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Managing the urban water cycle in a changing environment

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Abstract: Climate change will likely lead to higher climate variability which must be addressed by increasing the robustness, flexibility and resilience of urban water cycle systems. Other anthropogenic pressures such as urbanisation, population growth and other landscapes and watershed changes add to climate related stresses. The urban hydrological cycle is becoming more complex to manage and actions have to be planned and implemented in a context of increasing uncertainty. Urban water systems managers need to plan the transition of their current system into a more sustainable future, assuming a fundamental and widespread paradigm shift on how urban water cycles are managed. Sustainability and resilience have become the keywords. In Portugal, the Sectoral Strategy on the Adaptation to the Impacts of Climate Change on Water Resources addresses the climate related issues facing water service managers. It includes six specific programs for urban water cycle management, namely the promotion of water use efficiency, the diversification and reinforcement of water supply sources, the improvement of quality control and water treatment capacity for human consumption supply, the review and upgrade of wastewater drainage and treatment systems, flood risk management, and research and knowledge enhancement. This paper addresses the existing challenges and discusses the proposed course of action.

Key Words: Climate change adaptation, resilience, sustainability, variability

1. INTRODUCTION

Urban water systems provide a number of key services to the population, namely water supply (drinking or non-drinking) and waste water collection, treatment, disposal and reuse, but their sustainability is being threatened by a number of environmental, social and economic pressures. Environmental pressures, increasingly aggravated by climate change, are creating problems in the quantity and quality of water, which result in water stress situations. Social pressures, arising from changes in population dynamics and users preferences and expectations, are affecting water demand and consumption patterns. The growth of urban areas as a result of rural migration, abandonment of city centres to suburban regions and population age distribution changes are some of the dynamics that are radically modifying water demand projections. Finally, economic pressures from an increasing competition for existing resources, conflicts among potential users and financing difficulties lead to an increase of fixed and variable costs and threat the economic sustainability of urban water systems (Novotny *et al.*, 2010; Ramoa *et al.*, 2012; SWITCH, 2006).

Among these pressures, climate change is of particular concern, due to its cross-cut character and because it will most likely exacerbate current water problems. In particular in southern Europe, expected changes in precipitation patterns towards longer dry periods will cause a larger water scarcity risk. At the same time, more intense storms will lead to an increased risk of flooding and of water quality degradation. Cities in coastal areas will have to cope with a significant sea level rise, which may lead to extreme high water levels and disastrous flooding. On the other hand, saline waters coming into wastewater systems may significantly affect the performance of biological treatment and compromise the reuse of treated effluents for irrigation purposes.

Clear strategies are needed to deal with the climate change threat, both for reducing greenhouse gases (GHG) emissions (mitigation) and for preparing society to the inevitable change in climate (adaptation). Urban water systems have a role to play in both these areas. Water supply and wastewater management are responsible for 5 to 10% of total domestic electricity consumption, a small but still significant percentage that cannot be ignored in initiatives to reduce the overall energy consumption and GHG emissions (SWITCH, 2006). Wastewater treatment plants are increasingly becoming a source of renewable energy that can partially substitute energy production from fossil fuels.

Adaptation is particularly demanding due to the large investments that are required to retrofit existing infrastructures and to the significant uncertainty associated with current climate scenarios. Moreover, climate change adaptation will have to be integrated with the strategies to deal with the above mentioned environmental, social and economic pressures. It is also a challenge that requires action at all decision levels, from individual citizens and local water services utilities to regional and national governments (Novotny *et al.*, 2010; Adikari and Yoshitani, 2009).

The climate change challenge and the need to put forward an adaptation strategy is, however, an excellent opportunity to revisit the way we approach water management. There is a growing call for a paradigm shift, arising from the appreciation of the complexity of water management systems, with human, ecological and technological components, and from the recognition that many water related problems are associated with governance failures as much as with technical issues (Pahl-Wostl *et al.*, 2008, 2011).

Integrated water resources management (IWRM) and adaptive management (AM) are two paradigms that have been proposed to deal with the shortcomings of water systems governance and the challenge of making water management decisions under uncertainty (Pahl-Wostl *et al.*, 2008). A number of European research projects have been looking at the ways these ideas can be applied to urban water systems. The SWITCH project looks at water management in the “city of the future” by finding and promoting more sustainable alternatives to the conventional ways of managing urban water (Howe *et al.*, 2011). The TRUST project (Transitions to the Urban Water Services of Tomorrow) gathers the existing knowledge to provide a set of guidelines to help communities achieving a sustainable, low-carbon water future without compromising service quality (Smith *et al.*, 2012).

This paper presents the on-going efforts in Portugal to develop an adaptation strategy for water services, i.e. water supply systems and waste water drainage and treatment systems.

2. CLIMATE CHANGE IMPACTS ON URBAN WATER SYSTEMS

2.1 Water supply systems

Climate change will affect water supply systems (Figure 1). In Portugal, the largest impact on water supply systems will most probably be the reduction of water availability and the degradation of water quality at source (uptake location). The decrease of annual runoff and aquifer recharge, mainly in the south of the country, associated with an increase of flow variability, will probably lead to an increased risk of longer periods of drought conditions and conflicts among water users.

This trend is further accentuated by the possible degradation of the water quality during low flow periods or high flow periods, if erosion and contaminated runoff from non-point sources is not adequately controlled. The increase of air temperature and water temperature will reduce the ability to dissolve oxygen in water, cause algae blooms and affect biochemical processes in the water. Coastal aquifers that satisfy the population water needs in some regions face the risk of salinization due to sea level rise and the expected recharge decrease and evapotranspiration increase.

The expected increased variability in rainfall, runoff and aquifer recharge will affect the operating conditions of the water uptakes which will have to be prepared to deal with a larger variation of river and reservoir water levels and of piezometric levels. Water treatment plants will also have to accommodate the rapid changes in raw water quality possibly with the use of more chemicals, namely for coagulation, flocculation and disinfection processes.

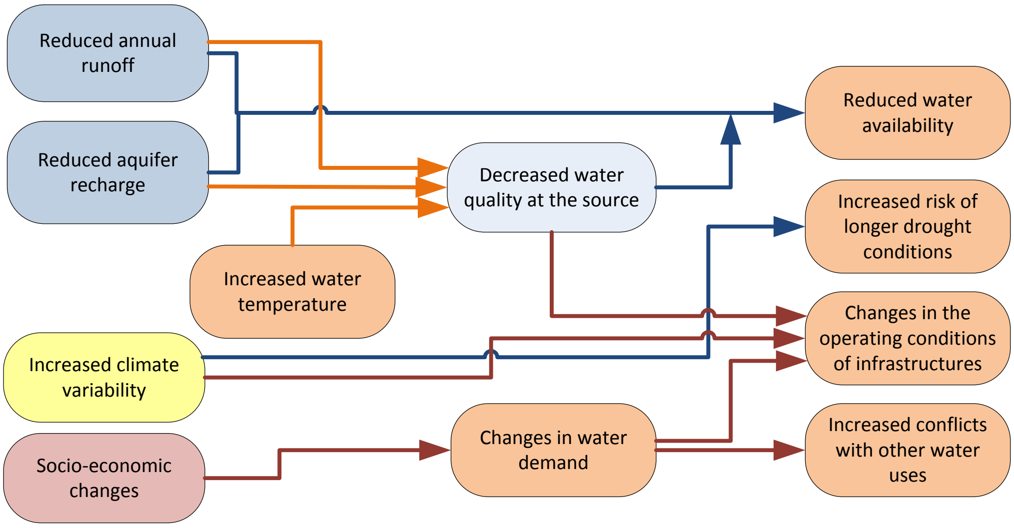

Figure 1. Impacts of climate change on water supply systems

Climate change may also indirectly affect water supply systems, mainly through changes in the water demand. As the society adapts itself to new climate conditions, demographic movements and adjustments in industrial activities can significantly change the spatial distribution of water needs and create imbalances between demand and supply capacity for some critical water supply systems. A major demand increase will require investments to reinforce the system capacity, while a reduction may threaten the economic sustainability of the system.

Along with possible increase of water demand from other uses, such as agriculture and power production, these expected trends will challenge the capacity to satisfy water demand in urban areas, particularly during spring, summer and autumn. In Portugal, it is likely that the existing north-south regional asymmetries in water availability will increase. This will put further pressure on the water management system and recommend the strengthening of an integrated planning approach at regional (basin) and national levels.

2.2 Waste water drainage and treatment systems

Waste water drainage and treatment systems will also be affected by climate change (Figure 2), mostly in their storm water drainage functions and in their reduced ability to discharge effluents to sensitive water bodies with increased contamination problems.

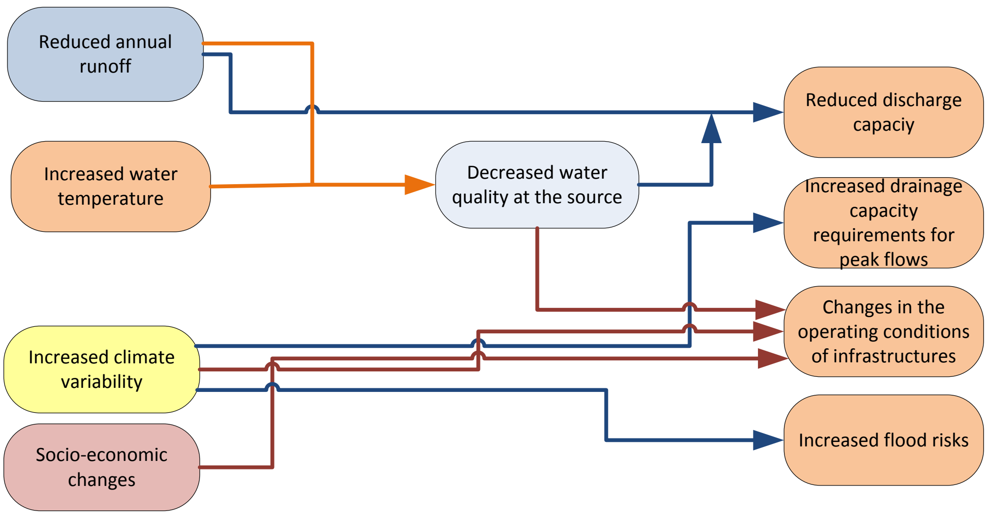

Figure 2. Impacts of climate change on waste water drainage and treatment systems

In combined systems, that are still common in the larger cities of Portugal, the expected change in the rainfall regime will probably lead to an increase of peak storm water runoff that will challenge the existing drainage and treatment capacity of combined sewer systems. The sea outfalls along the coast discharging treated effluents to the ocean may also have to deal with a reduction of the hydraulic capacity of the diffusers due to the expected rise of medium sea level and the resulting reduction of available gravitic heads.

Even if the existing drainage and treatment capacity is sufficient, the expected increase of peak rainfall values, interspersed with longer dry periods, will challenge the ability of the wastewater systems to deal with a higher variability of inflow and of its biochemical characteristics. The increased duration of low flow situations, associated with warmer conditions, carries the risk of sedimentation (non-self cleansing conditions), odors, toxicity and corrosion of sewer systems. Treatment plants will have to be prepared to receive a highly variable inflow with a diverse range of contamination levels. In addition, the ability to discharge effluents to receiving water bodies may be permanently reduced or, at least, conditioned during longer low flow periods.

Waste water drainage and treatment systems will also have to cope with a possible growing risk of flooding as its infrastructures are usually located in flood prone areas, namely by river banks or in coastal areas, which will be subject to an increase of floods peaks and higher mean sea level.

3. THE PORTUGUESE CLIMATE CHANGE ADAPTATION STRATEGY

Building on its on-going efforts to reduce its GHG emissions, Portugal adopted in 2010 the *National Strategy for Adaptation to Climate Change* that identifies the nine priority sectors for fast action. These priorities include two water-related areas, namely "water resources" and "coastal zones", a sign of the importance that Portugal gives to adaptation in this domain. Work started immediately with the *Sectorial Adaptation Strategy to the Impacts of Climate Change on Water Resources* that identifies possible courses of action to deal with the impacts of climate change in water resources planning and management, aquatic ecosystems and biodiversity, water services, agriculture and forests, electricity production, tourism and coastal zones (Oliveira and Cunha, 2012).

In what concerns urban water systems, the strategy considers six main programs, namely the promotion of an efficient water use; the diversification and reinforcement of water supply sources; the improvement of quality control and water treatment capacity for human consumption; the review and upgrade of wastewater drainage and treatment systems operational procedures; flood risk management; and research and knowledge enhancement.

The Portuguese Adaptation Strategy to the Impacts of Climate Change on Water Resources aims at reducing the country's vulnerability to the impacts related to water in a way that is sustainable from the technical, economic, environmental and social perspectives. It assumes that building a more resilient society to climate change is a long-standing challenge to be assumed by all, in a process open to new ideas and practices raised by reflection, debate and experience. The proposed adaptation actions address the factors that determine the vulnerability to climate change, namely: i) its exposure to climate conditions; ii) its robustness, i.e., its capacity to perform under new climate conditions; and iii) its resilience, i.e., its capacity to recover from adverse conditions.

Given the uncertainty associated with current climate change scenarios and their impacts on urban water systems, the strategy proposes a flexible action program that does not restrict future options and is able to cope with the uncertainty associated with current climate scenarios. It adopts a cautious approach and promotes the adoption of structural and non-structural measures that provide benefits for a wide range of scenarios or promote the flexibility to adopt further measures in the future, when the confidence in climate predictions is greater.

Recognizing that climate change exacerbates existing problems and management shortcomings, the strategy integrates as much as possible on-going initiatives to overcome these issues, such as the River Basin Management Plans, the National Water Plan, the National Plan for an Efficient Use of Water or the Strategic Plan for Water Supply and Wastewater Treatment. The adoption of these plans also fosters the integration of climate change adaptation in the current policies of management and planning of water resources. The strategy actually assumes that the key to a successful result is a sound governance system supported by a solid and capable institutional arrangement, a skilled scientific and technical community and operational monitoring systems.

The strategy recognizes that adaptation is a local process, conditioned by site-specific requirements, and that one size fits all solutions, if applied indiscriminately, will probably lead to bad results. The challenge is to convert the concept of adaptation into practical solutions with a high degree of acceptability. As such, the strategy calls for the involvement of local actors, such as water utilities, and assigns them the tasks of identifying climate change impacts and risks and of carrying the adequate adaptation actions.

4. URBAN WATER SYSTEMS ADAPTATION

4.1 Promotion of water use efficiency

The climate change adaptation strategy for the water sector attributes the highest priority to demand-side actions that limit the growth and, if possible, reduce the pressures on water resources. The reduction of the pressures on water resources, such as water abstractions or pollutant discharges, creates a buffer that may be used to ensure the satisfaction of water needs under future climate stressed conditions.

An efficient use of natural resources, including water, is one of the pillars of the public national policy and a National Action Plan to enhance Water Use Efficiency (PNUE) has been launched by the Portuguese Government in 2012 (APA, 2012). This action plan aims at raising current water inefficiency (water volume that is taken from nature but not used) for urban, agricultural and industrial sectors, which is estimated to be 25%, 37.5% and 22.5%, respectively. The goals for 2020 are 20%, 35% and 15%, respectively.

To achieve these goals the PNUE includes several actions to reduce real and apparent losses in public water supply networks and in building networks. Proposed actions include replacing some water distribution equipment with more efficient or adequate devices, decreasing the network water pressure and promoting water recycling. It also includes actions to control water consumption by changing behavior regarding water use. In some communities, these objectives will be achieved with changes in the water tariff scheme.

The climate change adaptation strategy adopts these goals and the proposed course of action.

4.2 Reinforcement and diversification of water supply sources

Demand control actions will not be sufficient to face the expected increase in climate variability and the consequent decrease of water availability. This challenge will also have to be met by improving the processes of planning and management of water resources and investing in the reinforcement and diversification of water supply sources.

Of great potential are solutions that promote better monitoring and forecast systems to evaluate both water availability and demand at the short and medium term associated with tools to optimize the yield from existing water storage and distribution infrastructures and to find acceptable solutions in case of conflict among different users.

In addition, the interconnection of water distribution networks will expand the operational options of water managers and help maintain reliable levels of water supply through water transfers between regions. The reuse of water and the development of distinct distribution systems to supply water of different quality to compatible uses are other approaches to diversify water supply sources. The National Action Plan to enhance Water Use Efficiency (PNUE) includes several specific actions to achieve this goal at the public network and building levels as well as to promote the use of recycled water for street washing, car washing and irrigation of gardens and sport fields' or agriculture.

In certain specific cases, the use of desalinated water to satisfy water needs may be an adequate option. However, to avoid an unfavorable situation where a climate change impact is addressed through a solution that requires the emission of GHG, the desalinated water should be produced in plants where a significant share of its power is obtained from clean sources.

Finally, the construction of new intakes and new reservoirs to store water from wet periods to dry periods will have to be considered mainly in the south of Portugal, where climate change is expected to be felt more severely.

4.3 Improvement of quality control and water treatment capacity for human consumption supply

The expected greater variability of water availability and water quality at the source will require changes in water treatment systems to ensure the capacity to deal with such risks. These changes may include plans to reinforce the installed capacity or to implement additional water treatment stages. The increased variability of operational conditions will mainly require the ability to dynamically change the sequence of treatment processes to cope with such changes. This means the existence of real-time decision making processes, supported by monitoring mechanisms that propose actions based on an accurate knowledge of existing and future operational conditions, such as raw water quality, existing treatment capacity or short-term water needs. It also requires the capacity to quickly change the water treatment process based on these conditions.

Water safety plans are a standard good practice recommended by a number of leading organizations, including the Portuguese Water Services Regulator (ERSAR). Its goal is to ensure drinking water safety through a comprehensive risk assessment and risk management approach, encompassing all steps in the water supply, from the intake to consume. As such, these plans should be used to anticipate the risks associated with climate change and to incorporate the appropriate response in the overall risk management strategy.

4.4 Review and upgrade of wastewater drainage and treatment systems

The Portuguese Adaptation Strategy proposes several actions to deal with climate change impacts in wastewater drainage and treatment systems, particularly the expected increased variability of its operational conditions.

The control of unauthorized inflows by illegal connections, infiltration through broken pipes and manholes or storm water runoff inflows in separate domestic sewers is already a concern in many wastewater utilities, but its importance is now reinforced to ensure the existence of the capacity of treatment to deal with the increase of wastewater treatment peak demands, especially in the case of combined systems. The control of storm water inflows is of particular importance and may be achieved by source control solutions (such as trenches, porous pavements and green roofs) that promote infiltration and storage and avoid or delay the water delivery to the drainage systems or through the construction of retention basins to delay water discharges to the treatment plant and limit overflows discharges into receiving waters. The incremental adoption of separate systems for domestic sewage and storm water runoff may also be a realistic option, in some specific cases. These changes can be encouraged through the application of tariff mechanisms that cover storm water runoff discharged into the waste water drainage and treatment systems.

The control of storm water inflows most probably will not be sufficient in many cases and the hydraulic and treatment capacities of many wastewater systems will have to be reinforced.

The expected change in rainfall patterns will lead to a change in storm flow patterns and probably to an increased duration of low flow situations, which carries the risk of organic matter sedimentation and an increase of activity of sewer slime layers, resulting in anaerobic conditions with release of odors, toxicity (due to hydrogen sulphide build-up over certain limits) and corrosion of pipes, manholes and structures and equipment of wastewater treatment plants (WWTP). Actions are therefore needed to maintain the sewer systems with self-cleaning velocities and control the risks of odor and corrosion situations, which may require preventive or corrective actions (e.g. periodical sewer cleaning, addition of oxidants and reactive products to the bulk water). In addition to the control of storm water runoff, some systems may need to be equipped with automatic gates and devices for flushing during long drought periods, and also be equipped with instrumentation for monitoring and real time control.

The change in rainfall patterns, namely the expected increase of peak rainfall values, interspersed with longer dry periods, will also need changes in the wastewater treatment plants to deal with a higher variability of inflow and biochemical characteristics of the influent. The installed treatment capacity may need to be enhanced by supplementary treatment lines prepared to be launched at short notice. In certain cases, like the Alcântara WWTP, in Lisbon, one of the major WWTP operating in Portugal, treating more than 700,000 e.p. (equivalent population), two distinct treatment lines were designed, one for just treating the dry-weather flow, trough bio-filters and another for treating polluted storm water using advanced physical-chemical treatments (ACTIFLO) that allow a response time of a few minutes (10 to 15 minutes), with removal efficiencies of more than 80% of Total Suspended Solids (SST) and more than 60% of Chemical Oxygen Demand (CQO).

4.5 *Flood risk management*

Urban water systems will have to cope with the expected increase in the risk of floods and inundations in two ways. On one hand, the expected increase of peak storm water runoff will challenge the existing drainage and treatment capacity of combined sewer systems. On the other hand, many critical infrastructures of urban water systems, such as water intakes, pumping stations, water treatment plants and waste water treatment plants, will be subject to an increased risk of inundation, as they are located in flood prone areas, namely by river banks or coastal areas, threatened, respectively by flood peaks and an increase of the mean sea level.

Actions to manage peak storm water runoff overlap with the above mentioned actions to deal with wastewater flow variability, where source control solutions and retention basins have particular relevance. In many cases, the hydraulic capacity and treatment capacity of the drainage system will have to be reinforced.

The increased risk of flooding will have to be managed by the rise of dykes or protection walls, water diversion works or even through the relocation of infrastructures at risk. It may be necessary to design combined drainage infrastructures vulnerable to inflows of saline waters inflows from the sea with overflows with crests over the maximum sea level (the most common option), or equipped with check valves, the solution adopted in Terreiro do Paço, Lisbon, Portugal.

4.6 Research and knowledge enhancement

The implementation of the Portuguese National Strategy for Adaptation to Climate Change to urban water systems is a challenge that faces many knowledge gaps, budget constraints and practical difficulties. Overcoming these hurdles will require a significant investment on research to reduce the uncertainty of climate change scenarios, improve meteorological and hydrological forecasts and develop and test adaptation strategies. In what concerns urban water systems, in particular, there is also a need for innovative, low-cost and low-energy technology, capable of dealing with highly variable operational conditions and improved monitoring and control systems.

Building resilience to climate change involves incorporating uncertainty and surprise as Olsson and Galaz (2009) suggest. More than simply trying to reduce uncertainty, this implies accepting that knowledge will never be perfect, and that unforeseen changes are inevitable. Research is needed to develop and test approaches that assume that lack of knowledge, namely by allowing room for innovative management attitudes and learning from the outcomes of such approaches.

Climate change adaptation also challenges the existing regulatory framework of water services utilities. As the adaptation costs will have to be transferred to the water service users, some guidelines will have to be put forward to balance the control of tariffs with the risk of postponing necessary actions.

5. CONCLUDING REMARKS

The design and management of urban water systems is being challenged by a number of growing environmental, social and economic pressures. Climate change contributes to the complexity of the decision process by exacerbating existing and rising pressures, adding additional uncertainty and by defying current urban water design and management practices. Urban water managers need to be aware of this challenge and develop the adequate long term adaptation strategies.

Adopt "no regret measures" is always an added-value. Having alternative water supply sources, increased storage capacity and access to remote sources for contingency use might significantly increase the resilience in terms of water supply and will be useful not only for climate change mitigation but for other critical situations that may occur. In terms of wastewater drainage and treatment, the use Best Management Practices for storm water, decentralized solutions and the availability of different treatment technologies may also increase the response capacity.

Using current best practices is the best way to prepare for the future, but always having in mind that we should be prepared for unexpected situations. The widest possible range of experiments should be encouraged to support learning by innovative pilot programs, instil flexible and resilient knowledge, so that the urban water cycle system as a whole can 'learn by doing' and avoid 'locking-in' to particular pathways.

Although some adaptations may be technologically possible, they may not be adequate for a specific situation, economically feasible or culturally desirable. Adaptation is a local process that must be organized at a local level, taking into account site specific situations. National plans are not the complete and final answer, but provide support to promote action by water utilities' managers.

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