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Climate change and the water sector in Europe: a review of research and technology development needs

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ABSTRACT

The Water supply and sanitation Technology Platform (WssTP) was initiated by the European Commission in 2004. It is led by industries in collaboration with academics, research organisations and water users to help structure the European Research Area and identify R&D needs for the water sector. In December 2008, the board of the WssTP identified the need to create a Task Force on Climate Change in order to build a working group focused on the issue and able to assist the EU Commission in the related Calls for Projects. The Task Force on Climate Change did a review on the research and technology development (RTD) needs related to each of the WssTP topics, highlighting the challenges they will face in a climate change context. This paper is based on the review carried out and presents its main conclusions. The RTD topics identified involve a broad range of expertise areas and can be divided into two main groups: mitigation and adaptation. The latter will be brought to the fore in this paper.

Key words | adaptation, climate change, research and technology development needs, water, WssTP

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INTRODUCTION

The Water supply and sanitation Technology Platform (WssTP) was initiated by the European Commission in 2004 to promote coordination and collaboration of research and technology development in the water industry. Different communities working in the water sector are present amongst its members and contributors: industrialists, research groups, policy makers, financiers and water consumers. The platform is divided into six Pilot Programmes (PP), each of them dealing with a major European water issue:

Pilot Programme 1: Mitigation of water stress in coastal zones
Pilot Programme 2: Sustainable water management inside and around large urban areas
Pilot Programme 3: Sustainable water management and agriculture
Pilot Programme 4: Sustainable water management for industry
Pilot Programme 5: Reclamation of degraded water zones (surface water and groundwater)
Pilot Programme 6: Proactive and corrective management of extreme hydro-climatic events

In order to complete the work done by the PPs, working groups known as task forces (TF) were created to handle the cross-cutting fields from the different programmes (Figure 1). The Task Force on Climate Change was created in December 2008, in order to assess existing knowledge and initiatives regarding climate change and to formulate specific recommendations for research and technology development (RTD) needs.

In this paper, the work carried out by the TF on Climate Change to achieve its goal is compiled, and the challenges each PP will be faced with in the future are identified. Finally a RTD-needs priority list, which has been drawn up by experts from conclusions of workshops, is developed.

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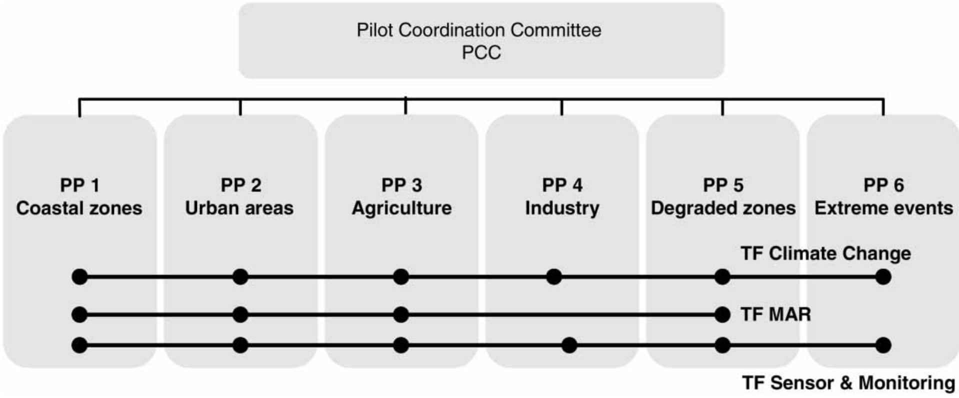

Figure 1 | Pilot Programme organisation, with the different TFs (Climate Change, Managed Aquifer Recharge and Sensor & Monitoring) as cross-cutting topics. *Source*: http://www.wsstp.eu/ [accessed 28 November 2011].

METHODOLOGY

The methodology followed by the TF on Climate Change to identify the RTD gaps (presented below) is summarised in Figure 2. The framework presented is simple: the members of the TF on Climate Change did a complete review of existing information, and afterwards, together with the experts of the PPs of the WssTP, the list of RTD needs was improved, validated and prioritised.

The first phase involved a review of different sources of information, which can be classified into four categories (Figure 2). A state of the art review of the main references on climate change was carried out including scientific publications, technical reports from water utilities organisations and other working groups or technological platforms. The next step was to identify past and current research initiatives and projects related to climate change and water under several EU funding programmes and to elaborate an exhaustive list with brief descriptions. A review of the outcomes of the main events and conferences held during 2009 was also carried out, and to end this first phase, an evaluation of some private institutions' research agendas was done.

After this first stage, a draft list of the RTD needs was developed and the results were presented by the task force members in a first workshop held in Genoa in June 2009.

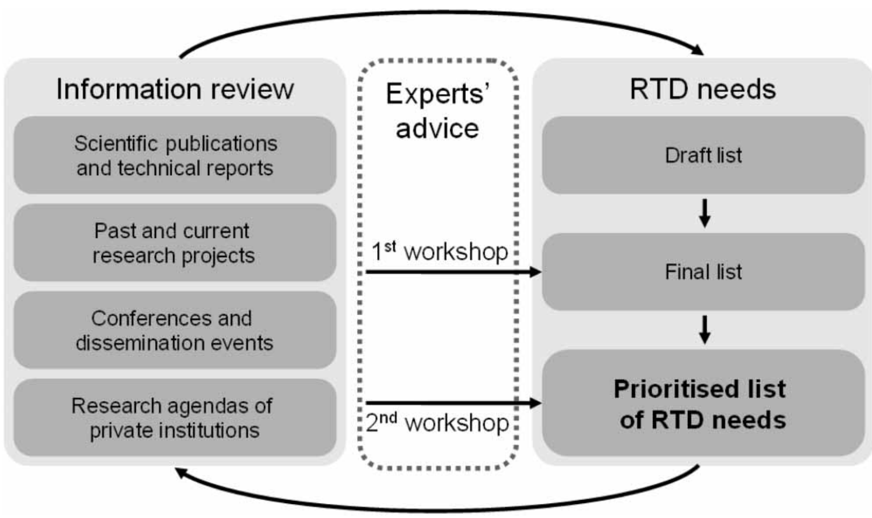

Figure 2 | Scheme of the framework used to obtain and assess the prioritised list of RTD needs.

The participants included 16 experts from 8 different European countries, all related to the water sector and working either at universities (University of Bologna), at private and public research organisations (CETaqua, Sintef, UKWIR, Labein, Kompetenz Zentrum Wasser Berlin, etc.) or at water utilities (Aguas de Portugal).

The aim of this workshop was to share the outcomes of the review phase with experts from the different PPs, and collect suggestions and supplementary information to complete the review carried out.

During the rest of 2009, with the information previously collected and with the collaboration of several participants of the PPs of the WssTP, the work on the RTD needs was finalised. One final aspect had yet to be analysed. The RTD needs identified in each PP had to be prioritised. This was the aim of the second workshop organised by the TF on Climate Change in April 2010, held in Barcelona. At this workshop, 27 experts from 8 different EU countries joined the task force coordinators to discuss and finally agree on how the previously identified RTD needs should be sorted by relevance. Among the organisations represented at the workshop were: CETaqua, Università degli Studi di Palermo, DHI, Agbar, Labein, The Macaulay Institute, Centre for Ecology & Hydrology, Fondazione AMGA, Kompetenz Zentrum Wasser Berlin, HRC-Cardiff University, Deltares and Cranfield University. More details about this workshop can be found on the WssTP website.

The participants were selected taking into account their expertise in the issues addressed by the different PPs, enabling group discussions in each field. Before the workshop was held, a questionnaire with a summary of the RTD gaps previously identified was sent to all participants so they knew in advance which topics were to be discussed. In order to avoid a bias in the final priority obtained, the groups were formed with people from different backgrounds (universities, private companies, public utilities, etc.) and thus discussions occurred among the experts within each group. Therefore, the prioritised lists may differ between the groups but some general conclusions can be drawn.

The RTD needs shown below include the outcomes of this whole process. Thus the results of this last workshop are presented and sorted by relevance, according to the participants. In the cases of PP 4, Sustainable water management for industry, and the TF on Monitoring and Sensors, the RTD needs were not prioritised because of the lack of participants with expertise in these fields.

CONTEXT: CLIMATE CHANGE AS A CHALLENGE FOR WATER-RELATED ISSUES

Among scientific communities, there is a general consensus on the fact that climate change is happening as a result of anthropogenic greenhouse gas emissions and changes in land use (IPCC 2007; Rosenzweig *et al.* 2008). Climate change impacts and increasing demands are escalating the pressure on water resources and, as a consequence, our society is becoming more vulnerable. Thus, water supply and flood protection systems should become more resilient, to protect against the potential impacts of climate change and the effects of floods and droughts.

Water utilities can use the risks associated with climate change impacts and their current levels of uncertainty as opportunities to improve social and environmental sustainability by promoting a number of mitigation and adaptation measures.

The global hydrological cycle has already been affected by climate change and this has been related to the observed global warming during recent decades (Vörösmarty *et al.* 2000; Charlton & Arnell 2011). Changes in precipitation patterns and intensity, increasing melting of ice, changes in soil moisture and runoff, frequency of extreme events (Christensen & Christensen 2007) such as floods (Dankers & Feyen 2009) and droughts (Lehner *et al.* 2006; Blenkinsop & Fowler 2007; Burke *et al.* 2006), sea-level rise and water quality problems are the proof of this influence.

At a European level, the *Impacts of Europe's Changing Climate* report (EEA-JRC-WHO 2008) extensively assesses the impacts of climate change on different regions of Europe and one chapter focuses on the effects of climate variations on water resources. The severity and the types of impact due to climate change vary depending on the region's geographical location. Europe's sensitivity to climate change has a 'distinct north–south gradient' (Sillmann & Roeckner 2008). Thus, different impacts between northern and southern regions can be expected. Water availability is expected to increase in northern regions, while the predicted trends in southern regions show an increase in the frequency of droughts and heat waves. In the Arctic zones, a decrease in the sea ice cover is projected as well as less glacier mass and permafrost in the mountain areas (Hagen *et al.* 2003; Kohler *et al.* 2007). More intense rainfall events are expected all over Europe.

The document also identifies a number of mitigation and adaptation actions to tackle the problem. These actions include the improvement of water efficiency, water re-use, metering and water pricing to stimulate awareness and encourage water conservation.

Climate change projections give an idea of the future evolution of climate and its impact on the water cycle. The *Special Report on Emissions Scenarios* (Nakicenovic & Swart 2000) establishes several hypothetical scenarios of greenhouse gas concentration in the atmosphere, based on four hypotheses of socio-economic evolution. Global climate models (GCM) predict the evolution of various climate variables according to each scenario. These changes will affect the water cycle, with a decrease of river flows in southern Europe for example and an increase in frequency and duration of droughts. A typical indicator of the situation of the global water resources is 'water stress', defined as the ratio between water withdrawal and water availability. It constitutes a way of evaluating how people are exposed to the risk of water shortage.

The World Water Commission (Cosgrove & Rijsberman 2000) and a consortium of the United Nations organisations (Raskin *et al.* 1997) established a threshold of 0.4 above which a river basin is assumed to be under severe water stress. Considering the A2 IPCC (Intergovernmental Panel on Climate Change) scenario for the year 2050, large parts of the world will suffer from water shortages (Alcamo *et al.* 2007). In Europe, the Mediterranean regions and some parts of Central and Eastern Europe are projected to reach a water stress index above 0.4. Therefore, it is clear that mitigation and adaptation strategies must be adopted to tackle the problem.

There are two approaches to cope with climate change: mitigation and adaptation. While mitigation aims at reducing climate change impacts, adaptation's main objective consists of adjusting the system properties to the new situation to diminish the negative effects of climate change. Less mitigation means greater climate change impacts and, consequently, requires more adaptation. Mitigation and adaptation should not be seen as alternatives to each other, as they are not discrete activities, but rather a combined set of actions in an overall strategy to reduce climate change impacts. Therefore, a combination of both strategies is the optimum approach for the water sector.

One of the most important factors for the achievement and implementation of the mitigation and adaptation measures needed to face climate change challenges is the adoption of an agreement on the amount of funding required. The Stern Review (Stern 2006) was set up to provide a report assessing the nature of the economic challenges of climate change and how they can be met, both in the UK and globally. The two main statements identified in the report are:

- Acting to counter climate change might cost about 1% of annual global gross domestic product (GDP) by 2050, by stabilising emissions of carbon dioxide in the atmosphere.
- But, the cost of not taking action was found to be far greater – risking up to 20% of the world's wealth.

Lord Stern revised this prediction, saying that the cost of inaction would be '50% or higher' than his previous estimate – meaning it could cost a third of the world's wealth (*The Independent*, 13 March 2009). How funds would have to be disbursed and distributed is a critical issue in the implementation of the measures required to stop increasing society's vulnerability while not affecting the achievement of the Millennium Development Goals.

This idea also appears in the recently published White Paper entitled *Adapting to Climate Change: Towards a European Framework for Action* (EC 2009a). It states that anticipating potential impacts and minimising threats to ecosystems, humans, infrastructures and economy contributes to gains in economic, environmental and social benefits. However, it recognises that further studies must be carried out in this field and that is one of the actions proposed.

It is also important to note that climate change has to be considered as one of the drivers of global change. Global change covers a much wider topic, as other issues such as land use change, population increase and globalisation are included in this concept. As mentioned in the IPCC Technical Paper VI (Bates *et al.* 2008), many non-climatic drivers affect water resources at global scale. Water resources are severely influenced by human activity (including agriculture and land-use changes) and affected in terms of both quality and quantity. Water use is strongly linked to changes in population, type of food consumed, socio-economic policies, land use, lifestyle and habits (Alcamo & Henrichs 2002). Some of these factors, such as industrialisation or intensive agriculture, will contribute to higher greenhouse gas emissions, which is the main culprit in climate change (Figure 3). Thus, it is paramount to evaluate how water resources will be affected by changes in these non-climatic drivers in order to fully assess the effects of climate change.

In order to ease the water stress many areas will face, the water sector must take into account the positive impacts of a change in the water management approach (Pahl-Wostl 2007). Management of water resources must be focused on both the supply and the demand sides, avoiding disproportionate water uses. Europe needs integrated water resources management (IWRM) to increase the efficiency and sustainability of the water sector. IWRM can be considered as an adaptation measure against climate change (Charlton & Arnell 2011). The Water Framework Directive (WFD; EC 2000) refers to this approach, promoting sustainable water use. Other aspects regarding good practices to help implement demand-side water management include: introducing water pricing across all sectors (providing incentives for efficient water use), raising awareness on water conservation issues (educational programmes, websites, advertisements, etc.) or considering alternative supply sources when demand still exceeds water availability (Papaiacovou 2001; Pollice *et al.* 2004).

Finally, even though adaptation and mitigation frameworks must be adopted at a global and national level, water resources management is a regional and local issue, and each region will have to adopt the strategies that better fit its situation.

RTD NEEDS BY PILOT PROGRAMME

In the following sections, impacts of climate change will be detailed for each theme included in the WssTP PPs and specific RTD needs will be identified.

As shown in Figure 1, there are some other task forces that deal with issues related to several PPs. As the effects of climate change will also affect these task forces (TF on Managed Aquifer Recharge and Sensor & Monitoring, for example), the RTD needs will also be identified and prioritised likewise in the PP.

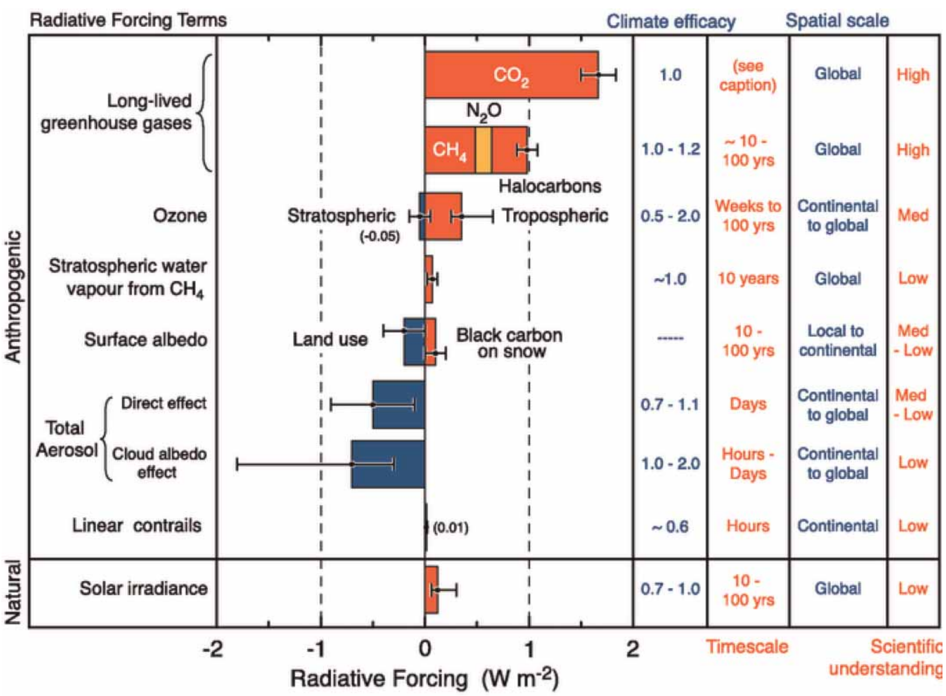

Figure 3 | Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic CO_2, CH_4, N_2O and other important agents and mechanisms, together with the typical geographical extent of the forcing and the assessed level of scientific understanding (LOSU). *Source*: IPCC (2007).

It is worth noting that even if the impacts studied vary in each of the next sections, the RTD needs identified may be the same. This is due to the fact that the needs considered are general transverse topics which can help cope with climate change in many different fields of interest.

Pilot Programme 1: Coastal zones

Coastal zones are experiencing the largest changes in land uses and the highest variations in water uses, as well as the major conflicts in water management, while they host the most productive ecosystems and are subject to the greatest scrutiny regarding water quality standards. It can be expected that potential climate changes will impact water resources and water infrastructures in coastal zones more than in other types of environment.

Some of the foreseen climate change impacts that could affect coastal zones are:

- Changes in the timing and volume of surface water runoff and groundwater. This will further amplify the changes in quality and salinity of surface and ground freshwater, transitional water and coastal water bodies, as well as further alter sediment and nutrient discharges. Water volumes and quality, as well as sediment and nutrient contents, play an important role in ecosystem health.
- The reduced discharge flows, as well as the forecasted sea-level rise, will facilitate further salt water intrusion inland, reducing the availability of freshwater in coastal areas and modifying ecosystems.
- The increase in sea level could also impact groundwater intake and withdrawal systems, and reduce the discharge capacity of wastewater systems.
- Owing to the predicted increase in frequency and intensity of extreme events, coastal zones will face a great risk of increased river and coastal floods, as well as ocean weather phenomena impacts such as typhoons, cyclones or wave surges (with the additional impact of coastal erosion).
- Forecasted climate change could also impact wetlands and temporary water bodies that play an important role in the coastal water cycle and related ecosystems, by alleviating temperature differences and maintaining moisture levels.

Therefore, the RTD topics that should be further developed are listed below. In addition, a summary of the prioritised list of needs can be found in Table 1.

- IWRM: integrate climate change models results and uncertainties into integrated water management scenario creation for coastal zones and river basins.
- Cost–benefit analysis for water management in coastal zones: to support decision making and determine which are the optimal levels of protection, evaluate ecological, economic, energy and social costs of different water-related mitigation and adaptation measures (see also Managed Aquifer Recharge TF section for evaluation of environmental performance through life cycle analysis).
- Modelling and monitoring: incorporate climate change constraints into specific coastal zones' hydrogeological frameworks, to improve predictions. Improve the monitoring systems for more adequate real-time data, forecasting trends and rapid responses.
- Alternative water supplies: to prevent saltwater intrusion, maintain coastal wetlands or buffer inter-seasonal variations in water availability (see also Managed Aquifer Recharge TF section).
- Flood risk management approach: evaluate the increase of coastal flood risk, taking into account climate change impacts and their uncertainties for the classification of the most vulnerable coastal regions and the improvement of mitigation and adaptive measures planning.

Pilot Programme 2: Urban areas

An average of around 20% of the water abstracted in Europe is used for public supply. However, consumption accounts

Table 1 | List of PP 1 RTD needs

	Prioritised RTD needs for PP1: Costal zones
1	Integrated water resources management
2	Cost–benefit analysis for water management in coastal zones
3	Modelling and monitoring
4	Alternative water supplies
5	Flood risk management approach

Reviewed sources: PP 1: Deltacomissie 2008; EEA 2009; EEA-JRC-WHO 2008; Swat *et al.* 2009; UNDP 2007.

for only about 20% of the abstraction, the remaining 80% being returned to the environment mainly as treated wastewater (EEA 2009). Nevertheless, this water is returned downstream from the abstraction source, where sometimes it cannot be recovered and it usually presents lower quality than in its natural status. In 2008, half of the world's population was living in urban areas, but this percentage is expected to reach 70% in 2050. Therefore, in cities, individuals may be more vulnerable to the water implications of climate change. Climate change must be seen as an urban problem with local impacts and solutions. The impacts caused will be very different depending on the European region, and the required measures will also be different, but a common approach to tackle the problem may be adopted.

Some of the foreseen climate change impacts that could affect urban areas are:

- Drier and hotter summers that will increase demands when water resources are at their minimum.
- The increase in the number and intensity of extreme precipitation events will cause sewer capacity problems, increase the risk of floods and worsen water quality of receiving bodies, because of polluted overflows.
- High flows in watercourses, due to an increase of rainfall and sea-level rise, may cause discharge difficulties in sewer systems.
- Warmer temperatures may cause quality and odour problems, and impacts on the water and wastewater treatment processes.

Measures that can be implemented in order to reduce water scarcity can be broadly grouped into demand-side measures (efficiency, pricing), supply-side measures (alternative supplies, infrastructure resilience), educational and social measures (awareness raising) and implementation of new regulations. Then, according to these categories, gaps in RTD were found for the following topics:

- Water efficiency and conservation: reducing leakages in urban networks (development of new detection technologies, creation of regulations to promote it), development of new water saving measures (water aerators in taps and showers, dual flush toilets, vacuum toilets or low water consumption household appliances), new regulations to promote water efficiency in buildings (giving incentives to retrofit urban buildings for water saving), planting species with low water requirements in public parks, etc.
- Water pricing: as the WFD already states, pricing provides incentives for the efficient use of water resources. Hence, the development of new tariff structures based on the volume of water used and on the seasonal periods is needed. Pricing may be applied to both water supply and wastewater services. In the case of wastewater, measures to favour discharges when receiving waters are more diluted or tariffs depending on the treatment level needed can be developed.
- Alternative supplies and technologies: more research is needed especially on how to maintain and operate them. Implementation and operational guidelines must be developed and cost–benefit studies should be carried out. Furthermore, a unified European regulation for quality standards and requirements for the use of non-potable waters is needed. Some examples of these technologies are: rainwater harvesting (reduces storm water discharges and water consumption), grey water re-use (with more research on quality issues related to retention time in tanks), reclaimed wastewater (gardens and golf courses irrigation, street cleaning), sustainable urban drainage systems (SUDS), etc.
- Urban floods: RTD gaps related to floods are included in the 'Pilot Programme 6: Hydro-climatic extremes' section.
- Infrastructure and assets: improving the adaptation capacity of our infrastructures will be of major importance in the coming years. There is a need to develop new methodologies to assess the vulnerabilities of our existing systems under a climate change situation (bottom-up approach and definition of hypothetical future scenarios). Besides, guidelines on how to plan, design and operate must be proposed and cost–benefit analyses must be carried out in order to evaluate the different alternatives studied. These methodologies may apply to water supply systems, sewer systems, WWTP (wastewater treatment plants) and dams. Also included in this topic are the development and use of DSS (decision support systems) to predict changes in demand and optimise supply management, real-time monitoring to determine catchment conditions (flows,

quality parameters, weather conditions), measures to increase the robustness of the supply systems (diversify supply sources and integrate them into combined systems, integrate demands in one management unit, improve the interconnection of supply and demand points), cost–benefit analysis, etc.
- Raising awareness: the previous aspects will be pointless unless good education and information programmes are implemented. It is paramount to disseminate water-saving information through different channels (websites, leaflets, newspapers, etc.) in order to change consumers' behaviour. Hence, more studies are needed in order to understand consumers' habits.

Table 2 summarises the list of needs explained above, clearly showing the prioritisation that experts agreed upon during the second workshop. As can be seen, three different topics have been assigned a first priority. This means that all of them are crucial, and must be taken care of equally.

Pilot Programme 3: Agriculture

Nowadays, agriculture is already affected either by an excess of water or by water scarcity, and climate change effects will stress existing impacts and cause new ones. Some of the foreseen climate change impacts that could affect the agriculture sector are:

- Higher evapotranspiration rates due to higher temperatures.
- Increased water demand for the hydration needs of livestock, due to higher temperatures.

Table 2 | List of PP 2 RTD needs

	Prioritised RTD needs for PP2: Urban areas
1	Water efficiency and conservation
1	Water pricing
1	Alternative supplies and technologies
2	Urban floods
3	Infrastructure and assets
4	Raising awareness

Reviewed sources: PP 2: AMWA 2007; Arkell *et al*. 2008; Bates *et al*. 2008; EEA 2009; EC 2009a; GPPN 2009; WRF website.

- Risk of lower yields and lower product quality due to an increase in the frequency and intensity of extreme events (floods, droughts, hail), which implies less income to farmers.
- Growing risk of pests and diseases due to new climate conditions: more insects due to higher temperatures, more fungi because of wetter conditions, etc.
- Indirect social impacts: migration, unemployment, instability, etc.
- Reduced water availability due to droughts and changes in rainfall patterns, thus increasing water cost and, consequently, food prices.
- Reducing the irrigated area could have negative impacts on the ecosystems: increase of forest fires and soil erosion due to land abandonment, less infiltration and, therefore, less aquifer recharge.

Therefore, the following RTD topics should be further developed:

- Best practices implementation: the following presents a list compiling best practices that may lead to a more efficient and sustainable use of the water for irrigation. In many cases there are studies that evaluate water savings due to these practices, but more research is required to better quantify their benefits (e.g. with cost–benefit analysis) and to improve available technologies. Some of these practices are: promoting crops that are more drought resistant, changing crops from high to low water demand, changing crop types to shift peak demand away from periods when water is scarcer, modifying the timing of irrigation to follow crop water requirements more strictly, varying sow and harvesting calendar to avoid high evapotranspiration rates and supplementary irrigation, implementing deficit irrigation practice, soil moisture conservation through the plantation of shadow trees on pastures, rainwater harvesting on farm roofs, etc.
- Increased efficiency: conveyance efficiency refers to the ratio between the abstracted water and the water delivered to the field. It varies greatly depending on the use of open channels or pressure pipes, or even on the lining of the channel. Further analyses on water saving due to conveyance systems are required, including cost–benefit assessments. Field application efficiency is also crucial and it consists of measuring how well an irrigation system transports

water to the plant roots. The variations between furrows, sprinklers and drip systems are significant, but further research must be done to evaluate which systems are more suitable for each type of crop and local situation.

- Raising awareness: technology improvements and new regulation implementation have to be complemented by education and information programmes for farmers. Improvement of information channels is needed, in order to facilitate access to information, and more education programmes are required (e.g. websites, eco-labelling, virtual water concept).
- Wastewater re-use: it can be used as an alternative source to irrigate crops in water scarce areas, and can also lead to inorganic fertiliser savings if this water is nutrient rich. There is the need for gathering regulations from different regions and promoting harmonised and adequate Europe-wide quality standards.
- Assessment tools: these tools include, indicators to predict and assess water scarcity (currently being developed by the European Drought Observatory), water footprint to identify areas with most water consumption, cost–benefit analysis including economic, environmental and social costs, etc.
- Agriculture policies: promoting subsidies linked to more efficient water use, changing technical specifications and requirements in order to promote technologies that reduce leakage, and penalising illegal water extraction are some of the measures which should be further analysed. Water pricing is another crucial tool to reduce water use. Several studies in the Guadalquivir basin (Spain) and in the Garonne basin (France) indicate that the implementation of a water pricing scheme has led to a decrease in water consumption.

As for the prioritisation of RTD needs in PP 2, two different topics were assigned the same priority, in this case, priority 5 (Table 3).

Table 3 | List of PP 3 RTD needs

	Prioritised RTD needs for PP3: Agriculture
1	Best practices implementation
2	Increased efficiency
3	Raising awareness
4	Wastewater re-use
5	Assessment tools
5	Agriculture policies

Reviewed sources: PP 3: Bates *et al*. 2008; Copa-Cogeca website; EC 2009b; EEA 2009.

Pilot Programme 4: Industry

Water use in the industry sector includes cleaning, heating, cooling, uses as raw material, solvent and constituent of the manufactured product. The manufacturing industry accounts on average for 11% of the total amount of water abstracted in Europe, with approximately half of it used for processes and half for cooling purposes (EEA 2009). It is critical for companies and investors to think about water importance and the business risks that climate change can cause because of the decrease in water resources.

Some of the forecasted climate change impacts that could affect the industry sector are:

- Changes in rainfall patterns can lead to less water availability in some regions.
- Lower flows in some rivers may require a reduction in the wastewater discharge to prevent a higher concentration of pollutants (regulatory restrictions).
- Increasing temperatures will increase the quantity of water needed for cooling purposes.
- Worsened water quality (more treatment needed) means an increase in water costs, leading to an impact on production costs.
- Reduction of water resources may produce conflicts with other water users and cause a negative public reputation.
- Uncertainty in water availability may cause risks that are difficult to predict and assess (operational interruptions, financial loss, refusal of operation licences, etc.).

Therefore, the following RTD topics should be further developed:

- Water recycle: identify and define specific on-site treatment plants for different types of industry and implement closed-loop water systems.
- Water re-use: promote rainwater harvesting for specific uses in different types of industry, define water quality requirements for specific uses and develop new regulations at European level.

- Improvements in production processes: analyse the processes involved in different industries and evaluate the benefits of changes to achieve greater water efficiency. An assessment and improvement of technologies for the detection of leakage are also needed.
- Cooling technologies: as cooling water accounts for almost half of the water use in industries, more research is needed to develop new cooling technologies or improve the existing ones.
- Heat recovery: develop technologies to enable energy recovery from warm water fluxes, implying indirect water savings.
- Assessment tools: water footprint is a valuable tool to identify water consumption in the industrial sector and it can promote incentives for production with a lower water consumption rate. Measuring water footprint is a way of mitigating water-related risks in terms of reputation (possibility of eco-labelling). A state of the art compilation of the existing methodologies is needed, as well as further research to develop new methodologies.
- Corporate action plans on water: development of plans taking into account climate change is increasingly important. These must include: measurement of the water footprint; assessment of the physical (water availability, quality, floods), regulatory (water pricing, regional regulations) and reputational (interaction with local communities) risks; they must integrate water into strategic business planning (developing a water management programme, provide position statements); and disclose the company's current water use and wastewater data.

As mentioned above, because of the lack of experts in this field during the second workshop, the RTD needs of this PP have not been prioritised. Still, it is important to keep in mind that all the needs summarised in Table 4, are essential in order to cope with the impacts of climate change in the industry field.

Table 4 | List of PP 4 RTD needs

	Non-prioritised RTD needs for PP4: Industry
1	Water recycle
2	Water re-use
3	Improvements in production processes
4	Cooling technologies
5	Heat recovery
6	Assessment tools
7	Corporate action plans on water

Reviewed sources: PP 4: EEA 2009; Morrison *et al*. 2009.

Pilot Programme 5: Degraded zones

Climate change can induce physical, chemical and biological changes that will affect both quantity and quality of water bodies. Moreover, European ecosystems are already threatened by anthropogenic activities and it is very difficult to differentiate these effects from the climatic ones. More effort must be devoted to analyse climate change impacts on degraded zones in order to prevent the appearance of new damage.

Some of the foreseen climate change impacts that could affect degraded zones are:

- Increasing temperatures may lead to poorer water quality (less oxygen, algal blooms, etc.), affecting aquatic ecosystems.
- Increasing temperatures will induce sea-level rise, causing saline intrusion in deltas and aquifers.
- More floods can cause an increase in the load of pollutants washed from soils and combined sewer overflows.
- Changing rainfall patterns may reduce the amount of water available for recharging aquifers in some regions.
- Decreasing precipitation in some areas will imply less dilution of pollutants in lakes and rivers because of lower flows and an increased difficulty in maintaining adequate ecological flows.
- Less precipitation can lead to an increase in forest fires because of the lower level of soil moisture leading to an increase in dryness of the fuel and, thus, worsen the risk of desertification.

All the previous impacts can be summarised into one: climate change can be responsible for the generation of new degraded zones. Therefore, the following RTD topics, which are also listed and prioritised in Table 5, should be further developed:

- Eco-engineering: taking advantage of water ecosystems' long-term climate resilience is a key strategy. More research is needed to develop sustainable strategies by

Table 5 | List of PP 5 RTD needs

	Prioritised RTD needs for PP 5: Degraded zones
1	Eco-engineering
2	IWRM and DSS
3	Monitoring
4	Assessment tools

Reviewed sources: PP 5: Bates *et al*. 2008; EEA 2009; EEA-JRC-WHO 2008; GPPN 2009.

implementing green remediation technologies (e.g. low energy consuming, low CO_2 emissions, self-sustaining technologies) and to reach WFD objectives. Some examples of eco-engineering techniques are: wetlands restoration (help prevent floods, regulate run-off, improve the quality of surface waters, control sediment washing and enhance groundwater recharge), CO_2 capture through phyto-remediation strategies (contaminated areas can benefit from an eco-technology and at the same time contribute to mitigation through CO_2 capture), remediation of contaminated groundwater through new technologies, self-purification processes, etc.

- Integrated water resources management (IWRM) and decision support systems (DSS): integrated management is needed to determine the optimal flow conditions of rivers (ensuring ecological flows) and to quantify impacts of excessive abstraction. River basin management plans (RBMP) (demanded in the WFD) must consider an integrated approach for water resources and must take into account climate change. Therefore, DSS are required to prioritise water allocations considering ecosystems as another consumer.
- Monitoring: included in 'Task Force on Monitoring and Sensors' section.
- Assessment tools: development and use of assessment tools or methodologies are required to determine levels of vulnerability of degraded zones, taking into account the potential impacts of climate change.

Pilot Programme 6: Hydro-climatic extremes

Climate change could exacerbate the increasing drought risk in some parts of Central and Eastern Europe, and especially in the Mediterranean region. Economic losses due to the 2003 drought reached €11.6 billion in 20 European countries (EC 2007b). Even though it is not possible to achieve a 100% reliable system, there are effective measures that can be implemented to reduce vulnerability to water scarcity in those regions.

Floods are one of the most important hazards in Europe both economically and in terms of lives lost. In 2002, the direct costs of flooding amounted to €13 billion (EC 2007a) and it has been proven that the annual number of reported floods and damages in Europe increased during the 1972–2002 period (Guha-Sapir *et al*. 2004). Climate change is very likely to increase the frequency of heavy rainfall events, increasing the risk in areas that are already vulnerable to floods. Thus, it is very important to carry out strategies to improve flood protection.

Some of the forecasted climate change impacts that could affect extreme events are:

- Drier and hotter summers that will increase frequency and duration of droughts.
- An increase in the number and intensity of extreme precipitation events that will raise the risk of floods and worsen water quality, owing to an increase in the load of pollutants washed from soils.
- Increased rainfall intensities that can lead to more soil erosion and, as a consequence, to a decrease in reservoirs' storage capacity.
- More intense precipitation will produce more combined sewer overflows.

Therefore, more emphasis should be put on the following RTD topics, focusing on the top priority ones according to the experts (as can be seen in Table 6):

- Drought management plans (DMP): the WFD encourages regions under water stress to implement DMP as a way to integrate a series of measures and include it in the RBMP. Risk management approaches must be fostered in order to improve preparedness and to promote the sharing of best practices developed in the DMP. These plans should include some of the water efficiency and saving measures mentioned in previous sections.
- Early warning systems: forecasting is mostly oriented to floods, but may be developed also to predict drought periods and constitutes another risk management measure. More work is needed to improve the spatial

Table 6 | List of PP 6 RTD needs

	Prioritised RTD needs for PP 6: Hydro-climatic extremes
1	Drought management plans
2	Early warning systems
2	Climate models at regional or local scale
3	Land management practices
4	Risk information availability
5	Assets' resettlement
5	Evaluation of uncertainty

Reviewed sources: PP 6: Bates *et al*. 2008; EEA 2009; EEA-JRC-WHO 2008; EP 2008; IMPRINTS project website.

precision and increase the lead-times (time to react) of these systems in order to facilitate public preparedness.

- Climate models at regional or local scale: current global climate models fail to thoroughly represent the climatic phenomena at local scale, and therefore, downscaling techniques are needed. Improvement of these techniques, taking into account smaller scales (micro-topography) and additional features (land use and vegetation cover), is needed to obtain more reliable projections. Special attention must be paid to future distributions of extreme climatic events. Further research is needed to determine the relation between mean values (climate model outputs) and extreme values under climate change conditions.
- Land management practices: flood plain restoration and river bank stabilisation can be a sustainable solution to increase protection against floods instead of other more traditional measures, such as constructing levees. Some other practices include: widening of floodplains to retain more water (i.e. The Netherlands' initiative 'Room for River'; V&W 1996), or replacing of crops in risk zones with grasslands, reducing economic loss and holding back water.
- Risk information availability: mapping of risks is already required by the Floods Directive (FD; EC 2007a) by the end of 2015 to raise awareness, reduce vulnerability and help stakeholders take decisions. Methodologies to take into account impacts of climate change need to be developed and implemented.
- Asset resettlement: measures such as removing assets from high-risk flooding areas must be further studied through work with satellite imaging for example. Cost–benefit analyses may be carried out to assess costs of resettlement as well as those for protection measures and take decisions from the results. There is also a need to detect which are the critical infrastructures of a country and to study how to protect them.
- Evaluation of uncertainty: in general, projections of climate change are subject to uncertainties, but these are larger when referring to predictions of precipitation extremes. Longer series of data are required to clarify the tendency towards an increased frequency and intensity of storms and, therefore, more work is needed in this field.

Task Force on Managed Aquifer Recharge (MAR)

Aquifers are an important water source in many European regions, especially in the Mediterranean area. Many of them are already under stress owing to growing demand, but climate change may cause additional impacts that can lead to disturbance of the hydrological equilibrium of the aquifers.

There are three key impacts that could affect coastal aquifers:

- Increased temperatures will cause sea-level rise, inducing saline intrusion into aquifers.
- Changes in rainfall patterns can reduce water availability in some areas, meaning that less water will be available for aquifer recharge.
- Changes in surface water runoff can produce changes in quality and salinity of groundwater.

Therefore, the following RTD topics should be further developed:

- IWRM including aquifers: in an integrated management scheme and implementing future scenarios, including changes in demand, artificial recharge, storage capacity and climate change, to increase preparedness to meet future needs.
- Vulnerability maps: develop maps evaluating vulnerability to factors such as contamination, salinity or climate change for aquifer areas.
- Assessment of natural purification processes: improve the monitoring of groundwater quality to understand better the natural purification processes that take place (e.g. natural filtration in unsaturated zones), especially when recharging with reclaimed water.

- Artificial recharge: study the use of alternative water sources to recharge aquifers (e.g. reclaimed water, storm run-off) and develop new techniques for aquifer recharge, injection of the water, and evaluation of environmental performance through life cycle analysis (LCA).
- Underground storage: study the viability of using aquifers to store water volumes from non-conventional sources during periods when supply and demand are not balanced.

A the list of the above RTD needs, taking into account the experts' prioritisation, can be found in Table 7.

Task force on Monitoring and Sensors

Many uncertainties are found in climate projections. Thus better monitoring is required to help understand and quantify which changes are happening and, if possible, distinguish between climate-related changes and those induced by other causes.

Climate change is introducing additional impacts to the already heavily influenced hydrological cycle. It is critical to detect its impact on water resources, to understand better the processes that are taking place and to define more clearly the adaptation measures that should be implemented. In this sense, monitoring plays a crucial role in the understanding of these processes. Therefore, the following RTD topics should be further developed:

- Hydrometric networks: a revision of the hydrometric network is needed in order to ensure that it will provide enough quantity and quality data to detect changes in natural stream flows.
- Monitoring wells: related to the agriculture sector, the monitoring of wells may be of great help to prevent illegal water use, as well as detection of climate impacts on aquifers.
- Sensors to monitor water quality: improvements in monitoring systems to measure and forecast different water quality parameters (such as algal blooms, pathogens (bacteria and viruses) in drinking water intakes, ecotoxicity and salinity in aquifers, etc.) can strongly support the decision-making process.
- Risk monitoring: monitoring combined with forecasting systems can provide real-time information and improve the operational response to flood events, increasing the response times and, consequently, public preparedness. Besides, in relation to coastal protection, sensors can also be used to control dykes during storms.
- Drought prediction: development of indicators to link specific phenomena with water scarcity impacts is needed, but it must be accompanied by the creation of a monitoring network.
- Information sharing: monitoring improvements should be accompanied by information-sharing practices between researchers, stakeholders and consumers. Database creation at European level should be promoted.

As for PP 4, these RTD needs have not been prioritised because no experts in this field were present at the second workshop. Table 8 summarises a list of these needs, which for now must be considered equally important, until a proper assessment of their relevance is carried out.

Table 7 | List of Task Force on Managed Aquifer Recharge RTD needs

	Prioritised RTD needs for TF MAR
1	IWRM including aquifers
2	Vulnerability maps
3	Assessment of natural purification processes
4	Artificial recharge
5	Underground storage

Reviewed sources: TF MAR: EEA 2009; EP 2008; GABARDINE project website.

Table 8 | List of TF on Monitoring and Sensors RTD needs

	Non-prioritised RTD needs for TF M&S
1	Hydrometric networks
2	Monitoring wells
3	Sensors to monitor water quality
4	Flood risk monitoring
5	Drought prediction
6	Information sharing

Reviewed sources: TF M&S: EC 2009a; EEA-JRC-WHO 2008.

CONCLUSIONS

In its 4th Assessment Report, the IPCC (2007) confirmed the earlier scientific findings about climate change.

Table 9 | Summary of the main RTD topics identified for each PP and/or TF. Numbers indicate their priority out of the total number of RTD needs identified in each PP, 1 being the most relevant topic. No prioritisation was carried out in the case of PP 4 Industry and the monitoring and sensors task force

Key RTD topics related to climate change identified in each PP	PP 1 Coastal	PP 2 Urban	PP 3 Agriculture	PP 4 Industry	PP 5 Degraded	PP 6 Extremes	TF MAR	TF M&S
Integrated water resources management	1	1		#	2		1	
Alternative water supplies and technologies	4	1	4	#			4	
Water efficiency and conservation measures		1	2	#				
Risk management approaches	5	2				1		
New assessment tools and methodologies	2	1	5	#	4	5	3	
Infrastructures' resilience	3	3	1			5		#
Monitoring and early warning systems	3	2	1	#	3	2	2	#
Eco-engineering approach					1	3		
Raising awareness		4	3			4		

Anthropogenic greenhouse gas emissions and changes in land use are modifying, among others, the Earth's surface temperature, the strength of winds and the presence of clouds. These changes will cause impacts on many aspects of the Earth such as water availability. Climate change, together with an increase in the anthropogenic water demand, is intensifying the pressure on water resources and, as a consequence, more regions will suffer from water scarcity in the future. Apart from impacts on water quantity and availability (e.g. increased frequency and intensity of extreme events, emphasised temporal and spatial rainfall variability), climate change may worsen water quality and cause economic (need for additional investment to adapt infrastructures) and social impacts (conflicts over diminished water resources, migrations, loss of territory). Therefore, it is important to emphasise the need for improving water efficiency and lowering energy consumption in many areas of the water sector.

In this context, the objective of this paper is to identify and prioritise the RTD needs that should be further developed in each of the thematic areas within the WssTP. This aim has been accomplished through a review phase of the main references related to climate change and the water sector and holding two workshops which made a crucial contribution to this process. Literature sources analysed in this paper are largely known by researchers, water company technicians or policy makers, but the classification and evaluation of research priorities identified in each thematic area constitutes a novel approach to decide which are the most critical RTD needs related to climate change and water.

The main conclusion is that climate change must be further assessed in the several PP agendas since it is a transversal issue that affects all of them. Even if it may seem an obvious statement and some PP had highlighted climate change as an existing pressure, many of the research topics identified in this process had not been specifically identified in the different PP vision documents. Table 9 shows a summary of the key RTD topics analysed above (grouping some of the specific needs into wider topics) with their correspondence to the different areas of study. This table shows how all the gaps identified belong to several PPs at the same time.

However, prioritisation of RTD needs between the PPs does not follow the same pattern. This is probably due to the methodology followed during the workshop, where participants were divided into small groups depending on their field of expertise. The groups sorted by relevance the RTD gaps in their area and only at the end were results shared among the groups. It would have been useful to have more time to discuss the outcomes among the several groups and identify the reasons for the discrepancies in the prioritisation. In any case, the evaluation of the main RTD topics from Table 9 shows some important coincidences in three crucial issues that affect several PPs. First of all, IWRM has been selected as the most relevant topic regarding coastal areas, urban areas and managed aquifer recharge, and is secondary in degraded zones. Similarly, the research needed in monitoring and early warning systems was classified within the first three research needs by all PPs. In the case of water efficiency and conservation measures, both urban areas and agricultural sector PPs consider it a critical gap to cover.

The next step, even if it is not the aim of this paper, would be to include these research needs into the implementation cases that each PP has identified. Implementation cases enable the PP participants together with their stakeholders to identify the matching research, development and technology demonstrations. They try to cover the competitive phase of practical application in specific European locations by creating commercial consortia. In this case and because of the transversal aspect of climate change in relation to the PP study areas, it would be useful to integrate several research needs that appear in some of them and combine them into an implementation case. This could be a way of taking advantage of the interactions and relations that actually exist between PPs and climate change and, then, present an integrated case which studies the feedback and nexus that are generated.

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