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Critical review of adaptation measures to reduce the vulnerability of European drinking water resources to the pressures of climate change

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Abstract

One of the consequences of the generally agreed rise of global temperatures, furtherly exacerbated by the growth of water demand caused by the needs of a growing population, is an increase of areas with water stress. This will imply and in part is already implying, an always greater imbalance between water (and in particular drinking water) demand and supply.

These issues are among those investigated by the “Adapting Drinking Water resources to the Impacts of Climate change in Europe” (ADWICE) project that had, among its main goals, the identification of priority adaptation measures aimed at reducing drinking water vulnerability to the pressures of a changing climate. In this paper these adaptation measures are described, with special attention given to their associated European water policy context.

The complexity of designing and implementing such adaptation measures will benefit from integrating drinking water concerns with wider water management, within a framework able to facilitate the necessary complex collaborations between various actors involved in the different scales of the decision making arena and to develop an effective science policy interfacing mechanism. Last, but not least, because drinking water is commonly considered by stakeholders and citizens to be a public service, drinking water managers should enable their involvement in the adaptation decision making process, to ensure their acceptance and cooperation and to prevent conflicts.

Keywords: Adaptation measures, drinking water, climate change, Europe

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1. Introduction

At global level, there is a general consensus that temperatures are rising and will continue to increase during this century (IPCC, 2007, 2012; Garnier et al., 2015). Human activities are estimated to have been responsible for approximately 1.0°C of global warming above pre-industrial level (range 0.8 to 1.2°C) and global warming is likely to reach 1.5°C by the 2050s at current rates (IPCC, 2018). A likely effect of this warming will be an intensification of the hydrological cycle (WHO, 2017) with, for example in temperate countries, a decrease in the number of rainy days but increasing rainfall intensity (Brunetti et al., 2001; Bates et al., 2008; EEA, 2008a; EEA, 2008b; Durack et al., 2012, Miralles et al., 2014; Feng and Wu, 2016; Giuntoli et al., 2015; Papadimitriou et al., 2016). Consequently, increased extreme hydrological events (droughts and floods), that both modify water quality and quantity, are anticipated. According to most climate scenarios for Europe, there will be an increase in annual river flow in Northern and Eastern Europe; whilst southern European rivers are likely to see marked flow decreases (EEA, 2008a; Alfieri et al., 2015).

However, changes in future freshwater availability are not just affected by the direct consequences of climate change, but also by non-climatic changes. In Europe, at present, approximately 51% of total water abstraction is used for agriculture, 25% for industry and energy production and the remaining 24% for public water supply (EEA, 2018), although this masks important regional differences in water usage and users. These uses, in relative and absolute amounts, will change as a consequence of socio-economic factors that, on the whole, will add to the effects of climate change in the establishment of freshwater availability in the years to come. Population growth and a trend towards more water consuming lifestyles are important factors in the set-up of future freshwater shortages with overall human water consumption increasing from 600 to 4500 billion cubic meters in the period from 1900 to 2010 (EEA, 2012a).

These challenges are furtherly exacerbated when population growth occurs in already water stressed areas such as, for example, semi-arid coastal zones, where there is little water supply margin available (WHO, 2017) and can be further aggravated by increased water demands from seasonal tourist fluxes (EEA, 2016a; von Medeazza, 2004). Consequently, water managers need to plan for and manage the uncertain future consequences of changing water resources availability, changing water quality and changing water demand.

1.1 European water legislation in the framework of a changing climate

European water resources have been subject to protection from a range of legislation since the 1970's, with Directives protecting water resources from sectoral pressures from, for example, agriculture (Nitrates Directive - Council Directive 91/676/EEC) and urban development (Urban Waste Water Treatment Directive - Council Directive 91/271/EEC). Growing awareness of horizontal (cross-sectoral) interactions affecting water resources and of the competing demands from numerous sectors (e.g. agriculture, energy and manufacture) and the environment, have created conditions for integrated water management, in which water protection has been mainstreamed into other EU policies, including the Common Agricultural Policy (CAP), the Habitats Directive and the Drinking Water Directive (Ludwig et al., 2014; Carvalho et al., 2019). This shift from single issue to integrated European water legislation culminated with the enactment of the Water Framework Directive (WFD) (Directive 2000/60/EC), which is widely regarded as the most substantial and ambitious piece of European water legislation to date (Giakoumis and Volvoulis, 2018; Prieto, 2009).

The WFD owes its innovative character fundamentally to having established a common framework for water management and environmental protection, introducing the concept of river basin management planning (Giakoumis and Volvoulis, 2018). Member States lay out strategies to solve water problems over time, through the preparation of River Basin Management Plans (RBMPs) (European Commission, 2019) in which programmes of measures are established which aim to achieve good status (which means chemical and ecological status for surface waters and chemical and quantitative status for groundwater) for all water bodies by 2015 (Quevauviller, 2014). This deadline can be delayed to 2027 if particular conditions in the legislation were applied (European Commission, 2019).

Another feature of the innovative character of the WFD consists of its cyclical approach, with the Directive requiring 6-yearly river basin management planning cycles, with the possibility to modify technical requirements at the end of each cycle. The European Commission (EC) and the European Environment Agency (EEA) are in charge for the periodical assessment of the WFD during every 6-year cycle (Quevauviller, 2014).

It has been estimated that the number of surface water bodies in "good status" increased by 10% during the first cycle (2009-2015) (Volvoulis et al., 2017). European water quality was slowly improving, due to a reduction of agricultural pollution, increased urban waste water treatment and the re-naturalization of several water bodies. Nevertheless, problems remain in many European basins, mainly due to chemical pollution, water over-abstraction and physical obstacles that worsen natural river flow and consequently, water quality (European Commission, 2019).

At present, the WFD implementation process is in the middle of the second 6-year cycle of river basin management (2015-2021). The EEA established that the majority of ground waters, but only around 40% of European surface water bodies, are in a good status. The next plan (2021-2027) will have to show how all remaining water bodies will be brought to good status (European Commission, 2019).

To provide the necessary scientific background for the development of climate change and water policies, the EU has funded numerous research projects under the 6th (2002-2006) and 7th (2007-2013) Framework Programs for Research and Innovation and, more recently, under Horizon 2020 (2014-2020), many of which are described in Quevauviller 2011 and 2014; Quevauviller and Gemmer, 2015; Escribano et al., 2017.

Despite its many strengths, the WFD does not explicitly consider climate change, or the associated floods and droughts, as an anthropic pressure, although several of its articles provide a framework to include the consequences of climate change in the planning process (Quevauviller 2011; Quevauviller, 2014). The Directive requires, for example, to collect information on the type and magnitude of "significant pressures" threating surface waters. This requirement can be implicitly considered to include climate change, on condition of acknowledging it is, at least in part, caused by human activities (Wilby et al., 2006).

The Commission will review the Directive within 2019. This revision is considered a unique opportunity to realign the WFD implementation to its initial objectives (Giakoumis and Volvoulis, 2018). Several effective actions to be added in the revision of the Directive have been suggested, including the explicit recognition of human activities among the causes of climate change and the consequent specific consideration of climate change related disasters (e.g. floods and droughts) (Quevauviller, 2014).

To complement the WFD prescriptions and also considering the likely future intensification of water related problems derived from climate change, significant additional European water policy developments have occurred since the WFD came into force, all calling for climate proof EU actions. These include the Floods Directive (Directive 2007/60/EC), the Water Scarcity and Drought Communication (European Commission, 2007) and more recently, the EU Strategy on Adaptation to Climate Change (European Commission, 2013).

The Floods Directive was issued as a consequence of a series of significant flood events in Europe. It requires Member States to assess and manage flood risks and to reduce their adverse consequences for human beings and for the environment through Flood Risk Management Plans (FRMPs) (European Commission, 2019). Because flood consequences are also likely to impact the achievement of "good status" objectives established by the WFD, the Floods Directive is coordinated with the implementation of the WFD from the second RBMP (2015-2021) onward (Quevauviller, 2014).

The Water Scarcity and Drought Communication sets out a number of policy options in view of the projected increase of water scarcity in Europe (Quevauviller, 2014). Finally, the recent EC Communication on EU Strategy on Adaptation to Climate Change was issued with the ultimate aim to make Europe more resilient to climate change. It supports on-going efforts within Member States, promotes information sharing, effort coordination and coherence among sectors and policies. The strategy addresses particularly vulnerable sectors, such as water resources, and provides funds to improve adaptation capacities (Escribano et al., 2017).

With particular reference to drinking water, the main topic of this paper, the Drinking Water Directive was issued in 1998 (before the issuing of the WFD), with the aim to protect human health from adverse effects of any contamination of water intended for human consumption (Council Directive 98/83/EC). However, no mention to pressures exerted by climate change is made, and climate change is not considered in the consolidated text of the Directive dated 2015, that contains its latest amendments. At the beginning of 2018 the European Commission published a proposal for a revision of the Drinking Water Directive built on a fitness check that established that it was fit for purpose but needed updating (EPRS, 2019). However, this recast also does not explicitly take climate change into consideration, despite the expected negative impacts on the quality and quantity of drinking water supply, due to the increase in extreme events, which condition for example their treatment and distribution (Khan et al., 2015; Luh et al., 2015).

This calls for the adoption of adaptation strategies to reduce the vulnerability of drinking water resources to the pressure of climate change (Boholm and Pruzer, 2017). These strategies have, moreover, to be aligned with other legislation such as the WFD and the European Urban Waste Water Directive (Council Directive 91/271/EEC) 1991). Whilst the impacts of climate change on drinking water supply have to be addressed at the water resource scale, the management of risks on drinking water also depends on complex collaborations among local, regional, national and even European levels (Orru and Rothstein, 2015).

Gaining the approval of stakeholders and citizens for climate adaptation for decisions taken by drinking water managers should prevent the occurrence of conflicts, that under a changing climate, are likely to increase (Harrison et al., 2013; Boholm and Pruzer, 2017; Escribano et al., 2017). Also crucial to an effective adaptation of drinking water management to climate change is the identification of new forms of integration of knowledge sectors, and in particular of risk knowledge, into the decision making process (Boholm and Pruzer, 2017).

Closely related to the great attention Europe devoted to the theme of water protection in a changing climate, on November 14th 2012, the European Commission issued a blueprint to Safeguard Europe's Water Resources. It describes the strategy that Member States should adopt to secure the availability of good quality water for people's needs, the economy and the environment throughout the EU (European Commission, 2012a). To support the Blueprint, the Directorate General (DG) Environment of the European Commission commissioned the ADWICE project to review the potential climate change effects on drinking water resources across the EU and to identify priorities among different types of drinking water supplies (Contract number: 070326/SER/2011/610284/D1) to maintain drinking water production and safety (Figure 1). Included within ADWICE task 2, the identification, collection and recommendation of priority adaptation measures to be applied in river basin management, to ensure the safety of drinking water supplies, form the subject of this paper.

1.2 Adaptation to the effects of climate change on water resources

Reducing the adverse consequences of climate change on drinking water resources in Europe requires complex, multi-scale and multi-institutions responses to both implement adaptation measures and support increased adaptive capacity (Lemmen et al., 2008). Adaptation actions can be taken at EU, national and river basin level. In particular, actions at the EU level may involve better implementation of water policies and relationship with other policies, together with supporting and guiding decision making at lower scales, through supporting robust frameworks, the exchange of experiences and the implementation of adaptation measures that support, as additional benefit, a reduction in the vulnerability to climate change (Holman and Trawick, 2011). These points were previously addressed in Section 1.1 .

The national level acts at the interface between the EU and the river basin level and includes, among the others, measures to be taken in areas most at risk, implementation of national policies and in certain Member States (e.g. in decentralized States), coordination of actions taken at the river basin level. Also requests for reporting by private stakeholders may, in some cases, be decided at this level.

At river basin level actions have to be refined, targeted and tailored to be successful and efficient. At this level, several measures may also be cross-fertilized by exchanging information with measures already implemented in other river basins. The main actions implemented at river basin level comprehend diagnostics, together with impact assessment of policies and communication. Among the actors involved are river basin managers, local authorities, cities and landowners that experience the vulnerability of drinking water resources and who may apply measures.

Adaptation measures can be proactive (anticipatory), concurrent or reactive. With this regard it is interesting to observe that in many cases planned proactive adaptation measures are considered more effective, as well as being less expensive in the long term. Nevertheless, it has also to be taken into account that implementing adaptation options to face uncertain future conditions entails maladaptation risks, apart from the risk to waste time and money.

2. Results and discussion

The ADWICE project identified four main challenges for successfully adapting to the potential pressures of climate change on Europe's drinking water resources:

- to better understand the impacts of climate change on drinking water resources (Section 2.1);
- to ensure sufficient supply of drinking water (Section 2.2);
- to secure the quality of drinking water supplies (Section 2.3);
- to minimise the impacts of adaptation measures on the environment and on socio-economic activities (Section 2.4).

For each of these challenges, the activities within ADWICE identified a number of priority adaptation measures that can be considered on the whole as a toolbox to be used by managers and decision makers responsible for the series of water bodies/services likely to be impacted by climate change. The adaptation measures to address each of the above mentioned challenges, together with their relative priority, are described and discussed within the following sub-sections.

2.1 Increasing the understanding of impacts of climate change on drinking water resources

With the aim of increasing the understanding of both impacts of climate change on drinking water and of the effectiveness of the related adaptation responses, a number of actions have been identified and grouped, according to their aim, into the following broad categories:

- build knowledge on the response of water resources to climatic and anthropogenic pressures and develop the ability to assess changes in availability (Mukherji and Shah, 2005);
- provide scientifically-grounded basis for management and adaptation (Mukherji and Shah, 2005; Quevauviller, 2010; Escribano et al., 2017);
- check the validity of modelling/scenarios through measured data;

In particular, cross-disciplinary research and historical observations are needed together with modelling expertise to assess potential direct and indirect impacts of climate change scenarios on drinking water (Qiu et al., 2019). Direct effects include those directly determined by temperature increase and/or by changes in precipitation regimen while, amongst the indirect ones, the consequences of different socio-economic scenarios on water demand, in response of climate change, can be considered (Henriques et al., 2008; Delpla et al., 2009; Rodriguez and Delpla, 2017).

After the identification of the impacts, the estimation and mapping of risks and vulnerability of drinking water bodies to, e.g. temperature increase, low flow or saltwater intrusion provides water managers with an indication of how urgently actions are needed (Hoque et al., 2016; Kanakoudis et al., 2017). With reference to these actions an entirely general principle establishes that: “Robust adaptation measures must be effective and cost-efficient, yet minimize side-effects, promote equity and must be technically and socially feasible within the implementation time-scale” (European Commission, 2009a).

As highlighted in the final report of ADWICE, approaches to adapt for example to floods, based on floodplain restoration, are generally cheaper than building grey infrastructures such as dams and dikes and could be regarded as win-win adaptation options (Dadson et al., 2017). Nevertheless, before being widely implemented, such solutions have to be carefully tested (as it was done, for example, in the case of the integrated Tisza river basin management plan), to exclude the possibility of occurrence of unexpected complications and to develop risk-based water management plans (ICPDR, 2010).

To profitably support such an approach, in the gathering of knowledge and in the monitoring of impacts, there is a need for efficient tools. To this purpose, Norrant-Romand (2013) suggested, for example, the implementation of a reference information network on the impacts of climate change on groundwater, the development of a national observatory of low flows and the creation of a national water withdrawal bank to monitor the changes of water demand.

To select suitable adaptation measures to be prepared to the impacts of climate change, but also to better suit water use to available resources, existing monitoring networks should be optimized and enlarged to collect further parameters and more accurate information on, among the others, meteorology, hydrology and water quality. This would greatly help, in the first stages of the adaptation process, to determine the vulnerability to climate change, as asserted by Mauser et al. (2012), in a paper referring to the Danube river basin. The gathered data should then be stored in homogeneous formats and then exchanged among Institutions at local, regional and transboundary levels (Escribano et al., 2017).

Based on these optimized monitoring data, forecasting and early warning systems should be implemented in different water related fields (e.g. floods, droughts, water quality). A common agreement should also be achieved on further research to bridge the identified knowledge gaps and to reduce uncertainty. Improved information sharing would strengthen the warning capacity and awareness about the status of the aquatic environment and water availability (Directive 2000/60/EC; European Commission, 2013; EEA, 2015; Escribano et al., 2017). In this context the further development of capacity building programs should also be promoted aimed at switching from "trial and error" approaches to those based on training and expertise exchange.

2.2 Ensuring sufficient supply

For convenience of exposition, adaptation responses to ensure sufficient drinking water supply have been subdivided into responses that act on drinking water supply and responses acting, on the contrary, on the water demand; both, in turn, include several categories (Figure 2).

2.2.1 Supply-side responses

Supply side responses are those aimed at increasing water availability in order to ensure drinking water supply in the long term, taking also into account the competing demand from other sectors. With this reference, during the execution of ADWICE the broad categories of measures listed below have been identified.

Promotion of water infiltration and retention

These measures allow groundwater recharge, keeping at the same time a greater water quantity available for plants (reducing in this way irrigation needs) and also limiting adverse impacts on water quality caused by runoff and soil erosion (Srivastava R, 2013; Feijt, 2015). Infiltration can be increased by implementing:

- agricultural practices that limit soil compaction (Holman et al. 2003, 2011);
- land use policies that, in particular in urban areas, reduce soil sealing (Norrant-Romand, 2013; Johnson et al., 2016). With this last reference in Belgium, for example especially in the context of flood prevention plans, limits to built-up areas and use of permeable materials are the main measures adopted (National Climate Commission, 2010).

Diversification of supply sources

Diversification of supply sources, together with their integration into a combined system allows to better respond to water scarcity using each resource, depending on its characteristics, for the most appropriate purpose (Arahuetes et al., 2018; Nabaprabhat and Elango, 2018; Qiu et al., 2019). In case of water shortages, both permanent and temporary, the use of alternative supplies (including reused and recycled water) to meet the demand of different socio-economic activities (agriculture, industry, etc.) may greatly help to ensure enough freshwater for drinking purposes. Potable and irrigation water can be both obtained through, for example wastewater recycling, brackish water treatment and rainwater harvesting (Lange and Donta, 2005), on condition that strict caution and careful monitoring are employed (Norrant-Romand, 2013).

Alternative supply mechanisms include desalination, used to remove salts not only from seawater, but also from brackish or saline surface water and groundwater, with the aim to make it available for human consumption or other uses (Sahin et al., 2015; WHO, 2017). The mechanism is being progressively used to supply drinking water, due to the increasing freshwater scarcity driven by climate change, together with population growth and overexploitation of water resources. Considering Europe, desalination plants are particularly widespread in Spain (among the highest users globally), Cyprus and Malta (Eurolab, 2013). Some authors assert that, despite the high costs of this solution, desalination will be required in the 21st century in Eastern Mediterranean and Middle East Countries to meet even the most fundamental freshwater needs, to manage drought caused by climate change (Dhakal et al., 2014; Miller et al., 2015; Gude, 2016; Missimer and Maliva, 2018; Cyprus Institute, n.d.).

When dealing with desalination, nevertheless, not only the high financial costs have to be taken into account. Desalination also entails heavy environmental costs due, among the others, to the much higher energy consumption (that in turn is likely to imply higher greenhouse gas emissions) required by the process, compared to those of other treatment processes. With this reference, in fact, it has been estimated that the energy needed to pump and treat freshwater into drinking water is around 0.6 kWh/m^3, while the energy costs of seawater desalination approximate 4.6 kWh/m^3 (Eurolab, 2013).

- **Increase of water storage capacity**

Many countries throughout Europe have built reservoirs. The Mediterranean region stores 38% of the total volume of reservoir water in Europe, followed by the Atlantic and by the Continental regions (30% and 20% respectively) (EEA, 2018). Spain, Turkey and Romania, in particular, are able to store more than 40% of their long term annual available resource, but also other countries, e.g. Bulgaria, Ukraine and Sweden hold large storage capacities (EEA, 2008c). Extending water storage capacity to secure water supply throughout the year, in this way managing uncertainty, has to be regarded as fundamental in a likely future context of growing severity and duration of drought and water scarcity, to ensure that water supply sources and associated infrastructures are robust enough to meet future demand (Kelly-Qinn et al., 2014).

Notwithstanding these unquestionable advantages, the construction of new reservoirs or the enlargement of the existing ones is often contested, mainly due to the high costs and to the large environmental footprint. Reservoirs are responsible for changes of the natural hydrological regimes and of sediment transport. They also represent barriers for migrating aquatic species, e.g. salmon and sturgeon (EEA, 2008e). Another inconvenience is that reservoirs, alone, usually are not enough and have to be used together with other supply and management options (Sahin et al., 2017; Nabaprabhat and Elango, 2018). These inconveniences make it important to be sure that, in any specific situation considered, not only reservoirs represent the most appropriate response to drinking water pressures caused by climate change in the long term, but also that other measures have already been put in place (UK Environment Agency, 2009).

▶ Increase of water body and water infrastructure connectivity

To this category of adaptation measures belongs the recharge/discharge of water bodies aimed at buffering changes of water level. This measure not only improves the resilience of existing water supplies, but also provides increased security in case of extreme events. The step can be used for both groundwater (e.g. with natural or artificial recharge) and surface water. To regulate the level of lake Balaton in Hungary for example, the Sió Canal was opened to drain surplus water while, in case of evaporation higher than natural inflows, the lake was recharged with other sources, to sustain the water level (Varga, 2005).

Also the increase of water infrastructure connectivity represents a solution to possible impacts of climate change on water resources (Duan et al., 2019). With this purpose, for example, the engineered redistribution of freshwater over space, using pipelines to transport water across distances of more than 100-200 km represents a measure already successfully adopted in the past by

Europe's largest cities, forced to rely on the surrounding regions, to supply drinking water to an always growing urban population, with always higher living standards and in many cases, with lower water availability (EEA, 2008d).

Optimization and development of abstraction infrastructures

Another option to adapt to and to meet an increased drinking water demand consists of the optimization of the existing abstraction infrastructures and the development of new ones. An example is the improvement of the operation of existing wells or the construction of new ones. Another example is the replacing of vertical abstraction points with horizontal (linear) drains to meet a decrease in groundwater level. With particular reference to the construction of new wells, it has nevertheless to be considered that, on the one hand it allows to increase water availability but, on the other hand, it might not permit to take into account the sustainability of the supply.

2.2.2 Demand-side responses

The measures described under this heading work by regulating the demand or increasing water efficiency, in this way acting directly or indirectly on drinking water availability.

Monitoring the consumption

Monitoring the consumptions, installing for example water meters, is necessary at first to identify trends and later to adjust the quantities of water used by different socio-economic categories.

Regulating demand and consumption

To regulate water demand and consumption several approaches have been identified during ADWICE and are briefly described below.

▷ Water allocation and restrictions

Apart from the obvious progressive reduction of water consumption, to adapt to climate change, water availability has to be reallocated to those uses considered socially and/or environmentally and/or economically most important (Borgomeo et al., 2016). Water use restrictions operated through licensing/permits and/or temporary bans (Salmoral et al., 2019) represent an efficient tool to regulate consumption during seasonal shortages and/or in geographic areas subject to water scarcity and droughts. The measure has already been implemented in numerous countries (e.g. France, Finland, U.K.) and could be always more necessary either to anticipate, or to cope with future climate change impacts, especially where increases in water efficiency already proved to be not sufficient.

To design and implement water use restrictions, field measures of all water abstractions for civil uses and industrial sites have to be taken into account (Ministries van Verkeer and Waterstaat et al., 2009a,b,c,d), together with monitoring and simulation data on water availability (e.g. groundwater level and surface water flow). When planning such restrictions, differences in response time of different drinking water sources have to be taken into account. Groundwater has, for example, in many cases larger storage capacity and responds more slowly to climate change than surface water systems. This often caused it to be favored to reduce drought problems, in some cases creating excessive pressures on the resource (Dragoni and Sukhija, 2008).

Not to run these risks, Bekesi et al. (2009), for example, with reference to an Australian aquifer, proposed an adaptive Groundwater Level Response Management (GWLRM) methodology which uses groundwater storage depletion as a basis to restrict existing allocation limits. Their aim was to direct water allocation towards sustainable levels on the basis of measured trends. According to these authors, a GWLRM correction, equal or lower than any calculated storage depletion, should be applied to the existing allocation limits as an interim tool towards the recovery of groundwater resources. Undesired declines in groundwater level, as might occur under climate change, would result in a reduction in groundwater allocation limits, although Bekesi et al. (2009) do not indicate how these reductions might be distributed between abstractors or abstraction sectors.

As suggested by principles established in the U.K., a way to increase adaptive capacity consists of the transformation of all the previously permanent abstraction licenses into limited ones and/or also of the adjustment of volumes and abstraction periods to seasonal availability (U.K. Environment Agency, 2009). The need to modify existing legislation to improve the preparedness for risks linked to water is recognised also in Finland. Here, for example, drought risks could be prevented by amending the Water Act to include provisions according to which withdrawal permits can be revised or new conditions can be imposed if drought has, or can be expected to have, significant harmful impacts on society, which otherwise cannot be sufficiently reduced (Finnish Ministry of agriculture and Forestry, 2011). Furthermore, the possibility is raised to revise some of the 220 regulation permits for Finnish lakes, because of changes forecasted in the timing of runoff and floods. Denmark on the opposite does not see a need for revising existing permits or regulations (at the time of the ADWICE project).

Connected to restrictions, allocation hierarchies are also often used to decide which sector to give priority in water distribution. Hierarchies can be based on different criteria. It can be decided, for example, to give priority to potable use, but also to sectors providing higher Gross Domestic Product and employment generation or to sectors allowing greater water savings, in case of activities responsible for significant water uses (Souza da Silva and de Moraes, 2018). Another principle to reduce water demand, implemented only in Spain (at the times of ADWICE execution), amongst the European Countries, is that of tradable quotas, that permits to freely organize water assignments among users (Varela-Ortega et al., 2011; Mukherji and Shah, 2005).

A key difficulty met when trying to develop sustainable abstraction management is the identification and quantification of illegal and/or unlicensed abstractions (Varela-Ortega et al., 2011; Mukherjiand Shah, 2005). Another problem, to be faced only in case of river basins belonging to different Member States, is the strengthening of cross-border governance for water allocation (Agence Wallonne de l'air et du climat, 2011; Kanakoudis et al., 2017; Renner and Meijerink, 2018).

Pricing policies

Always considering water demand reduction, various economic instruments can be employed (Rey et al., 2019). Water pricing influences both water valuation and the cost-efficiency ratio of adaptation measures and is recommended in many publications (with specific ref. to drinking water see, for example: Ministrie van Verkeer en Waterstaat et al., 2009 a, b, c, d, Zachariadis, 2010 and Lange and Donta, 2005).

Subsidies can also be used to promote water savings through specific water tariffs or quotas (Olmstead, 2014). It goes without saying that to decrease water demand, toxic subsidies (i.e. those contributing to excessive water use directly or through the support of practices such as certain cropping patterns) must be eliminated (Lange and Donta, 2005).

Awareness raising

Because consumers' behaviour greatly influences water demand, awareness raising plays an important role in regulating water consumption. The most commonly used methods to raise awareness include information campaigns to increase citizen's perceived water value (Ministrie van Verkeer en Waterstaat et al., 2009 a, b, c, d), the installation of individual water meters and the communication of knowledge through a public information portal (Norrant-Romand, 2013).

Water savings and water efficiency

Water savings in all sectors and for all uses either through a reduction of demand and/or through an increase of water efficiency, is highly recommended by all the European legislation dealing with climate change and water (e.g. European Commission, 2007; European Commission, 2009b) to prevent potential conflicts. To achieve water efficiency, both technological improvements (e.g.

water efficient devices, decision tools) and/or changes in practices (e.g. irrigation practices) can be considered. These measures may involve various sectors such as, for example, those listed in Table 1.

Table 1 Sectors involved and measures to be implemented to achieve water efficiency (table drawn using the bullet list on p. 165 of ADWICE final report)

Sector	Measures
Water distribution and Wastewater	- Leak detection and repair - Dimensioning infrastructures taking into account climate change
Energy	Improved performance of existing and future power plants in terms of water withdrawal and consumption
Construction	- Use of water saving devices in new buildings - Construction of water efficient buildings - Renovation projects to promote water reuse - Use of green infrastructures (e.g. green roofs)?
Agriculture and forestry	- Optimization of irrigation (e.g. schedule, drip irrigation) - Choice of low-water using crops - Regulation of evapotranspiration (e.g. optimized forest composition

2.3 Secure the quality of drinking water

A first broad distinction between measures to secure drinking water quality can be made considering the implementation time. This distinction includes measures carried out:

- before abstraction (e.g. water sources protection, maintenance of water levels, river bed management;

- during abstraction (e.g. construction of new wells where groundwater is less polluted);

- after abstraction (e.g. adaptation of water treatment processes).

During the carrying out of ADWICE another classification of the measures to ensure drinking water quality was performed considering the step of the DPSIR framework (Flörke et al., 2011) that each measure is targeted at. With this last reference, the measures identified are shown in Table 2 and a short explanation concerning each category is provided in the next sections.

Table 2 Adaptation measures to secure the quality of drinking water

DPSIR Target	Aim	Adaptation measures
Drivers	Influence the direct and/or indirect drivers of the use and degradation of drinking water resources (e.g. demand, land use)	
Pressure	Decrease pressures on water resources (e.g. abstraction/supply, pollution	Source protection: - Protection perimeters for surface and groundwater - Good agricultural practices in the catchment zone - Industry management and needs (e.g. incorporating climate change consideration into discharge licensing) - Identification and remediation of contaminated soils - Flood management - Aquifer barriers to seawater intrusion - Integrated planning and sound management (e.g. check planning activities likely to have hydrological

		consequences)
State	Modify the state of water resources (e.g. increase water availability, water quality);	Maintaining high water table level and minimum river flows
Impacts	- Anticipate impacts (e.g. droughts and floods, low water quality); - Cope with impacts (e.g. improve water treatment infrastructures	Adaptation of water treatments - Improving water treatment microbiological safety - Ensure infrastructure's treatment capacity - Desalination Construction of new abstraction wells

2.3.1 Source protection

This category of adaptation responses includes measures not different from those already implemented to cope, in general, with pressures on water quality. To tackle possible worsening of these pressures, caused by climate change, these measures could however be strengthened. The Danish Government's Climate Change Adaptation Strategy, for example, states that there may be a need for adapting present drainage and irrigation schemes to cope with possible alterations of precipitation patterns (European Commission, 2012b).

With particular reference to drinking water, the aim of source protection is the reduction of pressures on freshwater supplies, to ensure that the quality of the resource at the abstraction point meets the quality standards and requires limited treatment. To this end, the establishment of protection perimeters and the restriction of certain land uses, that may be responsible for soil and water pollution, are among the most commonly adopted measures.

Best practices in the agricultural and in the industrial sectors, aimed at preventing both point and diffuse pollution can also be promoted, together with afforestation. Considering agriculture, common adaptation options include limitations of fertilizer and manure application, changes in land use and crop types, reduced tillages and planting of vegetated buffer strips along water courses, together with their proper management (Stuart et al., 2011; TEHO project, 2011).

Also flood management can greatly help to improve water quality avoiding, for example, runoff and soil erosion. With this aim, the procurement of flood control structures for operational flood prevention, cooperation between authorities, as well as the reinforcement of infrastructures such as dikes and dams are among the adaptation responses most commonly implemented. The realization of green infrastructures, because of the multiple services provided, along with flood control, is also being progressively promoted.

Moreover, the development of barriers to prevent sea water intrusion and the identification and remediation of contaminated sites can be included among source protection measures. Drinking water contamination may also be caused by polluting substances bound to soil particles, as a consequence of former activities that, with climate change, see increased risk to be released in the aquatic environment. The identification of polluted areas within drinking water supply areas, and their remediation, should be considered, for example, in the drawing up of river basin management plans (European Commission, 2012b).

Integrated planning and sound environmental management cannot be considered as real adaptation measures, but rather as key principles to be followed to prevent water quality deterioration (UK Environment Agency, 2005). With this reference, for example, the Belgian National Climate Commission recommend to check building plans and other planning activities potentially capable to have hydrological consequences (e.g. runoff changes) (National Climate Commission, 2010).

Some Member States have already taken action in this sense. Romania, for example, has adopted the principles established by the "Code of attitudes to climate change mitigation in agriculture" (ACCRETE, 2007), that can be deemed as a sort of European farmer's manual. The document includes suggestions for adapting agricultural technology and process-specific activities of the whole agricultural production to climate change. Examples of best practices to lower GHG emissions are also included in the manual. At EU level a handbook of ideas, for integrating water topics into farm advisory services, addressed to administrators, was issued in 2010 (Berglund and Dworak, 2010).

2.3.2 Maintaining high water table level and increasing minimum river flows

Water quality and quantity are closely related through dilution. Supporting high water table levels and increased minimum river flows helps prevent low chemical quality and also salinization. The Netherlands, for example, is evaluating how the release into low-flow rivers of water stored in impoundments could improve water quality through dilution. Several adaptation measures under this heading are also suggested in Section 2.2, dealing with ensuring sufficient supply.

2.3.3 Improvement of water treatment

As already mentioned, reservoirs alone might not be enough to support natural supplies in the event of the predicted climate change and extremes. In these cases, to provide enough drinking water of acceptable quality, water treatment plants may need to be upgraded to be able to handle greater microbial, sediment and chemical loads. (WHO, 2017). These can be a consequence of degradation of the resource at the abstraction point and/or of variations of water flows in treatment infrastructures.

Whichever its origin, wastewater is usually treated using well established technologies; nevertheless some problems can occur during one or more of the steps in the treatment process, resulting in the contamination of drinking water delivered to users by the chemicals used in the treatment process (Hrudey et al., 2006). With this regard, for example, increased water temperature caused by global warming, with the consequent browning, is likely to induce greater treatment requirements, resulting in an augmented risk of chemical by-products pollution, in case of malfunctioning during the treatment process (Kovacs et al., 2013; Weyhenmeyer et al., 2016).

Regardless of the cause and/or of the particular pollutant considered, the upgrading of water treatment processes and infrastructures can be fundamentally achieved through:

- improving microbiological safety of drinking water treatment;
- adapting water treatment capacity of infrastructures;
- promoting treatments to allow the employment of alternative water sources (e.g. desalination and/or wastewater treatments).

2.4 Minimizing the impacts on the environment and socio-economic activities

Integrated planning and sound management play a key role to secure a sufficient supply of drinking water, limiting at the same time, the impacts of some adaptation measures, such as, for example, those caused on biodiversity by dams, or those caused by environmentally friendly measures on socio-economic activities (e.g. through land use restrictions). Adaptation responses are always more oriented towards the protection of ecosystem services, rather than towards the construction of grey infrastructures. Ecosystem services may lower negative impacts caused by climate change on drinking water either directly, or indirectly, apart from benefitting water uses different from drinking through, for example, reducing water treatment costs and improving water retention for agricultural purposes. Measures aimed at restoring natural conditions of water bodies create beneficial effects for both water quantity and quality.

Increasing the connectivity between water bodies belonging to a catchment enables to reduce pollutant concentrations through a more efficient occurrence of natural dispersal processes. In Belgium, in the Brussels Region, the “blue network” being implemented since 1999 is an integrated program for the purification and restoration of water bodies. It aims at restoring the continuity of the hydrographic system, also contributing to the upgrading of rivers, ponds and wetlands in urban areas (National Climate Commission, 2010). Always considering the restoration of natural conditions, other measures are: the remeandering of streams, that raises the carrying capacity of the system; the creation of buffer zones, that improves water retention and water quality; the establishing of active flood plains, that can provide protection from floods (Laaser et al., 2009).

Ecosystem services also provide several environmental and socio-economic benefits that represent win-win opportunities across sectors (e.g. increase recreational purposes and biodiversity safeguard). It has however to be referred that the above mentioned measures also present drawbacks in terms of implementation difficulties (e.g. wetland restoration can take a long time to become effective), or can reduce, in the short term, economic development (e.g. certain land uses are forbidden in safeguard zones) or can impede certain uses (e.g. remeandering does not allow navigation). To tackle these drawbacks, the carrying out of a comprehensive risk-benefit assessment should be promoted, mainly in cases in which trade-offs between services are inevitable.

3. Concluding remarks

The study presented in this paper allowed to identify different types of adaptation measures aimed at addressing the main challenges to be faced to increase the adaptive capacity of the environmental systems, to the likely future scarcity of water and in particular of drinking water. As already mentioned, these challenges include the understanding of the impacts and the assurance of a sufficient drinking water supply, guaranteeing water quality and minimizing, at the same time, possible impacts of adaptation measures on the environment and on socio-economic activities.

A number of principles emerged from the present study, for the implementation of adaptation strategies aimed at reducing the vulnerability of drinking water resources to climatic changes in Europe over the coming decades:

1. Drinking water concerns need to be integrated with other water issues, because water bodies used for drinking water supply in many cases represent water supplies for other purposes and also because decision makers and water managers have often to take decisions based on all water uses, not only on potable use.

2. Adaptation to climate change does not necessarily require new measures or responses, as climate change is, in many cases, likely to exacerbate existing “non-climate” pressures, which already required adaptive measures. For example, to reduce non-climate pressures on water resources, a reduction of abstractions could have been implemented, that could also contribute at increasing the resilience to climate change through the maintenance of water levels.

3. Adapting to climate change within the water, and in particular within the drinking water sector, does not generally entail a single action; multiple approaches at different scales need to be embedded within an adaptive management framework. There is general agreement among scientists that these approaches need to be integrated both horizontally (cross-sectoral harmonization of policy and practice, e.g. between water and land use) and vertically (across the scales of governance involved in management, from the EU and the national, downwards to the local level).

4. Linked to the point above, management of the risks associated with the impact of climate change on drinking water resources depends on complex collaborations among the different levels of decision making within an elaborate regulatory framework.

5. Climate change has or will have considerable impacts on water bodies in terms of quality and quantity, infrastructure capacity and resilience and water/wastewater treatment. Consequently, different actors (e.g.: EU and national decision makers, scientists, river basin managers, water

utility companies) will be impacted in different ways. Because each of them may be able to implement only certain types of measures, effective coordination and collaboration are essential prerequisites to the success of any of the planned or applied adaptation strategy.

6. Adaptation is a dynamic process, with strategies and management decisions that have to be continually updated during their execution, in the light of changing conditions and increased understanding of the problems.

7. Water resources are variable in space and time and moreover, drinking water is not necessarily available in the needed quantities when and where it is required. This entails the need for a systemic approach, over water resources and over their life cycle, to optimize water use. For example, increased groundwater abstraction as a short term response to surface water shortages, might be harmful in areas where an increase of drought frequency, severity and duration is expected.

8. Given the unavoidable uncertainty in our understanding of the impacts of climate change on different water resources, adaptation measures should be developed in such a way to enable maximum flexibility, so to bring benefits under a range of conditions, rather than being planned for what are thought to be the most likely future conditions. Win-win situations, no-regret measures and actions that improve the resilience of water bodies and in particular of those used for drinking purposes, to climate change, have to be prioritized.

9. Nevertheless, whilst a toolbox of potential measures has been identified, following the above mentioned flexibility principle, these will need to be carefully tailored to the local situation (which is that within which adaptation measures have to be realized) taking into account the need of specific water bodies (e.g.: rivers, lakes, groundwater) and specific future challenges that have to be faced (e.g.: water management, salt water intrusion).

10. A significant gap has been recognized between scientific knowledge of climate change impacts on water resources and adaptation capacity at the local level. To bridge this gap, participatory approaches coordinated by organizations with capacity and authority to integrate scientific knowledge and adaptation policy are highly recommended.

11. Increase public awareness and participation through, for example, educational public campaigns on climate change impacts on drinking water, will help the effectiveness of demand-side measures. Providing information on the planned measures before their coming into force is, in fact, important to guarantee the involvement of the general public and this, in turn, considerably conditions its acceptance and cooperation that are fundamental to make many of the planned measures effective.

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Figure captions

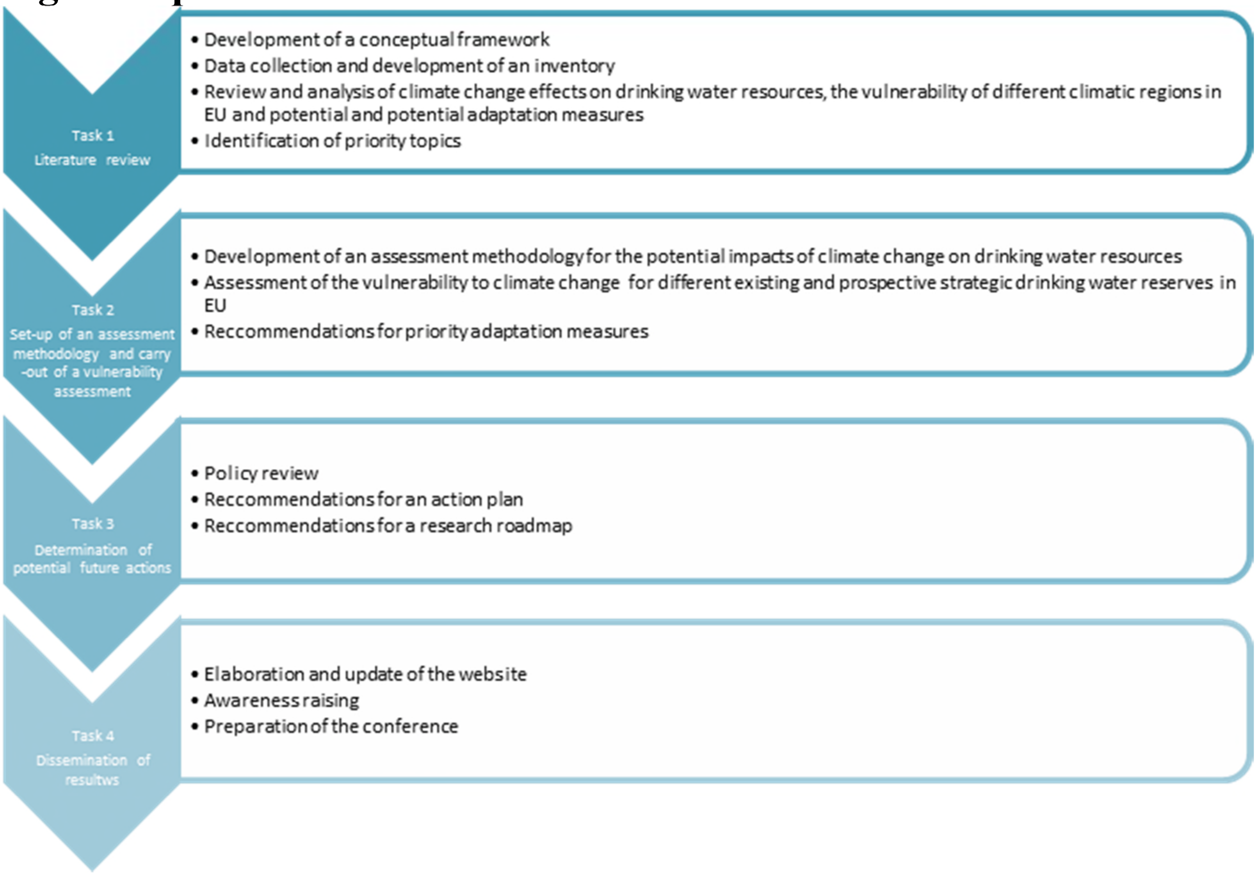

Figure 1 ADWICE project task and sub-task structure. (After: BIO-Intelligence Service, 2012. ADWICE project inception report)

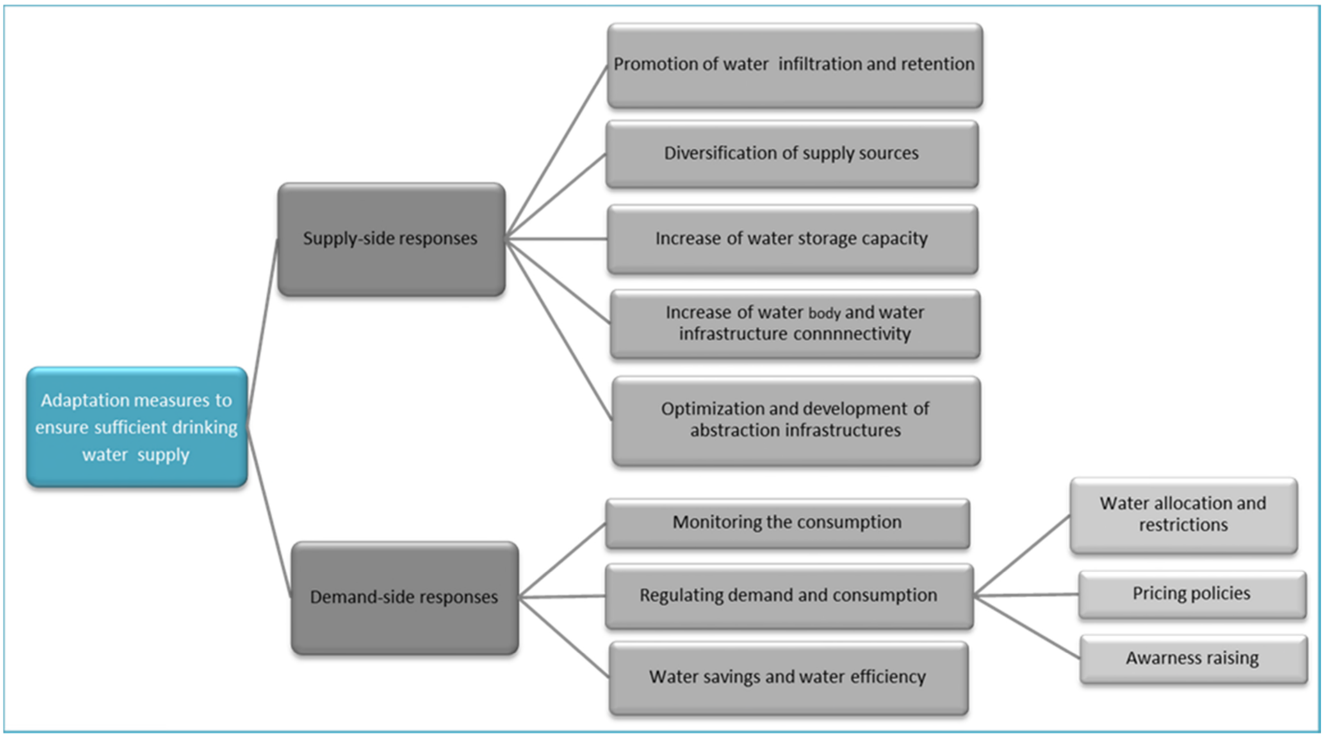

Figure 2 Adaptation measures to ensure a sufficient supply of drinking water

Critical review of adaptation measures to reduce the vulnerability of European drinking water resources to the pressures of climate change

Garnier, Monica

2019-06-24

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