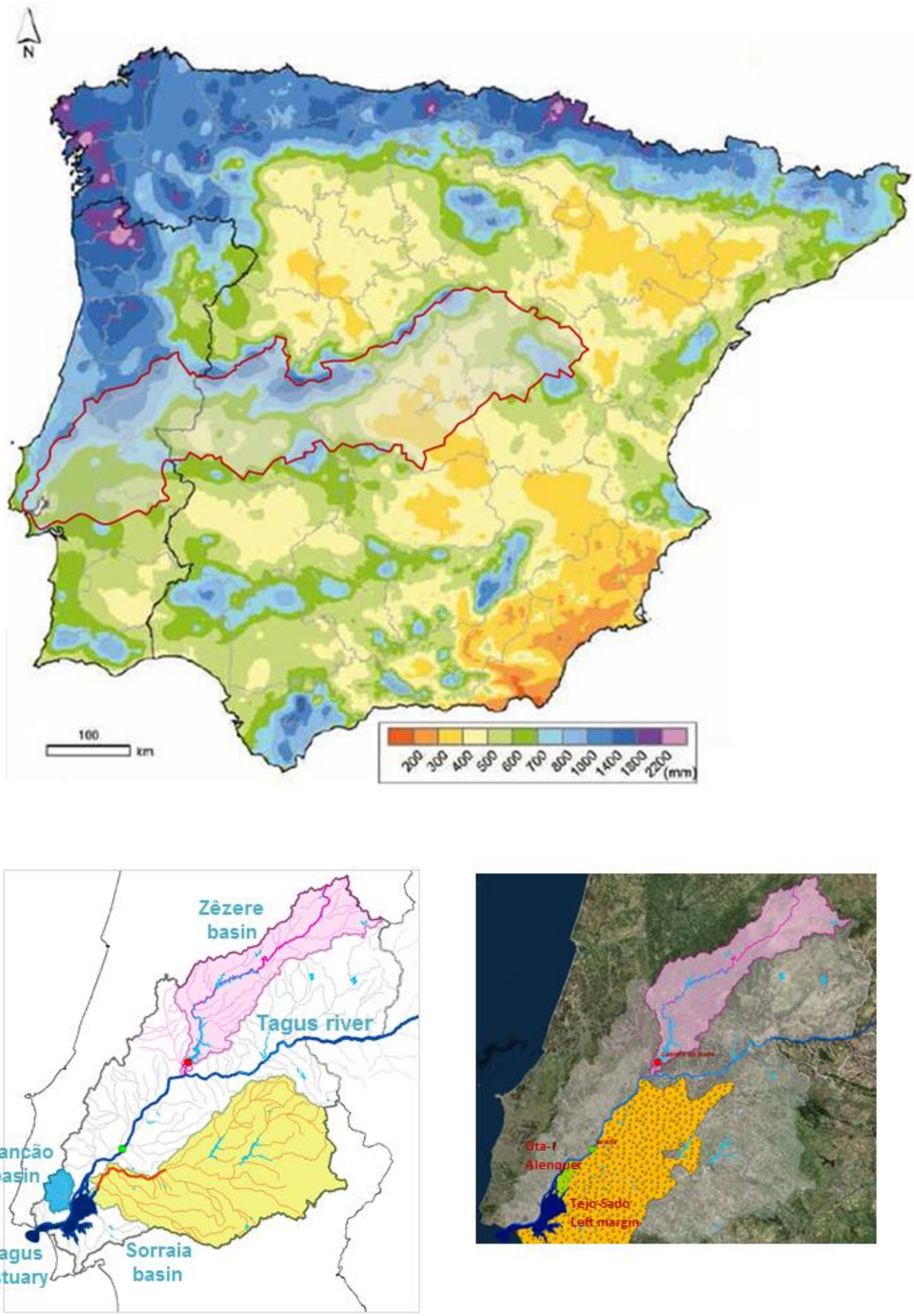

Figure 31. Transboundary Tagus basin water divide overlaid on the Iberian Peninsula's rainfall field (annual average) and water sub-systems to be addressed as BINGO case-studies

2.5.2. Hydrometeorological regimes, land-use, and morphology

2.5.2.1. Inland Surface Waters

Pristine Conditions

The determinant geographical characteristic of the Tagus River comes from its buffer nature as divider of the rainfall regimes – wetter at north and dryer at south. This feature can be quantified by the differences in the pristine average daily flow between the two main tributaries in each margin: the flow value in the main northern tributary (77 m^3/s) is four times greater than the flow from its southern counterpart, in spite of having less 30% of drainage area. Associated to these longitudinal unbalanced flows the entire basin displays marked seasonality both for river regimes and for inter annual sharp fluctuations in water availability (from torrential floods to prolonged droughts according to oscillations in the Atlantic moisture forcing). The torrential climatic characteristic is further geomorphologically intensified by the shape of the basin where steep tributaries from the right margin drain the runoff quickly to the main channel.

The elongated shape of the transboundary basin contributes to a more linear increase of the flow amounts towards the outlet than in an amphitheatre-shaped basin making the downstream flows also more dependent on the upstream conditions in the main channel.

Man-Made changes

To overcome the intrinsic flow seasonality derived from the climatic divide where the Tagus basin lies, several large dams were built in the Tagus River and its tributaries. These water works eventually had huge repercussions on the natural flow regime due to the driving forces presiding the inception and development of the water resources planning exercise. These were: 1) lack of coordination on both sides of the border for the planning goals and its timing (although several water sharing conventions between Portugal and Spain were updated to solve emergent problems); 2) the nature of most of the outlined solutions – which foresaw the upstream creation of high regulation capacity dams for irrigation and, even further, the option to resort to water transfer solutions on headwaters, leading to the subtraction of considerable volumes of water formerly available downstream.

In the Spanish part of the Tagus basin these man-made changes subtracted 80 m^3/s from the daily average flow at the Portuguese-Spanish border, totalizing an average of 2.5 billion of m^3 per year (Rodrigues, 2007), which is equivalent to a 27% reduction. On the northern wet tributaries of the Portuguese side of the basin, where the majority of the existing regulation capacity was set up almost exclusively for hydro power generation, the reduction effect on the amount of water flowing to the Tagus is negligible, although it changes the flow regime. The only relevant reduction of flow from the right hand margin tributaries occurs in the Zêzere River due to the water intake from Castelo do Bode reservoir to supply the Lisbon Metropolitan Area (accounting for a 7% reduction in flow). As for the southern tributary (the Sorraia River) – with lower flows and where the irrigation from surface water sources is intensive – the reduction of the natural flows due to water consumption has the same significance, in percentage, as the one reached in the Spanish counterpart of the basin (26.5 %), although the absolute magnitude of the reduction is 14 times less. Currently the average yearly amount of water reaching the estuary by the Sorraia tributary (505 Million m^3) is only 5% of the total inflow from the Tagus main stream (Rodrigues et al., 2009).

2.5.2.2. Groundwaters

Pristine Conditions

Ota-Alenquer is a small unconfined karstic aquifer located in Tagus right margin, with 9.38 km^2 of area and its water resources are higher than those that should be expected if the aquifer was recharged only thorough direct infiltration from its outcropping area. Its pristine conditions are almost unknown as far as piezometric levels are concerned because there are very scarce piezometric data. Flow directions and hydraulic gradients are unknown, although a main flow direction NW to SE from Montejunto Ridge to the two main springs of the aquifer (Ota and Alenquer) is suspected. Water quality in its pristine conditions was and still is in general of good quality (Cavaco & Benoliel, 1997).

Tagus-Sado aquifer is a large porous aquifer with several distinct water bearing units, defining an upper, an intermediate and a lower aquifer, more or less isolated from each other; in its WNW border it is overlaid by the Tagus Alluvium aquifer. Before exploitation started in the 1970's, general flow in the upper aquifer was from the borders towards Tagus River and its tributaries (Figure 32) as well as into the Tagus Alluvium aquifer (Almeida et al., 2000). The lower aquifer, in the central area of the basin, used to have piezometric heads above those of the upper aquifer, and of Tagus Alluvium aquifer, and often above the topographic surface, with the lowest units showing higher heads (Mendonça et al., 2004; Amaral et al., 2009; Mendonça, 2009). Flow towards the Atlantic is assumed to occur at the West border of Setúbal Peninsula (Almeida et al., 2000). In the past, waters usually had good quality, with no pollution problems, although upper aquifer's waters were of a much poorer quality and, in some areas, with salinity problems, due to the nature of the water bearing rocks. Tagus-Sado had a vertical zonation of hydrogeochemical facies, more chlorinated in the upper aquifer (Almeida et al., 2000).

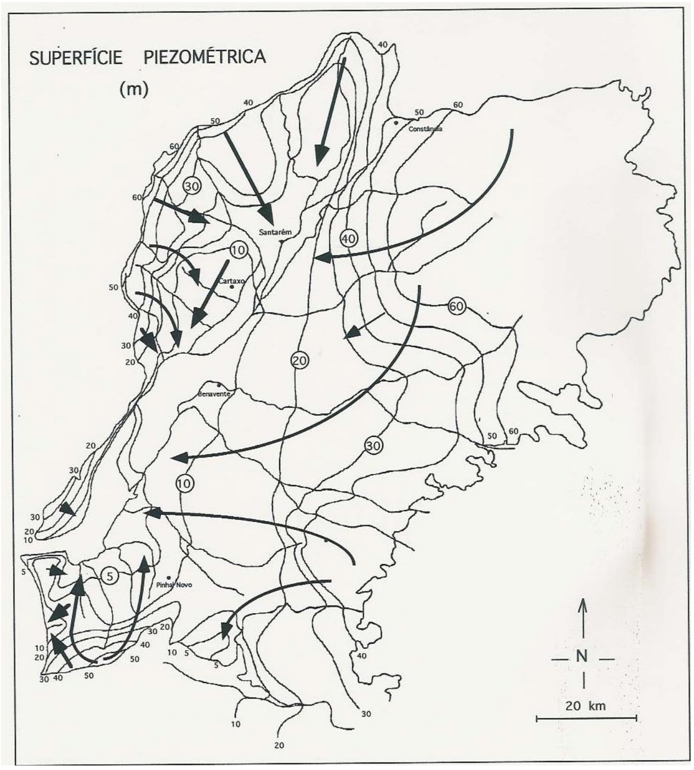

Figure 32. Pristine piezometric levels and natural groundwater flow in Tagus-Sado + Tagus alluvial aquifers (Simões (1998))

Man-Made changes

Due to lack of data it is impossible to ascertain if any piezometric or hydrodynamic changes had occurred on Ota-Alenquer aquifer. The very few data available suggest that over-exploitation does not occur and this aquifer is deemed in good quantity and quality status in the latest Tagus Watershed Plan (ARH, 2011), having negligible pollution issues.

Tagus-Sado aquifer is the water supply source to 770,420 inhabitants, in 29 municipalities, several of which in the Lisbon Metropolitan Area (Lobo Ferreira et al., 2011). Overexploitation in several areas of the aquifer, and in particular in the lower aquifer, generated a drawdown of the initial piezometric levels and changed the relationships between (1) water bearing units inside the aquifers, (2) Tagus-Sado and Tagus Alluvium aquifers, (3) aquifers and surface water bodies. Horizontal and vertical flow direction changes occurred due to piezometric changes, with upper aquifer units now showing higher piezometric heads than the lower ones, inverting the vertical flow (Almeida et al., 2000; Mendonça et al., 2004; Barreiras et al., 2009; Amaral et al., 2009). On the whole, there is a decreasing trend in piezometric heads, with negative values in several areas (Almeida et al., 2008). Water quality in Tagus-Sado has good status but important quality issues occur: several wells are in poor status, some with nitrates above the limits and there are statistically significant increase trends in nitrate and ammonia (ARH, 2011). Changes in flow directions have contributed to this (Almeida et al., 2000; Mendonça, 1993). Tagus Alluvium has poor quality, nitrates being a major problem due to intensive farming, with increasing trends in SO4 and Cl, possibly due to overexploitation and saltwater intrusion from the Tagus estuary (ARH, 2011; Lobo Ferreira et al., 2011). Tagus Vulnerable Zone includes the whole Tagus Alluvium aquifer and large areas of Tagus-Sado aquifer (ARH, 2011). Saltwater intrusion has been suspected for both aquifer systems (Almeida et al., 2000; Simões, 1998; Ribeiro, 1993 & 1998; Oliveira et al., 2000).

2.5.2.3. Transitional Waters

The Tagus estuary is a mesotidal, coastal plain estuary. It has a surface area of about 320 km^2, with a deep, long and narrow tidal inlet connecting the Atlantic Ocean to a shallow, tide-dominated basin. This basin has extensive tidal flats and marshes that cover about 40% of the inner estuary. About 40 km upstream, the estuary markedly narrows at the bay head. In this area, the estuary is bordered by low elevation terrains extensively used for agriculture and often protected by dykes. The estuarine bottom is mainly composed of silt and sand, of both fluvial and local origins; marine sands are confined to the mouth and inlet channel (Freire et al., 2007).

Tidal ranges vary between 0.55 and 3.86 m at the coast (Guerreiro et al., 2015) but resonance significantly amplifies the semi-diurnal tidal constituents within the estuary (Fortunato et al., 1999). Simultaneously, the estuary is strongly ebb-dominated due to the large extent of the tidal flats (Fortunato et al., 1999).

On average conditions, the saline tide reaches about 50 km upstream from the mouth, near Vila Franca de Xira. During droughts, saline water has been detected about 14 km upstream, at a water uptake (Conchoso). The estuary is usually partially mixed, although it can be stratified when neap tides are combined with high river discharges (Neves, 2010).

Included in the Metropolitan Area of Lisbon, the estuary comprises along its margins 11 municipalities with about 1.6 million of total inhabitants, mostly concentrated in its western and northern sides (Tavares et al., 2015). This densely urbanized water front contrasts with a large extension of productive agricultural areas on the eastern side of the estuary and along the “Mouchões”, the local term for the islands formed by alluvial deposition (Figure 32). Several critical and sensitive infrastructures are exposed along the estuarine margins. The estuary also hosts a natural reserve (the Tagus Estuary Natural Reserve) that is one of the most important sanctuaries for birds in Europe, covering about 14,000 hectares.

The detailed land use cartography of the estuarine fringe (defined by the Portuguese law as the 550 m wide fringe above the water line at the highest astronomical tide, and that in the present case covers a total area of 130 km²) shows that the most important occupation types are the agricultural (35 %) and the urban (34 %) zones, with smaller contributions of industrial, port and airport facilities (24 %), green spaces (6 %) and natural areas (1 %) (Rilo et al., 2012).

2.5.3. Extreme events prone areas

The analysis of historical occurrences, registered between 1865 and 2013, shows that the probability of occurrence of one or more flood events in the Tagus estuarine margins in one year is 26 % (Rilo, et al., 2015). The potential flooding water levels in the estuary mainly result from the association of spring tides and storm surges episodes, while the impact of large fresh-water discharges on the water level in the estuary is limited to the upstream sector (Vargas et al., 2008; Guerreiro et al., 2015, Freire, et al., 2015).

The impact of flood events in the Tagus estuarine margins is well illustrated by past occurrences as the February 15th 1941 wind-storm, considered the biggest catastrophe that occurred in the Iberian Peninsula in the last 200 years (Muir-Wood, 2011). The flooding, associated to strong wave action driven by southwesterly winds combined with a major storm surge, had a wide spatial impact along the estuarine margins between Cascais and Vila Franca de Xira causing high human casualties, extensive material losses (e.g. ships, port facilities, houses, infrastructures), and major disruption of services (e.g. telephone and electricity lines and road and railway systems) (Muir-Wood, 2011; Freire et al., 2015).

Another important flood event in the estuary occurred on February 27th 2010, associated with the Xynthia storm (Bertin et al., 2014) that had similar characteristics as the 1941 event (Breilh et al., 2014). No human losses were registered but both margins, between Oeiras and Vila Franca de Xira, were impacted with considerable damages in the water front infrastructures including the Port of Lisbon facilities (Freire et al., 2015). The analysis of oceanographic, meteorological and river discharge data shows that, in both events, the estuarine high water levels resulted from the combination of spring tide and storm surge conditions (Freire et al., 2015).

As for the floods in the sub-basins within the Lisbon Metropolitan area, the Trancão river flooding is paradigmatic. The Trancão river basin is located at the northern limits of Lisbon, covering an area of 279 km^2 heavily industrialized and densely populated. The Trancão River is 30 km long and flows into the Tagus estuary, near the upstream limit of the estuary. The climate is temperate with a dry summer season. The average annual rainfall is 836 mm (PGRHT, 2012).

From the 1960's, the proximity to the metropolitan area of Lisbon led to the urban and industrial expansion in the Trancão river basin, with construction works occupying floodplains with potential for agricultural development and housing on steep and erodible hillslopes. Urban, agricultural and industrial effluents have been discharged into the Trancão River and its main tributaries, the Loures and Póvoa rivers, and dramatically modified the region (Pinheiro et al. 1999). Since the 1990's the situation has gradually been reversed with a series of interventions, namely the construction of wastewater treatment plants, the improvement of the drainage system and the rehabilitation of the riverbanks in the Trancão river mouth.

The Trancão River and its tributaries are prone to rapid floods due to intense rainfalls, strong slopes of the river basin headwaters and the existence of extensive urbanized areas. These flash floods originate high rates of soil and bank erosion, supplying large volumes of sediments and debris that clog narrow cross-sections of the river Trancão tributaries, increasing the water levels upstream and the flood hazard. In the historical flood events of 1967 of 1983, extensive inundations were observed, with overtopping of levees, which caused human casualties and severe social and economic impacts in most of the basin, particularly in Póvoa River and Loures lowlands. More recently, flood events were recorded in 1996, 2008 and 2012.

Table 4 summarizes the significant flood events in the lower Tagus river basin and its impacts.

The southern areas of the Tagus basin are more prone to droughts than the northern ones. The intensification of reservoir construction in the Sorraia back in the 1950's was the end of a planning process to struggle against the high seasonality and inter annual variability of water available for irrigation.

In the last 75 years, several major drought episodes occurred. The severity of each of these droughts, quantified as return period (T), varied from North to South due to the latitudinal spreading of the Portuguese territory along the Atlantic coastline. Particularly severe were the hydrologic years of (Brandão and Rodrigues, 2006): 1944/45 (with severity ranging from a 50-year return period in Northern Portugal to a 100-year return period in the Southern part of the territory); 1975/76 (North: T=25 years; South: T=10):

1980/81 76 (North: T=10 years; South: T=25); 1991/92 76 (T=15 years in both North and South); 1998/99 76 (North: T=5 years; South: T=15); and 2004/05 76 (North: T=250 years; South: T=175). The 2004/5 drought had also a bi-annual significant severity (North: T=120 years; South: T=35).

Table 4. Significant flood events in the lower Tagus river basin

Date	Location	Impacts
February 1941	Tagus estuary	28 casualties 14 people injured 130 people affected
November 1967	Lisbon region	462 casualties 1100 people affected
February 1979	Lower Tagus	2 casualties 115 people injured 1187 people evacuated
November 1983	Lisbon region	19 casualties 2000 people affected
December 1989	Lower Tagus	1 casualty 61 people evacuated
December 1996	Lower Tagus	
Winter 2000/2001	Lower Tagus	
February 2008	Lisbon region	2 casualties 110 people affected
February 2010	Tagus estuary	
April 2013	Lower Tagus	

(Source: Portuguese National Authority of Civil Protection (http://www.prociv.pt/), EM-DAT - Emergency Events Database (http://www.emdat.be/), 1) Project MOLINES Database (Rilo et al. ,2015))

2.5.4. Climate change settings

2.5.4.1. Hydrometeorological & Tidal gauged evidence

Like elsewhere in the world, global warming is raising the mean sea level in the Tagus estuary. Analyses of the Cascais tide gauge data indicate that the sea level rise (SLR) rate is consistent with global estimates: for instance, the mean sea level rose by about 0.15 m in the 20th century (Antunes and Taborda, 2009). The agreement between the SLR at Cascais and the global values is due to the negligible vertical movement of the surrounding area (Guerreiro et al., 2015). Within the estuary itself, SLR enhances the amplification of the tidal range by resonance. Although this effect is partly being offset by the accretion in the estuary, the extreme water levels within the estuary still rise faster than the mean sea level (Guerreiro et al., 2015).

The evolution of the wind pattern with climate change remains poorly understood. Statistics of winds predictions in this region for the end of the 20th and 21st centuries do not support the hypothesis of a significant change in the wind regime (Guerreiro et al., 2015). Similarly, there is no strong evidence of a change in storminess in the Portuguese coast. Studies based on wave buoy data (Quadrio and Taborda, 2010) and results of hindcast models (Dodet et al., 2010, Bruneau et al., 2011) suggest that the statistics of significant wave heights have remained stable for the past decades. Similarly, wave statistics in this region for the end of the 20th and 21st centuries indicate that extreme waves will not change significantly (Andrade et al., 2007) or will decrease (Ribeiro et al., 2012).

During the 20th century, the climate observations in Portugal suggest an evolution characterized by three distinct periods regarding the average air temperature: a warming between 1910 and 1945, followed by a cooling between 1946 and 1975, and a more accelerated warming between 1976 and 2000 (Miranda et al., 2006). The precipitation is characterized by large interannual variability and no clear trends were observed in its annual values (Miranda et al., 2006). However, a significant decrease of the precipitation was observed in February and March.

A significant increase of the average air temperature (2-9 ºC) is predicted by the end of the 21st century in Portugal (Miranda et al., 2006). The changes in the hydrological regimes are more uncertain, but decreases of the precipitation in the mainland during spring, summer and autumn are expected (Miranda et al., 2006). In some regions these decreases can be of 20%-40% relative to the present values (Miranda et al., 2006).

2.5.4.2. Expected scenario's outcomes from available projections

Studies of climate changes in the Tagus watershed have been performed, forecasting changes in precipitation, temperature and runoff, based on SIAM I (Santos et al., 2002), SIAM II (Santos et al., 2006), ENSEMBLES (van der Linden & Mitchell, 2009) and PESETA (Ciscar, 2009) results. As such, the Tagus Watershed Plan predicts for 2100 a summer temperature rise of 4 to 6 ºC and a winter rise of 2 to 3 ºC, a winter precipitation increase up to 10% and a sharp reduction of summer and autumn precipitation up to 60%, which leads to predictions of runoff reduction from 1 213 to 6 066 hm^3/year for the whole Tagus watershed (ARH, 2011). The frequency of extreme events, namely droughts and floods, is expected to increase (Santos et al., 2002).

The aquifers' recharge will also be affected by the above changes and several studies have already assessed these changes but most do not concern *Ota-Alenquer* or *Tagus-Sado* aquifers. Cunha (2006, in Tomé, 2007) using data of HadCM3 in a A2 scenario found recharge reductions up to 45% in the basins south of Tagus for 2050, larger recharge reductions in spring and summer and a general recharge decrease for all seasons (except, sometimes, for winter). Oliveira et al. (2012) using ENSEMBLES temperature and precipitation results in A1B scenario, determined for *Torres Vedras* aquifer a recharge reduction between 2 and 16 % in 2050 and 18 to 60 % in 2100; for *Monforte-Alter do Chão* aquifer recharge reductions range from 6 to 36 % in 2050 and 16 to 64 % in 2100 (Lobo Ferreira et al., 2012). In this same study, an impact analysis of recharge changes impacts on GDEs was also performed. Changes in recharge are especially critical for small aquifers, in particular karstic, because due to their reduced storage capacity, these aquifers will not be able to profit from any eventual recharge increase associated with increased winter precipitation/extreme events (Oliveira et al., 2005). Analysis of climate change impacts on limestone aquifers' water quality was performed by Oliveira (2011).

For the two BINGO aquifers, *Ota-Alenquer* has no analysis of changes in recharge, flow directions, hydraulic linkage with *Montejunto*, interactions aquifer/surface waters or spring outflows and activity periods under climate change scenario. Only for *Península de Tróia*, in *Tagus-Sado*, project SIAM II (Santos et al., 2006) presents recharge reductions of 10 % - 40 % and saturated thickness reductions of 5.1 % to 7.4 %. Ferreira (2012), for the coastal aquifers of *Arriba Fóssil da Costa da Caparica*, under 1.5 m sea level rise, 42% precipitation reductions and the current exploitation volumes, projected advances of 20 m in saltwater intrusion and a drop in piezometric levels in up to 1.5 m. Recharge changes will impact aquifers' exploitation rates. An exploratory study by Novo et al. (2012), using climate change influenced water demands scenarios, projected exploitation rates above 50 % for *Tagus-Sado* aquifer and up to 75% for *Tagus Alluvium.*

2.5.5. Water management hot-spots and issues to be tackled

The Tagus river basin with its marked differences between a northern mountainous and wet zone and a southern flatter zone with a dryer climate, gave way to different water uses throughout the time that are to be impacted differently by climate change and were selected as important BINGO-Portuguese case studies to be addressed, namely: the water supply to the Lisbon Metropolitan Area, with its bulk water transfer from the Zêzere basin to Lisbon and the supplement alternatives, and; the agricultural deficits, within the Sorraia basin and adjacent Lezíria, currently so dependent on surface water but where groundwater can be a reinforcement alternative (both on quantity and quality terms). The third issue to be tackled as a Portuguese case study in BINGO concerns the flooding impacts in the Lisbon metropolitan area at the mouth of the Tagus River, with the complexity of its very densely populated and urbanized zones and its important estuary.

2.5.5.1. Water Supply to Lisbon metropolitan area

EPAL - Empresa Portuguesa das Águas Livres, SA is responsible for managing the abstraction, production, transport and distribution of drinking water to about 2.9 million consumers in 35 municipalities in the region of Lisbon, ensuring supply in quantity and quality. In 2013 about 199 million m€ of water were supplied (545.205 m^3/day).

It is the largest water company in Portugal, supplying about 30% of the national population, including Lisbon Metropolitan Area. The quality of water supplied is more than 99% compliant with the required quality standards. The water losses in the transport and distribution system have reached the lowest levels of Europe (9% in Lisbon).

The main EPAL water abstraction sources are:

- Castelo do Bode reservoir - located in the in Zêzere river, 9 km upstream the Tagus river, it is the main water source, accounting for 70 to 80 % of the water supplied;
- Tagus river in Valada do Ribatejo – located in Tagus upper transitional waters limit, contributes with 12 to 23 % of the total volume supplied;
- Groundwaters – are EPAL strategic reserves, accounting presently for less than 10 % of water, with six abstraction points from Ota-Alenquer aquifer system and 16 points in Tagus Alluvium.

EPAL is a highly innovative company, using the best available practices to efficiently fulfil very high efficiency criteria. Willing to keep high performance standards under climate changes EPAL is contributing to this case study to retrieve from it adaptation strategies on water supply sources under climate change scenarios, namely: how they will behave in quantitative and qualitative terms; if these changes or other competing uses for the same sources (ex: electricity production and recreation) can compromise any of EPAL performance goals, and finally; up to which extent can abstraction be shifted from superficial to groundwater's sources, in case superficial sources become problematic for any reason, without compromising water body quality objectives established under Water Framework Directive.

In WP3 these issues will be accomplished in two phases:

1st Phase – Analyse the impact of climate changes in water bodies where abstractions occur:

- Castelo do Bode reservoir (main water abstraction source) - so far this water body has good ecological and chemical quality. Eutrophication processes will be modelled to see if it can evolve under different climatic conditions (mainly temperature and solar radiation) or smaller water storage volumes and, particularly, if nuisance species are prone to appear;
- Tagus river in Valada do Ribatejo – presently this water abstraction is already operated according to tides. It will be modelled to check if saltwater intrusion can compromise this water abstraction;
- Groundwaters – Groundwater systems Ota-Alenquer, Tagus-Sado and Tagus Alluvium have diverse importance for water supply. Ota-Alenquer is mainly a system of support/reinforcement to supply, while Tagus-Sado is an important supply source for several municipalities. Issues amongst these systems are also distinctive: Ota-Alenquer might be prone to large changes in water availability while Tagus-Sado and Tagus Alluvium are expected to have major quality issues and possible changes in hydraulic connections to surface waters, influencing their base flow. In Ota-Alenquer aquifer a new model will be attempted, focused on recharge changes under the new average climate conditions. If possible, modelling changes in flow and spring discharge will be done. For Tagus-Sado/Tagus Alluvium aquifers, a new model will be developed for flow and transport, attempting to study: (1) recharge changes under new average climate conditions, (2) flow changes inside aquifers and pollution problems arising from this, (3) hydraulic connection changes between aquifers and river network, (4) evolution of saltwater intrusion, (5) identification of areas most affected by these changes, (6) new groundwater quantity and quality conditions for the new average climate conditions.

2nd Phase – Analyse water body status under different abstraction volumes:

For each of the water sources it will be analysed how far water abstraction can be increased, without compromising water status, or without compromising other uses.

2.5.5.2. Agriculture in high quality soil types

Surface water (quantity / quality) & GW constrains in drought conditions

Several important agricultural areas are located within the lower Tagus region, particularly the irrigation areas of Lezíria Grande de Vila Franca de Xira and of Vale do Sorraia.

Lezíria Grande de Vila Franca de Xira

The irrigation area of the Lezíria Grande de Vila Franca de Xira (Aproveitamento Hidroagrícola da Lezíria Grande de Vila Franca de Xira – AHLGVFX) covers 13420 ha (Figure 33). One of the main cultures in the region is rice, representing about 41 % of the irrigated cultures in 2014, but the tomato culture has also increased in the past years. The annual investment in cultures is about 60 million euros per year.

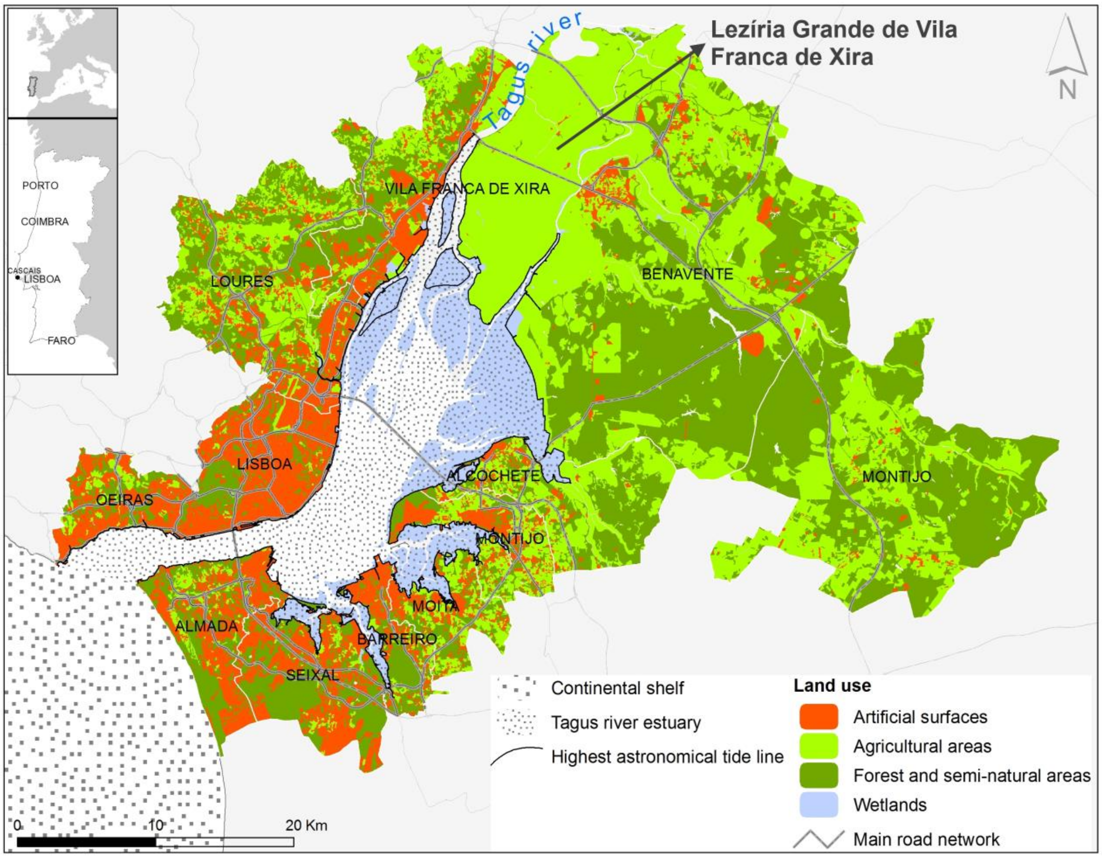

Figure 33. Tagus estuary and location of the Lezíria Grande de Vila Franca de Xira (adapted from Tavares et al., 2015)

The irrigated area in the Lezíria Grande de Vila Franca de Xira is about 10000 ha, 40 % of which are irrigated under pressure and 60 % are irrigated by gravity. The main water supply is located in the Tagus River, at Conchoso, and its maintenance is fundamental to guarantee the required water demands for the cultures in the area. In particular, rice requires 8000 m³/ha more of water than the other irrigated cultures. Besides the Conchoso, other water intakes exist in the Tagus, Sorraia and Risco rivers. Since the Conchoso water intake is located close to the limit of the salinity propagation in the Tagus estuary, the water intake can be limited by the tides. Moreover, during very dry periods, the salinity at this water intake can reach concentrations that are inadequate for the cultures, with adverse effects for the local economy. In past, namely during the 2004/2005 drought and in 2012, emergency measures were undertaken to minimize the negative impacts of water scarcity and, in particular, the loss of cultures. These measures comprised the route of the freshwater available in the Sorraia River.

The agricultural areas along the eastern side of the estuary, that are below the present mean sea level and separated from the estuary by walls and dykes, are also frequently affected by flooding episodes of both oceanic and fluvial origins. During the February 2010 event, in the Lezíria Grande de Vila Franca de Xira, the dikes were overtopped and destroyed in some places leading to agriculture land losses. When the overtopping occurs due to high sea levels, it is possible that the water involved has significant concentrations of salt, which can further damage the cultures. Thus, in the Lezíria Grande de Vila Franca de Xira the impacts of both droughts and oceanic floods will be analysed to support the management of this agricultural area under extreme climate events.

Vale do Sorraia

The 56% of agricultural area of Sorraia basin has two main distinguished realities:

- *Sorraia valley irrigation perimeter*, a small area of 4.3 % (15365 ha) of the total agricultural area, irrigated by a public network, supplied by two main reservoirs (Montargil and Maranhão), complemented with three smaller ones. Private agricultures are associated (Associação de Regantes e Beneficiários do Vale do Sorraia) to perform the management and operation of the irrigation system. Agriculture is intensive in this valley, using best available irrigation techniques. The main cultures are rice, corn and tomato, with a significant economic impact in the region. Tomato production feeds the canned tomato industry, also of large importance in the region.

- *Remaining Sorraia agricultural area*, the largest area, with private agricultures abstracting from groundwater or small private weirs. The level of efficiency in agriculture practices vary in the region.

The impact of frequent and/or long droughts in Sorraia valley irrigation perimeter is the main focus of this case study, both from quantitative and quality perspectives. Both the hydrology and the water quality of Sorraia River, with its agricultural pollution, will be modelled.

The main objectives are to analyse under predicted climate change scenarios: if present types of Sorraria cultures are sustainable and it is possible to use part of the water to irrigate Lezíria Grande de Vila Franca de Xira, an adjacent agricultural area, also include in the Portuguese case study.

Surface flows and associated pollutants will be modelled for different types of uses of soil, to test for adaptation to climate changes.

For Tagus-Sado/Tagus Alluvium aquifers, the modelling tasks described formerly will be performed for the new drought conditions, to identify extreme changes in recharge, water levels, quality and quantity status and overexploitation situations, etc. Once climate change and economic constraints shall change land use, which will have impacts on recharge and exploitation rates/overexploitation, modelling will also attempt to use land use scenarios to evaluate changes in (1) recharge, (2) exploitation rates and impacts on water levels, (3) quality issues and (4) areas most affected by these. For Ota-Alenquer aquifer, although farming has a very minor role in this aquifer, analysis of its response to drought conditions will be attempted.

2.5.5.3. Pluvial Flood vulnerability in urban areas

Trancão river basin

The potential for damage from floods in the Trancão river basin is mostly related with the rapid runoff response to intense rainfall events and the existence of roads and buildings constructed in flood-prone areas and constrains in the river channels. In response to frequent flooding, floods in the Trancão basin were studied in the past and several interventions were foreseen in the Regulation Plan of Trancão river basin (HP, 1994), although they have not been implemented. Nevertheless, the importance of the flood risks in the Trancão river basin was recognized in the context of the EU Floods Directive (Directive 2007/60/EC) and the flood risk management plan is being developed. Despite these efforts, flood damages in the Trancão river basin need to be estimated considering urban development and land-use decisions in a context of climate change in order to define and support appropriate flood management measures.

2.5.6. Outlook

The model framework for the Tagus study site has been divided in five models, taking into account the issues to be tackled.

The surface water models are of two types: water resources availability and flood process changes in a suburban basin. For the groundwater studies a model which allows for the modelling of variably saturated flow, unconfined flow, contaminant transport, density/viscosity-affected flow, multilayer wells, flexible meshing and situations of activation/deactivation of areas inside the modelling area was selected.

MIKE.HYDRO Basin (Grijsen, 2013) will be developed to model the Zezere sub-basin (where is located the main water supply reservoir in the Tagus basin), as well as in the contributing area spanning from the confluence of the Zezere with the Tagus to the water intake upstream the estuary, to assess the potential changes in water resources availability and water quality due to climate change. The water quality issues will be tackled by a QUAL-2 type subroutine. MIKE.HYDRO Basin will also be applied to generate future scenario time series to feed the drought studies in the Sorraia basin.

HEC-HMS (HEC, 2015) coupled with HEC-RAS (HEC, 2016) will be applied to model the floods in an area where both climate and man-made pressure are contributing to change the pristine flow patterns.

Thefinite elements model FEFLOW (DHI, 2015; Hesch, 2009) will be applied to simulate groundwater flow under confined/unconfined situations, recharge variations, and use/pollution changes and saltwater intrusion due to sea-level rise in the main Tagus aquifer systems that are assumed to be in connection with the Tagus river network, Tagus estuary and the ocean, tackling both quantity and quality issues might arise in these aquifers emerging from climate change. Two-dimensional and three-dimensional baroclinic models will be developed, calibrated and validated for the Tagus estuary to study, respectively, inundation and droughts in the Lezíria Grande de Vila Franca de Xira area. The Tagus estuary models will be based on the unstructured grids modeling system SCHISM (Zhang et al., 2016) and will update previous modelling applications in this estuary (Guerreiro et al., 2015, Fortunato et al., in press, Rodrigues et al., 2013). These models will provide information about the maximum water levels and the salt water propagation in the estuary. The validated models will be used to simulate the relevant past and future extreme scenarios. Two monitoring stations will also be installed in the Tagus estuary aiming to obtain data of water levels, salinity and water temperature, to support the validation of the models and a continuous characterization of the system.

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2.6. Badalona, Spain

2.6.1 Location of the site

Badalona, with more than 215,000 inhabitants within its administrative limits on a land area of more than 21.2 km^2, is located in the eastern Catalonia (Spain) and is part of the Barcelona metropolitan area (in Spanish AMB). It is situated on the left bank of the Besòs River facing on the Mediterranean Sea, and backed by the Serra de la Marina mountain range (Figure 34).

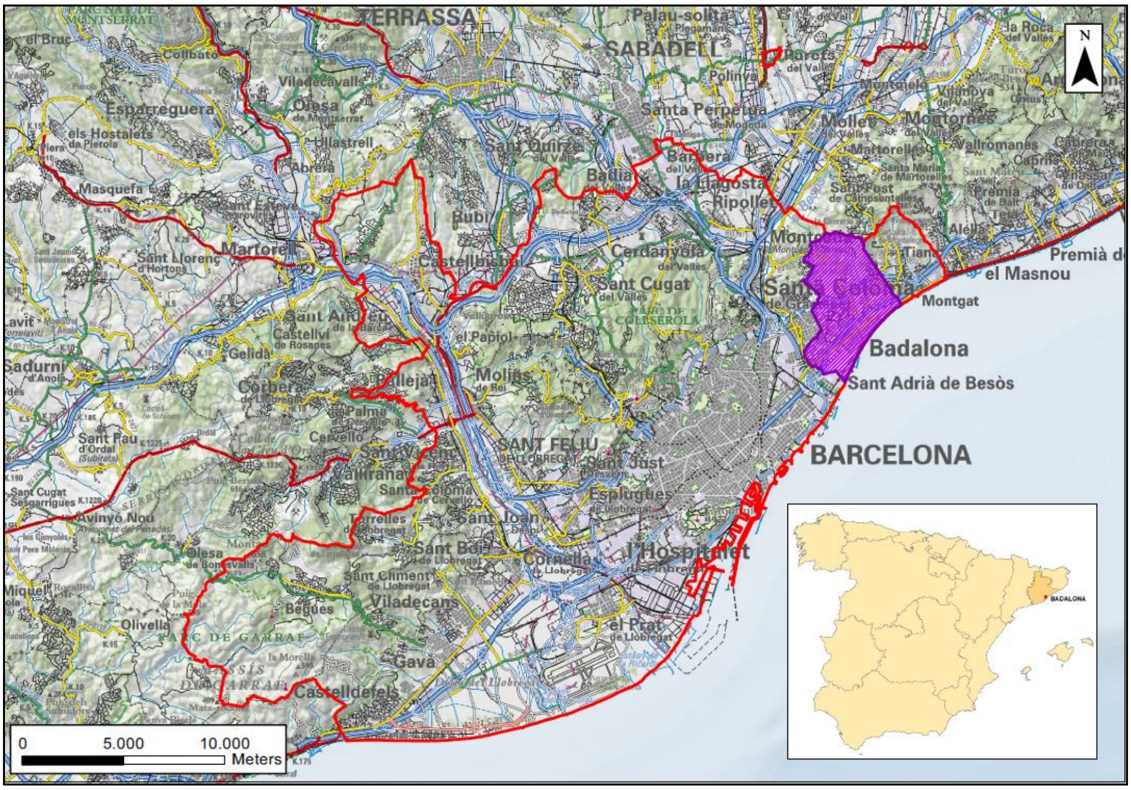

Figure 34. Map including Badalona location and AMB administrative limits (in red)

Badalona is the third most-populated municipality in Catalonia after Barcelona and L'Hospitalet de Llobregat. The administrative land of the city is divided into 6 districts and 24 subdistricts (likely known as "Barris") as shown in the Figure 35. The average population density of the city is around 10.000 inhab./Km^2, although this value can increase significantly in some districts of the old town and the city center.

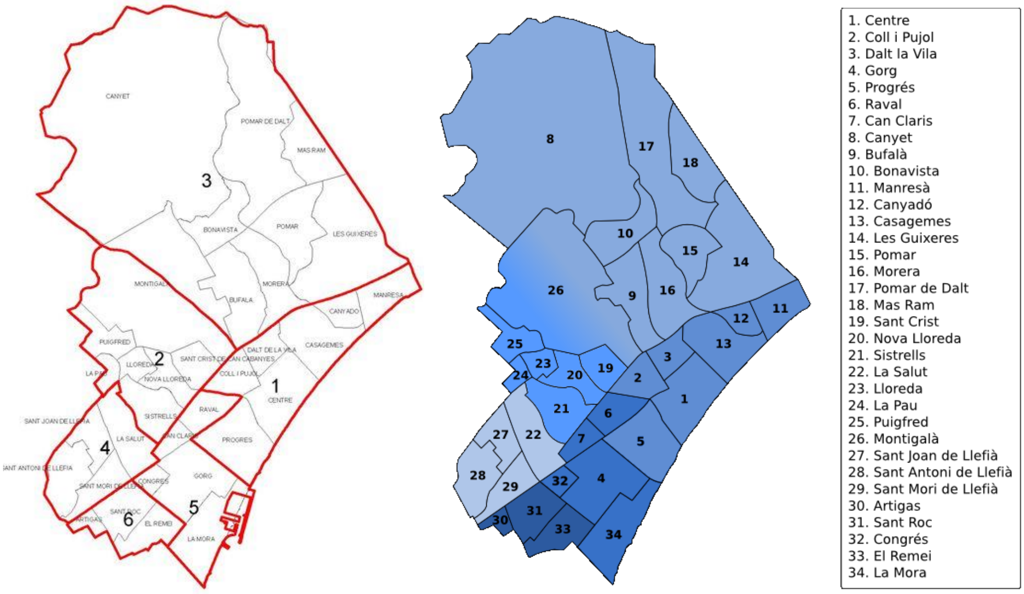

Figure 35. Districts (on the left) and subditricts (or Barrios) in Badalona

2.6.2 Local climate

Badalona benefits from a classic Mediterranean climate with bright cool winters and even brighter hot summers, but occasionally suffers heavy rainfalls of great intensities and flash floods events. The yearly average rainfall is 573 mm, although it is not rare that 50 % of the annual precipitation occurs during two or three heavy rainfall events generally occurring in summer and autumn (Figure 36).

Climate parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual
Average temperatures (ºC)	10,1	10,6	12,1	13,8	17,0	20,8	23,8	24,4	21,5	17,9	13,5	10,8	16,4
Rainfall (mm)	48,0	29,4	35,3	43,4	51,0	43,4	17,9	50,1	73,5	79,8	55,4	46,2	573,4
Average wind speed (km/h)	10.6	10.3	10.3	9.6	9.3	8.9	9.3	8.8	9.2	9.1	10.1	10.8	9.6
Predominant wind direction	NW	NW	W	SE	ESE	SE	SE	SSW	W	NW	NW	NW	NW

Figure 36. Average values of temperature, rainfall, wind speed and predominant wind direction. Data from the meteorological station of the Museum collected in the period 1968-2008 (Source MeteoBDN.cat)

Three rainfall gages have been recently (2013-2014) installed in Badalona. Due to the shortness of these rainfall time series, no specific Intensity Duration Frequency (IDF) curves for Badalona could be elaborated. However, due the short distance between

Badalona and Barcelona (a few hundred meters), it will be possible the use of Barcelona IDF for the purpose of the BINGO project.

These IDF curves were recently updated on the basis of a rainfall series data of 81 years (from 1927 to 1992 and from 1995 to 2009) (Casas *et al*., 2010) (Figure 37 and Table 5). On the basis of these IDF, a new project storm (Plubarna 2010) (Figure 38) with a return period of 10 years was deduced for the design of sewer network (Casas *et al*., 2010d).

Apart from the three rainfall gauges cited above, some rainfall gauges distributed around the city exist. They were recently installed (between 2007 and 2008) by non-official institutions. Due to the short recorded times series and the non-official nature of the source, these data cannot be used to elaborate IDF curves and design storms. Finally, one rainfall gauge (from Servei Meteorològic de Catalunya, SMC) is working since 2005 (Figure 39).

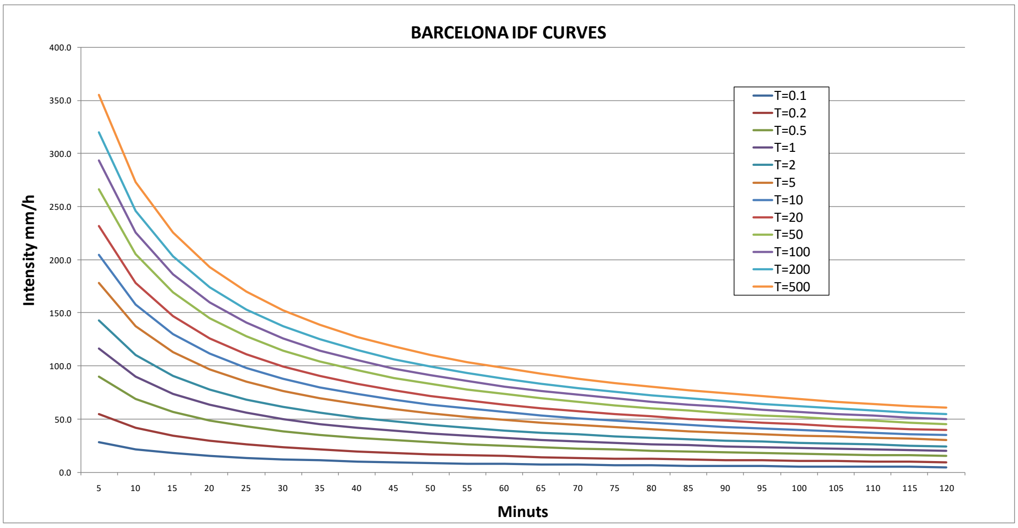

Figure 37. Barcelona IDF curves (Casas *et al*., 2010)

Table 5. Maximum rainfall intensities expressed in mm/h for the Barcelona IDF curves

t (minutes) T (years)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
0.1	38.2	26.7	20.6	16.7	14.3	12.7	11.3	10.2	9.4	8.8	8.3	7.8	7.5	7.3	7.0	6.7	6.5	6.2	6.1	6.0	5.9	5.5	5.3	5.4
0.2	60.3	45.0	35.8	29.3	24.9	21.8	19.4	17.6	16.2	14.9	14.0	13.1	12.4	11.7	11.2	10.7	10.2	9.9	9.5	9.2	8.9	8.5	8.2	8.0
0.5	92.2	70.5	57.6	48.0	41.4	36.5	32.6	29.7	27.4	25.1	23.3	21.9	20.5	19.3	18.5	17.4	16.6	16.1	15.3	14.7	14.2	13.6	13.2	12.6
1	118.2	92.1	77.0	64.9	56.9	50.5	45.8	42.0	38.6	35.2	32.6	30.5	28.5	26.7	25.5	23.7	22.6	22.0	20.7	19.9	19.6	18.6	17.6	16.9
2	144.1	112.0	94.3	80.4	71.4	63.8	57.9	53.2	49.1	45.0	41.7	39.0	36.7	34.4	33.2	30.8	29.5	28.8	27.0	25.9	25.0	24.5	24.0	22.8
5	178.5	137.4	115.7	99.6	89.2	80.1	72.3	66.1	61.2	56.6	52.5	49.1	46.5	43.9	42.5	39.8	38.3	37.4	35.4	34.2	33.5	32.0	31.2	30.5
10	204.7	156.1	131.3	113.6	102.1	92.0	82.6	75.2	69.7	64.8	60.1	56.3	53.4	50.7	49.2	46.4	44.9	43.8	40.8	39.7	38.2	36.4	36.0	35.5
20	231.0	174.6	146.5	127.3	114.6	103.6	92.6	84.0	77.9	72.8	67.4	63.2	60.1	57.3	55.8	52.9	51.4	48.2	46.0	45.2	43.4	41.9	40.4	39.0
50	265.9	198.7	166.2	145.0	130.9	118.6	105.3	95.1	88.4	83.0	76.7	72.0	68.7	65.8	63.3	59.2	57.8	55.2	53.3	50.8	48.9	48.2	46.3	45.2
100	292.2	216.8	180.9	158.3	143.0	129.7	114.8	103.4	96.2	90.6	83.7	78.6	75.1	72.1	69.6	65.5	62.9	60.3	58.9	56.3	54.4	53.7	50.8	50.4
200	318.7	234.8	195.5	171.3	155.0	140.8	124.1	111.4	103.8	98.1	90.5	85.0	81.4	78.4	75.8	71.8	68.4	65.5	64.0	61.8	60.0	58.1	56.3	53.7
500	353.4	258.5	214.5	188.4	170.6	155.2	136.2	121.9	113.6	107.8	99.4	93.4	89.5	86.5	85.0	82.2	78.4	76.5	72.8	70.0	67.3	67.5	61.7	60.8

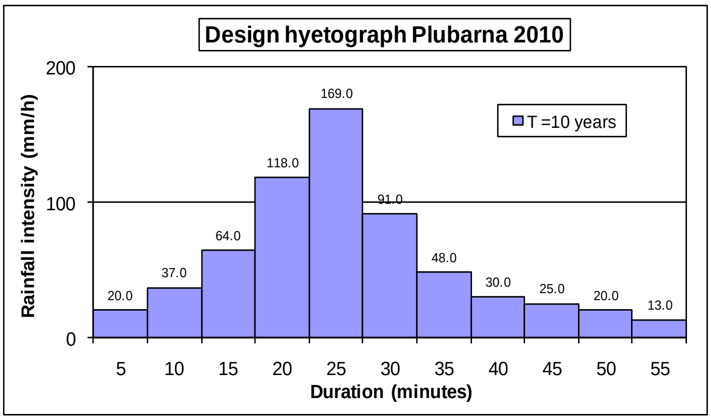

Figure 38. Barcelona project storm (Plubarna2010) (Casas *et al*., 2010)

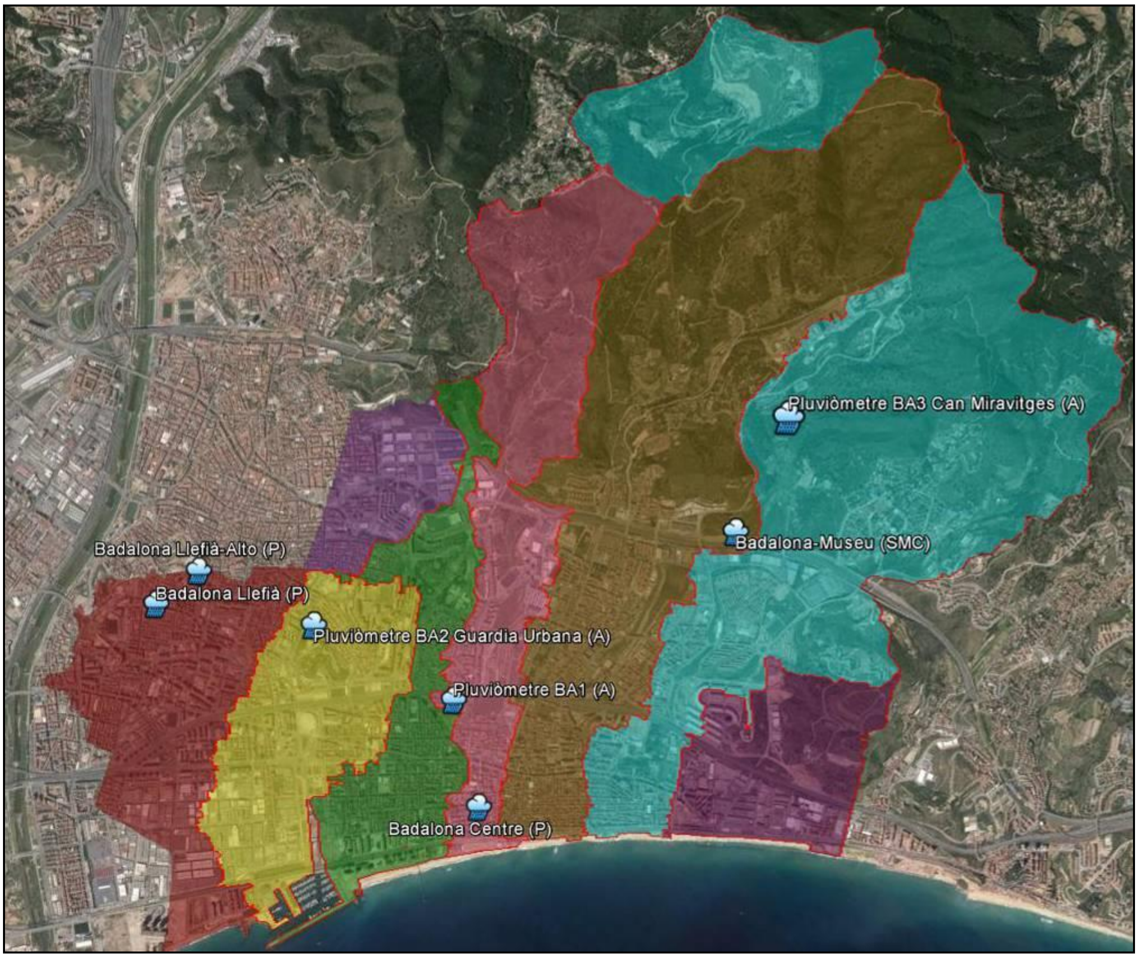

Figure 39. Rainfall gauges locations in Badalona (P=Non-official gages; A=Gages exploited by Aquatec and SMC= Gage exploited by SMC)

2.6.3 Hydrological descriptions

The morphology of Badalona presents areas close to the Serra de la Marina Mountains with high gradients (more than 30% in some areas) and other flat areas close to the Mediterranean Sea. Quick hydrological response of these areas can generate runoff with high peak flow and significant flow velocities, with consequent erosion problems during storm events. Seven natural ephemeral watercourses ("riera de Canyadó", "riera de Canyet o d'en Folch", "riera de Sant Jeroni", "torrent de la Font", "torrent d'en Valls", "torrent d'en Vallmajor" and "font de Sistrells") coming from the upper part of city (with significant flow and solid transport during heavy storm events) have been channelled under the urbanized area. The works started in 1920 with "La riera del Canyet" and the last works finished at the beginning of the nineties. These channels have poor capacity during heavy storm events, generating flooding problems (Figures 40 and 41) and combined sewer overflows to the sea via the outlets situated on the beach.

Figure 40. Main water course and catchment of Badalona

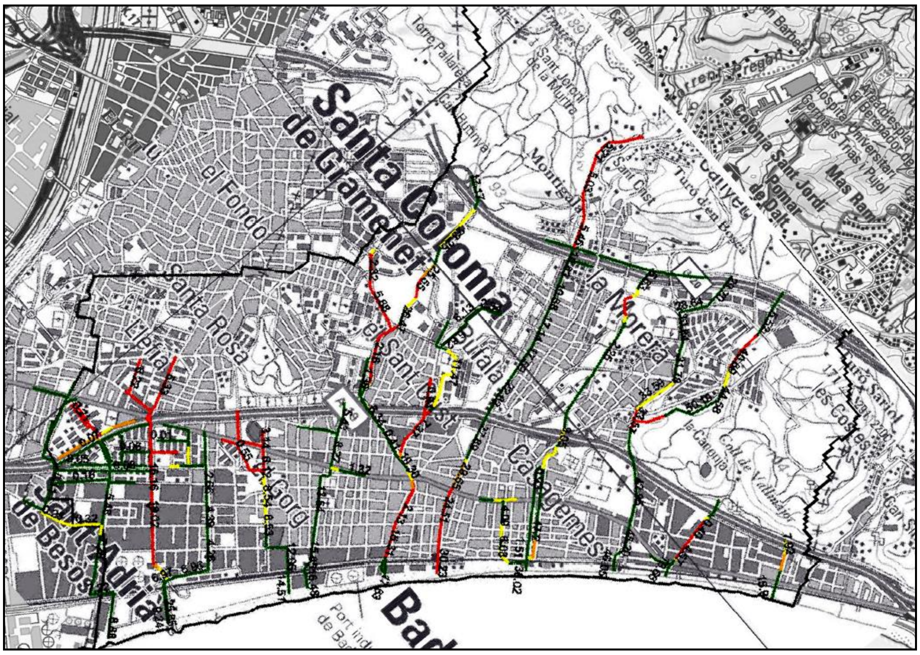

Figure 41. Representation of the hydraylic behaviour of the chanelled Badalona's water courses under the urbanized area for a design storm with a return period of 10 years. Red lines represents sewer floods

2.6.4 The sewer system management in Badalona

Urban drainage in Badalona has a special relevance due to the climate and morphological characteristics of its catchments described above. The high demographic density and land imperviousness exacerbate urban flood risk and affect negatively on river and coastal water pollution during rain events.

Badalona drainage network is mainly a combined system with 318 km of sewers, 26% of them allowing man-entry.

There are nine catchments in the city (Figure 42). Most of them discharge from the mountain to the sea where waste water is intercepted by sewers that drive them to the Besòs Waste Water Treatment Plant (WWTP).

A weir exists in every interception. During rain events, part of the stormwater can entry into the WWTP, while the excess generate Combined Sewer Overflows (CSOs) through the mentioned weirs.

Badalona presents several km of beaches, which are the receptor of 21 points with potential polluted CSOs (Figure 59). The pollution is directly linked to the presence and nature deposits in the network and the contaminants conveyed during the wash-off of the surfaces.

Figure 42. Badalona sewer network. Green colour represents sewer network managed by Badalona municipality, while in red colour network managed by AMB is shown

In 2012, Badalona Drainage Master Plan (DMP) was elaborated with proposed works for 168 M€, of which more than 10 M€ have been already invested. The elaboration of the DMP is based on Geographic Information System (GIS) and a Modelling System (in terms of quality and quantity), including the sewer network (sewer network), the WWTP and the receiving waters (marine model). Nowadays, the model is being updated including the last implementations within the sewer network, such renovated pipes and the Estrella storm water reservoir in order to minimize the effects of heavy storms events, in terms of flood protection, and improvement of the water quality in the receiving water bodies.

The main features of Badalona sewer network are:

- 318 km of pipes
- 9232 manholes
- 9 gates
- 57 weirs
- 20 siphons

Several deficiencies had been detected through the elaboration of the DMP and the expertise of local stakeholders:

- Entrance of sand and stones in the network from the upstream catchment (natural basins). Nevertheless the existence of interception structures at the entrance of the sewer network, sediment generated in Serra de la Marina discharges into the sewer network through sediment trap structures causing several problems (reduction of sewer pipe capacity, pollution of the bathing water, etc.).

  The factors that override the operation of these structures are:

  - Some of them are not designed to retain fine sediments, but they can block trees or large garbage.

Figure 43. Interceptors structures avoiding large objects and sediment trap in the upper stream part of Canyet's catchment (Source: Advanced Mangement of Sediments in Sewers. R+D+i Alliance)

  - Some of them are not efficiently designed due to the existence of lateral grids allowing the entrance of sediments.

Figure 44. Sediment trap in the upper stream part of Vallmajor's catchment (Source: Advanced Mangement of Sediments in Sewers. Internal SUEZ R+D+i project)

- Some sediment traps are full of sands and there is no plan to remove it.

Figure 45. Plenty sediment trap in the upper stream part of Canyadó's catchment (Source: Advanced Mangement of Sediments in Sewers. Internal SUEZ R+D+i project)

- Accumulation of sediments along the network (Figures 46 and 47), especially in the sand-tramps at the pumping station of Badalona Harbour: Sediments come from upstream natural catchment, but also from the urbanized catchment.

Figure 46. Examples of sediments within Badalona's sewer network (right) and the deposits extracted at the Badalona Harbour pumping station (left)

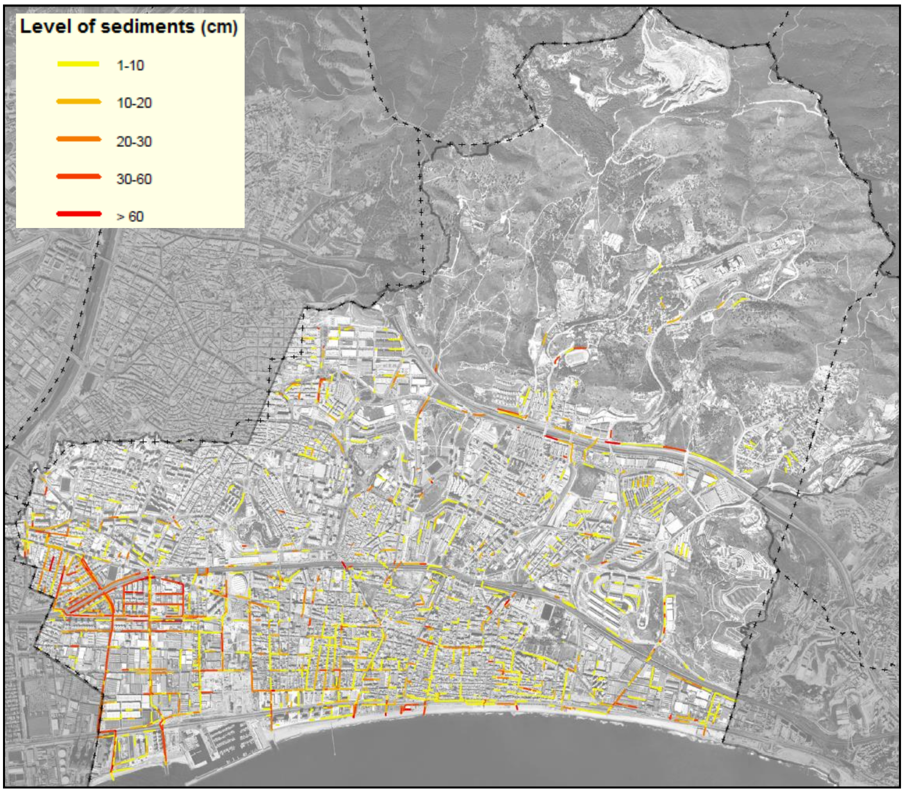

Figure 47: Level of sediments for Badalona's sewer network (Source Badalona DMP)

- Odours in the network close to Besòs river:

  Flat area highly urbanized and with sediment showing high organic content.

- Material deterioration and aging infrastructures

  These problems can generate structural failures with collapse of road bed and other urban structures.

Figure 48. Material deterioration in the Badalona sewer network and some example of structural problems

- Partial clogging caused by beach sand in the overflows infrastructures that generate a distorted functioning of their hydraulic behaviour

Figure 49. Clogging phenomenon of the overflows infrastructures (Source Badalona DMP)

An integrated mathematical model simulating the 1D sewer flow and the 2D marine model allows to obtain useful information in terms of:

- Hydraulic behaviour of the sewer network (on the basis of the knowledge of water levels, velocities and flows in the network)
- CSOs related to specific rainfall inputs
- Effects on the receiving waters (bathing waters) in terms of pollution concentration through the simulation of propagation and decay processes.

The integrated model was developed in the framework of the elaboration of the Badalona DMP with a specific planning purpose, so it is not currently exploited.

Due to the general absence of sensors and field data, model was not adequately calibrated, so a qualitative calibration was done.

This integrated model was based on the 1D MOUSE sewer model (Figure 50) developed by Danish Hydraulic Institute and COWAMA marine model (Suñer *et al*. 2008) (Figure 51) developed by CLABSA and Hidromod, a Portuguese technical consulting company specialized in the software developing in the field of fluid mechanics and spin-off company of Technical University of Lisbon.

Specifically through a sewer quality module, pollutant hydrographs can be estimated and constitute the inputs for the COWAMA marine model, that allow to study the Fecal Coliforms an E. Coli concentrations in the bathing waters ant their mortality depending on solar radiation, salinity and temperature.

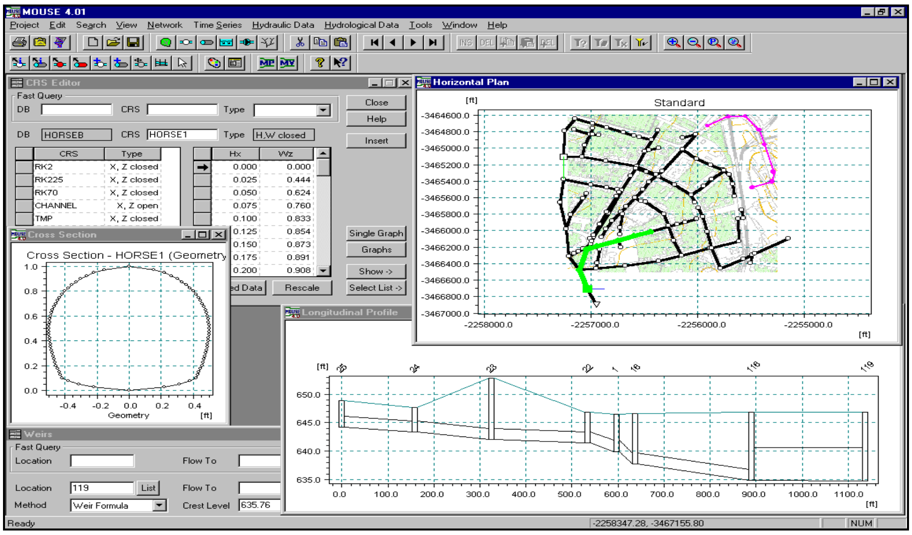

Figure 50. Badalona MOUSE sewer system modelling

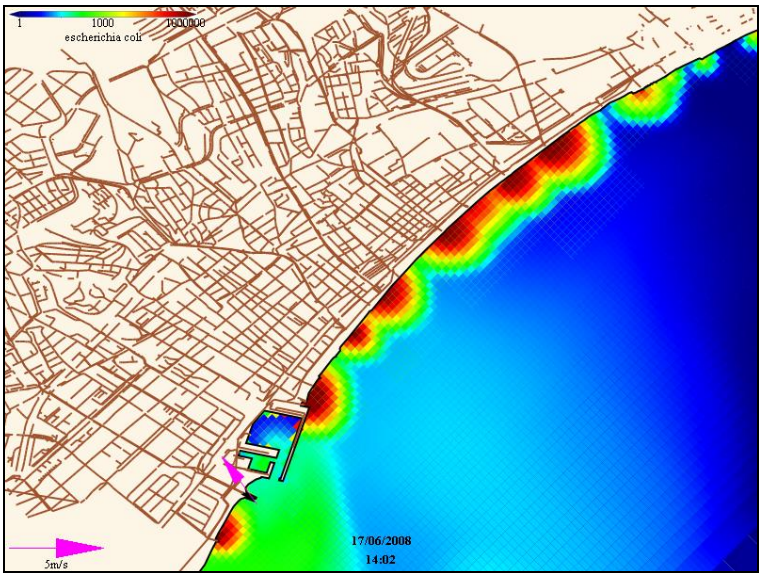

Figure 51. Badalona COWAMA system modelling

As said, in the framework of BINGO project, sewer model is being updated and exported to Infoworks Integrated Catchment Modelling (Infoworks ICM) provided by Innovyze company. A 2D model for the overland flow simulation will be coupled with the 1D sewer model and integrated to an updated marine model. Finally the integrated model will be calibrated using the existent field data and the existent sensors (17 flow depth level sensors and 3 rain gauges) located in the municipal network (Figure 52) and some new sensors that will be acquired in the context of BINGO project and that will be installed in the nearness of the interceptor in order to analyse CSOs during storm events and the dry and wet flow reaching the WWTP.

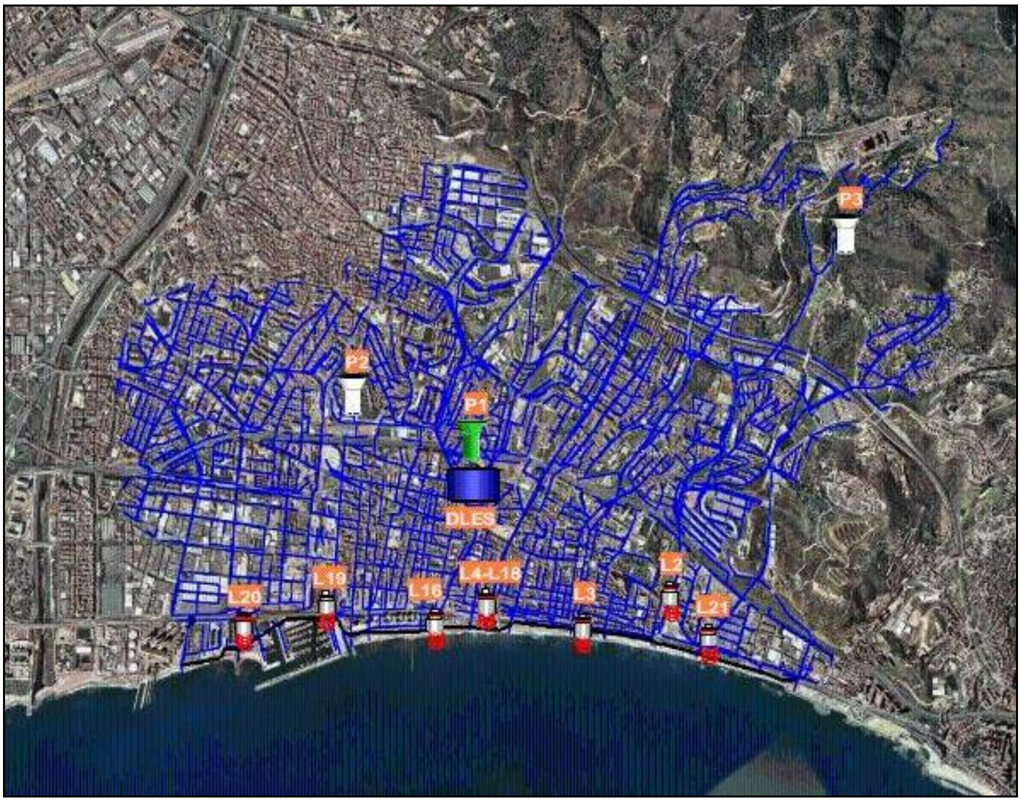

Figure 52. Sensors network location in the Badalona research site

2.6.5 Land use

There are two important elements to define the characterization of the catchments and the water system: runoff surfaces and land uses.

On one hand, the different existing runoff surfaces in Badalona must be defined (Figure 53) in order to produce correct inputs to hydrological-hydraulic model.

As mentioned, a good option to achieve a correct assessment of the flood hazard in urban areas is the simulation of the 2D overland flow through a 2D surface model coupled to a 1D model sewer hydraulic modelling and considering a detailed digital elevation model (DEM) of the whole analysed domain.

In this framework, a key aspect for a correct modelling is the detailed representation of the typology of the urban surfaces in order to reproduce their hydrological response in a reliable way.

With this aim, surfaces in Badalona have been classified in several categories (Figure 53), whose hydrological characterization will be done during the elaboration and the calibration of the hydrological-hydraulic model. From the Figure 53, it is possible to observe the high occupancy of impervious area in Badalona.

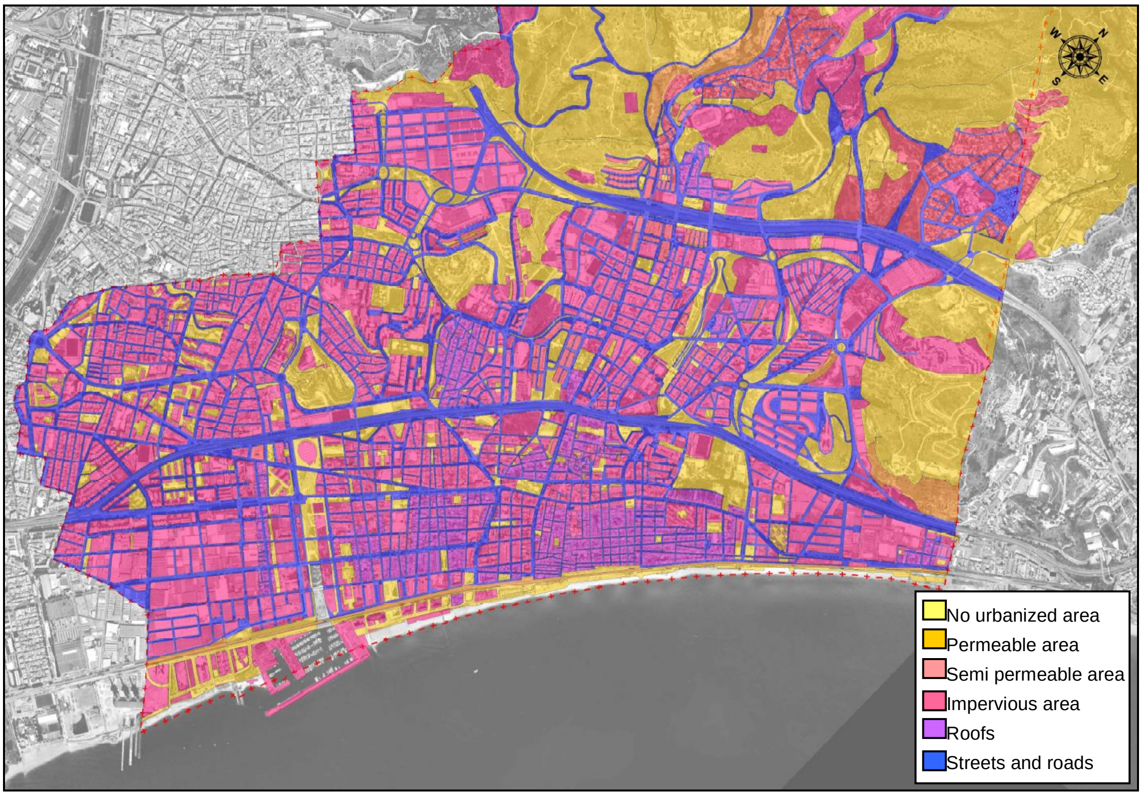

Figure 53. Surface classification in Badalona

On the other hand, the European Directive 2007/60/EC of October 23rd aims at the reduction of adverse consequence on human health, on the environment, on cultural heritage and on economic activity. With this aim flood hazard, vulnerability and risk assessments are required. The vulnerability analysis requires:

- An inventory of the elements at risk and all possible damages
- The examination of flood exposure characteristics of the receptor system
- The social context

In order to establish these points, the land uses (established in the Barcelona Metropolitan Territorial Plan approved by the Catalan Government in 2010), have been taken into account (Figure 54).

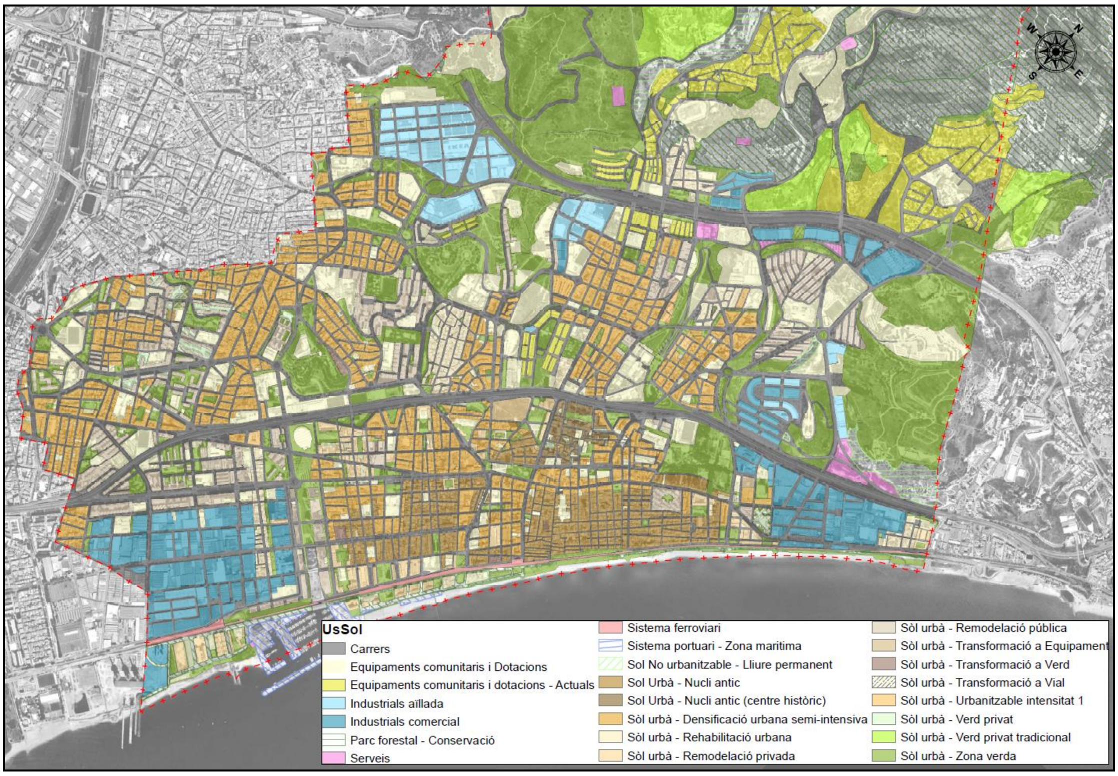

Figure 54. Land uses defined in the Barcelona Metropolitan Plan approved by the Catalonia Government in 2010 for Badalona

Due to the strong social and economic impacts of flooding in ground floors or basements, the land uses types of these floors have been specifically analysed (Figures 55, 56 and 57). As can be seen in the following figures the most common land use types are the warehouses, parking and industry, followed by residential areas in the ground floor.

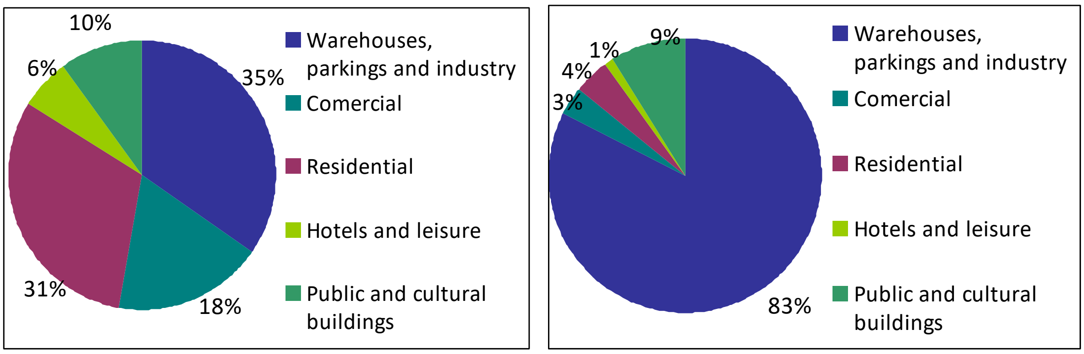

Figure 55. Land uses types in ground floor (left) and first basements (right), according to the cadastre data 2016

This background will permit complete flood vulnerability and risk assessment during severe flood events.

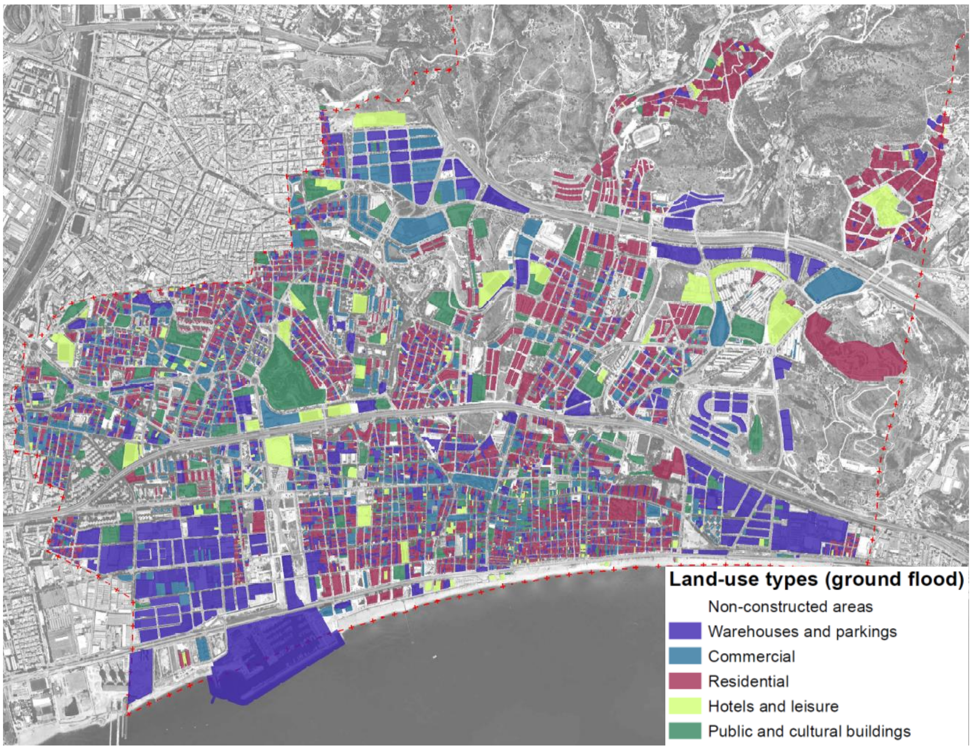

Figure 56. Land uses types for the ground floor parcels in Badalona

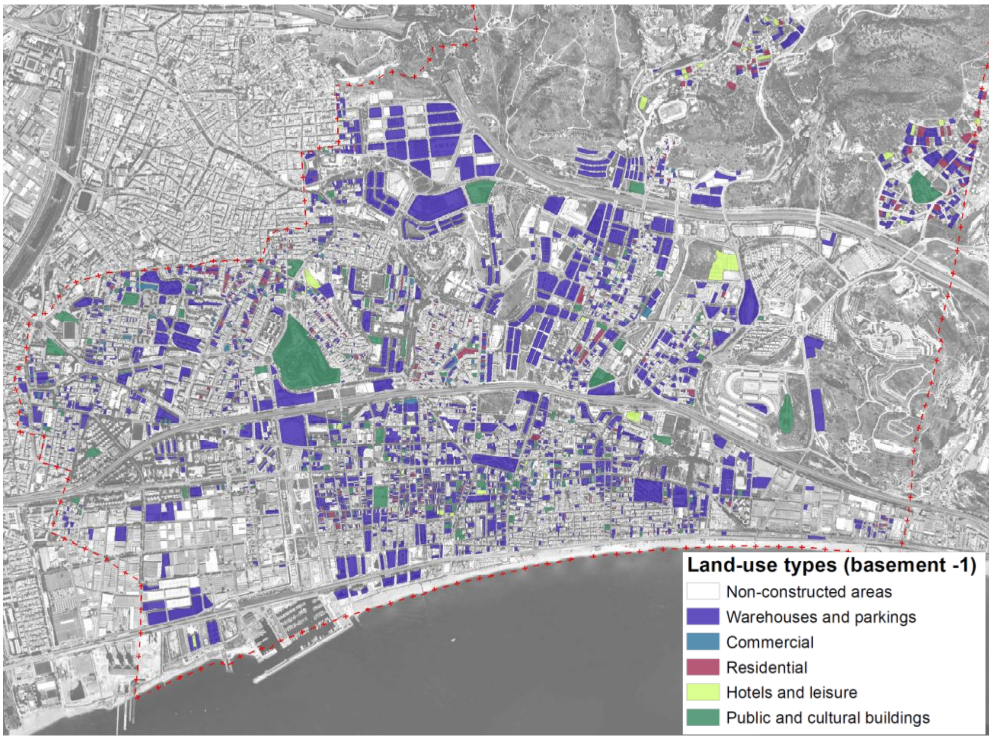

Figure 57. Land uses types for first basement floor in Badalona

2.6.6 Water use

The most valued resource and one of the main sources of income in Badalona are their beaches, which stretch along nearly 5 km, with an average width of approximately 55 m and about 187.000 m^2 of sand. This space is occupied by 1.3 millions of visitors per year. In fact, beaches are one of the most used spaces by people living in Badalona and surroundings due to the general good quality and quantity of services offered along the coast. In order to accomplish these conditions, Badalona city council has approved the quality politics and the services catalogue.

Thereby, the AMB and the city council, are constantly working in tasks related to the manage the beach cleaning and the quality of the bathing waters in order to improve the quality of the service offered, to guaranty human safety and protect the environment.

Figure 58. Badalona Pescadors beach during bath period (right) and after that a storm event had taken place (left). (Source: Badalona city council and webpage www.ccma.cat)

Unfortunately, when the sewer flows overcome the capacity of the sewer interceptors Combined Overflows occur. This generally occurs a few times per year. As a consequence the CSOs generate significant pollution into the receiving water bodies and the beach sand. Accordingly, leisure activities are not allowed during hours or few days and the beaches have to be cleaned as defined in RD 1341/2007.

The results of Advanced Management of sediments in sewers (R+D+I SUEZ internal project) show that pollution is directly linked to the presence and nature of deposition in sewer network (up to 50% of the contamination load). Other sources of contaminants are the wash-off of the surfaces and the dilution of the wastewater.

Figure 59 shows the 21 different CSOs points, located along Badalona beaches, and identified in the context of the DMP and simulated in the marine model (COWAMA).

Figure 59. CSOs from the "Aigües de Barcelona" interceptor along Badalona beaches. (Source: Badalona city council)

2.6.7 Studies conducted in the past at the site

The Mediterranean region is an area exposed to a large number of pressures, such as natural events and pressures related with the human activity. These pressures transform the territory in a more vulnerable area every day. These conditions make necessary the development of studies in order to determine the impacts of these pressures over the territory and analyse different measures to minimize the effects.

In this regard, many studies on these subjects were developed in nearby areas. One of them, concerning climate change effects on heavy storms will be described below due to their importance or similitude with the BINGO project. This study was carried out in the framework of the CORFU European project (Collaborative Research on Flood Resilience in Urban areas), an interdisciplinary international project that looked at advanced and novel strategies and provided adequate measures for improved flood management in cities. In this project, seven research sites (Barcelona, Beijing, Dhaka, Hamburg, Mumbai, Nice, Songdo and Taipei) were involved. One of the most important results of this project was the assessment of the influence of climate change on IDF curves for the metropolitan area of Barcelona (Spain) and extreme flooding events through a calibrated 1D/2D detailed coupled model. Moreover, a detailed flood damage assessment in the Raval district of Barcelona was developed (Rodríguez *et al*., 2014; Russo *et al*., 2015).

In this work, a total of 114 daily rainfall series (from six thermo-pluviometric station located in the metropolitan area of Barcelona using the information provided by five general circulation models under four future climate scenarios of green house gas emissions and applying statistical downscaling methods) for the period 1951 – 2099 were analysed. For almost all the scenarios and periods considered, the increase on the expected hourly rainfall has resulted slightly higher than the corresponding daily rainfall (Rodriguez et al., 2014).

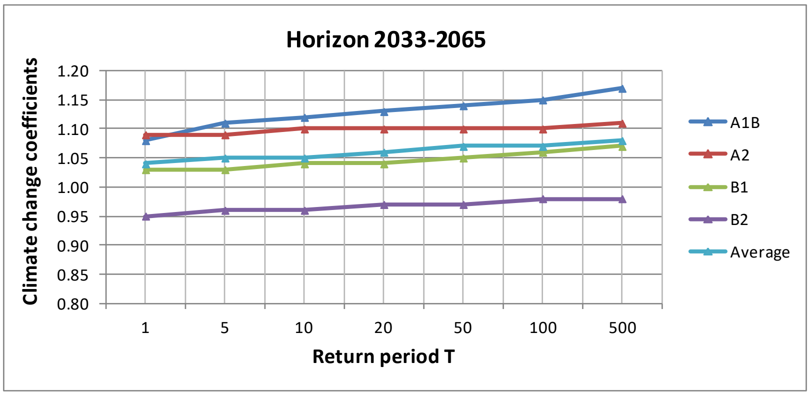

Figure 60. Climate change coefficients for several return periods and climate scenarios calculated using spatial and temporal downscaling techniques

The computational performances achieved for the created model presents significant computational time savings via parallel processing and hardware configuration. These aspects convert the model in an appropriate tool for real-time strategies and as core of early warning system (Russo *et al.*, 2015).

With the development of synthetic depth damage curve regionalized for the Barcelona case study, an exhaustive economic impact assessment can be carried out when heavy storm events occur. A GIS-based toolbox was developed in order to calculate the expected annual damages (EAD). This enable the determination of the critical points of the Raval district in terms of flooding impacts establishing a very useful framework to assess flood impacts in urban areas (M.Velasco *et al.*, 2015).

Figure 61. Damage maps in Raval district in Barcelona for 1, 10 and 100 years of return periods

2.6.8 Known water problems

Due to the geographical factors highlighted in sections 2.6.1 and 2.6., significant consequences take place at the Badalona research site, causing moderate-heavy storms events. It is obvious that significant flash floods can occur in this region, in fact, these regions are considered as flood prone areas in the risk maps defined by the "Ministerio de Agricultura y Medio Ambiente". Furthermore, the main part of watercourses has been channelled and buried. In multiples cases, the sewer system has been connected to these streams.

Figure 62. In pink colour, flood prone areas are shown (Source Civil Protection Agency)

This map is a visual interpretation of the terrain (topography and morphology) as a result of the study of previous floods, aerial photographies and field visits of riverine areas.

Some significant events with tragically consequences can be listed in the last 15 years:

- 14/09/1999: As a result of precipitations between 50-100 mm at a very short period of time a lot of rivers overflooded. More than 125 k€ were claimed to insurance companies for direct damages (underground parkings and subways flooded).

Figure 63. Jornet river flooding in Badalona during the event of 14/09/1999 (Source: environmental and sustainability service of the city council of Badalona)

- 05/08/2008: coastal flooding with more than 80 k€ claimed to insurance companies for direct damages.
- 20-22/10/2009 (cumulative rainfall of 90 mm): significant problems at some location such as at Folch river where the flow depths in some streets reaches several cm.
- 29/07/2010: (cumulative rainfall of 57mm): some rivers overflood but fortunately only at some locations the flood remained for a while.
- 12-16/03/2011: (rainfall of 24 mm in few minutes) plenty of basements flooded, River overfloods and tree falls.
- 05/08/2013: sewer flooding with significant consequences in several subways, railways and underground parkings.
- 28/07/2014: sewer flooding with high rainfall intensities (>90mm/h).

2.6.9 Outlook

BINGO will deternine some global scenarios (including climate change) where flash flood events and CSOs can take place in Badalona city. Once these events will be defined, BINGO partners involved in the project and other external stakeholders will work together in order to choose the best adaptation measures to cope with the adverse consequence of climate change. Besides the influence of the climate change in increasing of number of flash floods events and CSOs, the existence of sediments (generally with high organic matter load) within the sewer pipes represents one of the most important problems for this case study due to the potential problems of clogging, pollution to the receiving water bodies and odours in flat areas.

In this context, special attention is given to the composition and location of in-sewer sediments along the urban drainage network. Field research is ongoing in Badalona's sewer network in conduits, also in weirs connected to the beach in cooperation with the city council and Technical University of Catalonia (UPC). The current sewers sensors network (that includes 3 rain gauges and 15 water level sensors) will be updated with the installation of other sensors for real time monitoring of spills in two selected points, These systems will measure important variables like temperature and water level before and after the overflow and the turbidity that will permit the correlation with some relevant parameters used for water quality characterization. As said, two different locations have been selected according to the characteristics of the contributing subcatchments: "Maria Auxiliadora" and "Canyadò" stream, respectively, urban and rural subcatchments.

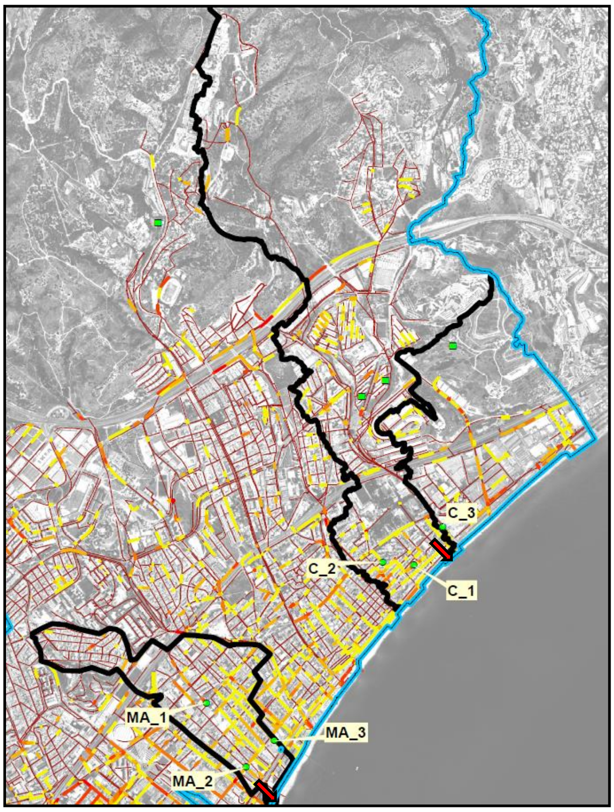

Figure 64. New control points for the sediments assessment

A field samples campaign will take place in three control points in each subcatchment cited above and their composition will be analysed for determinng the organic content, density and granulometry. These are key parameters to simulate sediment transport in commercial modelling tools. In fact, taking into account these parameters a new transport sediment modelling will be developed and implemented in a comercial software (InfoWorks ICM by Innovize; http://www.innovyze.com/products/infoworks.icm/) and integrated within the hydrological and hydraulic 1D/2D model. A general problem of current softwares is the difficulty to reproduce properly the transport phenomena because of they do not consider the cohesive properties of the sediments in urban subcatchments. For this reason, this issue will be treated with special regard. At the same time, weekly samples of seawater are collected and analysed. The studied parameters are Enterococcus Faecal and Escherichia Coli included in the RD 1341/2007. A new protocol has been established in the frame of BINGO contest in case of rainfall event. Three new control points along the “Pont del Petroli” bridge has been selected and added to other points neared Badalona beaches. Thanks to these set of points, the study of the propagation and mitigation of bacteria cited above can be realized updating the COWAMA marine model currently existing in Badalona. The new data will allow a calibration model in order to analyse the behaviour of the sea during CSOs events. COWMA software is developed and distributed by AQUATEC (http://www.cowama.com/).

Figure 65. Three new control points along the “Pont del Petroli” bridge. (Source: http://www.pontdelpetroli.org/)

2.6.10 Bibliography

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