Resilient Water Supply

Feedback from validation and demonstration in partner cities WP5.2

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Authors
Klaasjan J. Raat (KWR), José Menaia (LNEC), Edvard Sivertsen (SINTEF) (eds)

Quality Assurance
Dr. Gerard A. van den Berg (KWR), dr. Edvard Sivertsen (Sintef)

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Contents

1 Introduction

PREPARED *Enabling Change* gathered urban utilities in Europe and worldwide to develop advanced strategies in meeting the upcoming challenges for water supply and sanitation brought by climate change. The project linked comprehensive research with development programmes in these utilities. The PREPARED vision provided significant synergistic opportunities that the utilities can utilise to improve their preparedness for the ongoing changes related to the provision of water supply and sanitation.

Water supply systems comprise the whole chain from water source (groundwater and surface water), to treatment and distribution, and climate change will impact all elements of this chain. River floods are the most common natural disaster in Europe, and flood damage is expected to increase in the next decades. Among the assets at risk are water wells, and flooding of wells may obstruct the supply of safe and sufficient water in affected areas. More frequent, more rapid and more severe raw water quality depreciation events caused by heavy rain incidents are expected. Also, higher temperatures and severe droughts may significantly change the raw water quality with negative impact on the water treatment plants and water supply networks. Water supply systems have to adapt to changes in raw water qualities, such as increased concentrations in natural organic matter, microbiological substances and low density particles.

PREPARED work package 5.2 specifically addressed water supply systems and aimed at developing technologies and practices that make these systems resilient to climate and other changes. Work included:

- development of practical guidelines to make water well fields 'flood proof'(del. 5.2.1), including an overview of methods to detect and repair leaks in wells (del. 5.2.3)
- development of design and operational protocols for aquifer storage and recovery (ASR) systems, based on experiences and recent developments in Europe and worldwide (del. 5.2.2). ASR enables the subsurface storage of water to balance periods of high water supply with high water demands;
- assessment of current approaches to handle climate change related raw water quality changes, and options to make multi-barrier treatment systems climate robust (del. 5.2.4/ 5.2.5), and
- development of remedial actions to prevent adverse effects of re-growth in networks at higher temperatures (del. 5.3.6).

The outcomes of PREPARED are to be used as input for the planning and rehabilitation programmes of the participating cities. This report provides 6 examples of how results from work package 5.2 were taken up by partner cities and implemented in their operation and planning. It is our sincere hope that these examples inspire other actors of the water sector in Europe to help make their systems resilient to climate change.

1.1 Outline

This report provides 6 examples of climate change adaptive measures (to be) taken at water utilities in PREPARED partner cities. All examples are related to the work undertaken in work package 5.2 *Adaptation of water supply systems*.

Descriptions include a short review of the work undertaken in PREPARED (background), a description of uptake and implementation of the work in partner cities, and concludes with an outlook on future developments and actions at the utilities.

The following examples are included in this report:

Chapter	Description	PREPARED del.
2	Flood proof wells in Eindhoven, the Netherlands	5.2.1
3	Sustainable water management with ASR in Eindhoven, the Netherlands	5.2.2
4	Adapting water treatment to severe droughts and intense rainfall events in the Algarve, Portugal	5.2.4 / 5.2.5
5	Adaptations to the multibarrier treatment at Norrvatten, Sweden	5.2.4 / 5.2.5
6	NOM removal in Oset water treatment plant, Oslo, Norway	5.2.4 / 5.2.5,5.2.6
7	Adapting chlorine residual modelling to Lisbon drinking water temperature and NOM	5.2.6

2 Flood proof wells in Eindhoven, the Netherlands

Klaasjan J. Raat,(KWR), Sef Philips (Brabant Water),Inke Leunk, Gerard A. van den Berg (KWR)

Additional reading: *Rambags et al., 2011. Prepared Del. 5.2.1.*

2.1 Background

River floods are the most common natural disaster in Europe, and flood damage is expected to increase in the next decades. Water well fields are among the assets at risk, and flooding of wells may obstruct the supply of safe and sufficient water in affected areas, both at the short and long term:

- Short-term (days tot weeks): interruption of power supply, assets out of operation; risks for microbial infection; need for backup water supply.
- Mid-term (weeks to months): leakage through infrastructure (direct risk); microbial infection of raw water, introduction of chemical substances; additional monitoring and ad hoc treatment.
- Long-term (months to years): infiltration of flood water in underlying aquifer and introduction of chemicals; need for adjustment in treatment.

To safeguard the water supply during and after floods, several practical measures can be taken at forehand. The design of water wells should be adjusted, to prevent the short-circuiting of water into the well. In addition, it is essential to have clear management procedures before, during and after floods. These should be drafted in a contingency plan, providing clear instructions on how and when to act, for all persons and institutions involved. With a clear contingency plan and the appropriate technical design, water supply can be assured during and after floods. Many of the technical measures are relatively easy to implement, such that with little cost investment existing well fields can be made flood proof already.

2.2 PREPARED results put into practice

The Genneper Parken is a nature and recreation area located between the rivers Dommel and Tongelreep in the southern part of PREPARED partner city Eindhoven. Two drinking water well fields of Brabant Water water supply are located in the Genneper Parken area: well field Klotputten and well field Genneper Parken Zuid (Figure 2-1). Constructive measures alongside the Dommel river are planned by the Water Board,aiming to prevent water problems in downtown Eindhoven. Climate change and the planned constructive measures will increase the risk of river flooding and inundation of the Genneper Parken area to once per 200 years. This flooding poses a risk for the drinking water supply to the city.

Well fields Klotputten and Genneper Parken Zuid abstract water from a semi-confined aquifer (25 – 78 m depth) and a confined aquifer (208 – 278 m depth). The deep confined aquifer is well protected from any activities at the land surface, yet the superficial semi-confined aquifer is not: pollutions will eventually end-up in this aquifer (if not adsorbed and/or removed during soil passage). Three major risks for the water supply associated with flooding of the Genneper Parken area have been identified:

- Deteriorating water quality of the superficial semi-confined aquifer due to infiltration of poor quality flood water (long-term risk);
- Interruption of power supply, damage to infrastructure, obstruction of the water supply (short-term risk);
- Short-circuiting of flood water into the semi-confined and deep confined aquifer: direct leakage via production wells and observation wells, short-circuiting via the gravel packs alongside production wells.

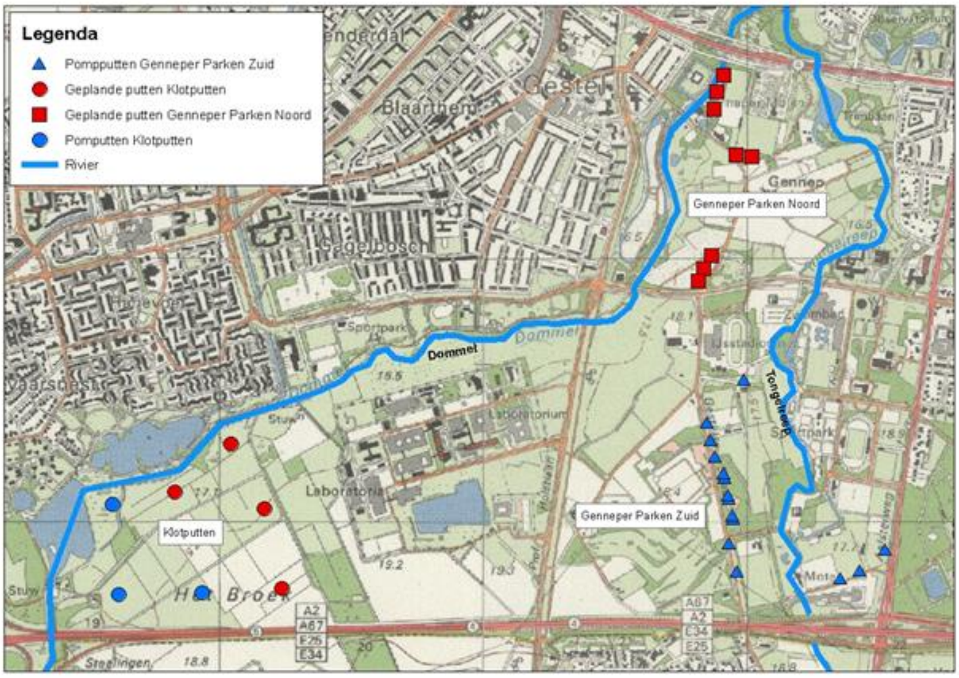

Figure 2-1. The Genneper Parken nature and recreation area and location of well fields Klotputten (dots) and Genneper Parken (triangles) and Noord (squares). Current water production wells in blue; new (planned) production wells in red.

Following the guidelines of PREPARED 2011.007, a series of measures have been drafted to safeguard water supply from these well fields both during and after floods. In addition, the investment costs to execute and implement these measures have been drafted. Proposed measures include(Leunk, 2011):

<u>Preventive measures production wells:</u>

- Construction of (planned) new production wells on mounds,
- Watertight sealing of well heads (well chambers) of current production wells,
- Adaptations to electrical / power supply systems.

Preventive measures Genneper Parken area:

- Setup contingency plan, listing actions and responsibilities before, during and after flooding,
- Locate all observation wells and private production wells in the area. Seal these wells watertight,

Shortly before and during flood

- Start execution of the contingency plan and all the action therein. Actions include:
- Warn, instruct and coordinate all organizations and workers involved,
- Safeguard infrastructure, remove water vulnerable assets,
- Seal off production wells
- Adjust operation according to contingency plan. If wells are kept in production, increase monitoring of raw water, add a disinfection step to the water treatment, to ensure microbiological safety .

After flooding

- Execute actions according to contingency plan, including:
- Cleanup terrain, wells, pipelines and other infrastructure,
- Restore the water quality in pipelines by flushing with good quality water
- Follow the appropriate procedures (including monitoring) to recommission each of the water production wells, with extra notice on microbial microbiological safety.

2.3 Future outlook

The PREPARED work and the additional local study by Leunk (2011) have increased awareness on the risks of flooding for the drinking water supply, both at Brabant Water and the Water Board. Most of the proposed preventive measures will be taken at well field Klotputten, which is most at risk. Measures include construction of 4 new production wells on mounds, reconstruction of one of the current production wells on a mound, watertight sealing of the remaining 3 production wells, and sealing of the observation wells in the area. It has been agreed that the Water Board will cover for part of the costs associated with these preventive measures as well as the costs involved in restoring the water supply after a river flood. The construction / renovation work is planned for next year (2015).

2.4 References

Leunk, I., C. van Rosmalen, W. Kessels, 2011. Waterberging in een wingebied. Risico's en kosten inundatie pompputten (Eindhoven). KWR 2011.079, KWR Watercycle Research Institute, the Netherlands. (in Dutch)

Rambags, F., K.J. Raat, I. Leunk, G.A. van den Berg, 2011. Flood proof wells. Guidelines for the design and operation of water abstraction wells in areas at risk of flooding. PREPARED 2011.007.

3 Sustainable water management with ASR in Eindhoven, the Netherlands

Gerard A. van den Berg (KWR)

Additional reading: *Rambags et al., 2013. Prepared Del. 5.2.2.*

3.1 Background

The Municipality of Eindhoven, as representative of a consortium with Water Board De Dommel and Water Supply Company Brabant Water, is the Dutch Utility partner in PREPARED. The Eindhoven region experiences several water management challenges. Parts of the city of Eindhoven are occasionally flooded due to extensive stormwater flow, in combination with high groundwater levels. In many post-war city districts dewatering facilities have been removed. In addition, since the 1980's the number of industrial groundwater extractions has been decreased. In contrast to flooding during winter months, surrounding rural areas are characterized by water shortage during dry (summer) periods, which may negatively affect agricultural activities and nature.

The planned shutdown of the groundwater extraction at Vredeoord (Eindhoven) will result in additional water stress in part of the city of Eindhoven as groundwater levels will further increase, which results in even less buffer capacity within the groundwater system.
In recent years, the municipality has taken several water management measures such as a reduction of the number of CSO's, decoupling of stormwater drainage from the sewer system, and the construction of drainage sewers. At the same time, agreements have been made with the water supply company to maintain and translocate groundwater extractions for public drinking water supply.

The present day water management practice in the Eindhoven area, as well as in many parts of The Netherlands, aims at quickly draining the excess stormwater through the surface water system to the main rivers (in Eindhoven the Dommel, a tributary of the river Meuse) and, eventually, the North Sea. This, however, also results in a low groundwater recharge in surrounding areas and potential water shortages during periods of droughts. To increase sustainability and to actively adapt to climate change, especially adapting to longer and heavier rainfall periods, water managers aim at realizing a transition into active water storage within the region, thus promoting a more sustainable and robust water system which is better equipped to face water stress. A possible option would be infiltration of WWTP effluent after periods of heavy rainfall and drainage water (Vredeoord groundwater) in the periphery of the city. Water quality monitoring may determine the need for additional treatment (e.g. active carbon) to reduce potentially present pesticides in WWTP effluent during heavy rainfall periods.

At the location Vredeoord groundwater is extracted when groundwater levels exceed certain levels. After aeration and sand-filtration this water is discharged into the surface water system. Figure 3-1 shows that in recent years groundwater extraction is minimal during summer months. The present water quality after treatment allows infiltration, but some soil contamination sources in the intake area of the extraction need attention.

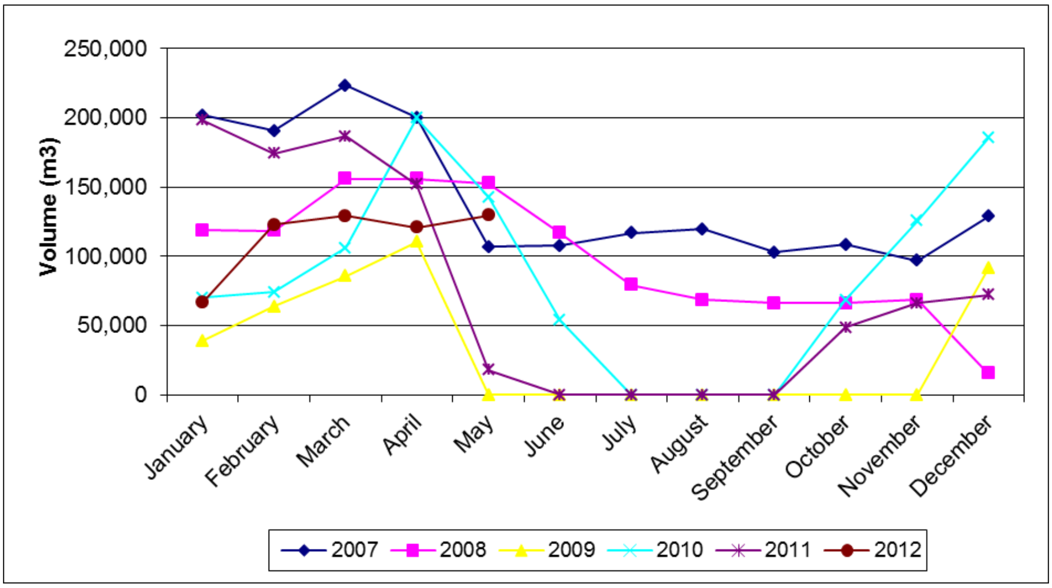

Figure 3-1 Monthly volumes of extracted groundwater at Vredeoord

3.2 PREPARED results put into practice

Stakeholders in the region (Municipality of Eindhoven, Water Board De Dommel, Water Supply Company Brabant Water and Province of Noord-Brabant) have initiated the demonstration case 'Water voor het Groene Woud'. This demonstration aims at a more sustainable use of excess stormwater in the city of Eindhoven by temporary storage in the subsurface with the aim to reduce drought effects. Main advantages of the approach to temporarily store water in subsurface aquifers are:

- Realisation of flexibility between periods of water shortages and periods of excess water, thus balancing water demand and water availability
- A reduction in the surface area needed for storing water aboveground
- Use of the natural capacity of the subsurface to store water
- A decrease of the risks for urban water problems, such as water on the streets, in cellars and tunnels
- The potential to combine climate goals with ecologic objectives in the broader region surrounding the city of Eindhoven including the Groene Woud area.

The demonstration will be carried out in three stages:

- Stage 1: initial stage (2012/2013)
- Stage 2: pilot, including monitoring (2014/2015)
- Stage 3: full scale application (2016)

During the PREPARED project, stage 1 activities have been carried out. The views of the different stakeholders have been defined, as well as their common ambition. In addition, for the successful implementation of the pilot (stage 2) and the full scale application (stage 3), support for the concept has been realized at representatives of agriculture, nature conservation, and cities and municipalities in the region. A preliminary business case has been developed.

The success of the demonstration depends on alignment with other initiatives and projects in the area. In this perspective, the Dutch national initiative 'Deltaplan Hoge Zandgronden' also aims at achieving a balance between water demand and water availability, taking into account effects of climate change, which may result in changing precipitation patterns and longer periods with water shortage, by implementation of best practices.

A management memorandum was prepared and provided to the Steering Group 'Deltaprogramma Hoge Zandgronden' with the aim to (1) inform the Steering Group on the initiatives in the Eindhoven region and to (2) ask the Steering Group to earmark these initiatives as innovation with high potential for the implementation of the 'Deltaprogramma Hoge Zandgronden'. Implementation of the initiative should result in a reliable, sustainable, climate proof and flexible water system in the region of Eindhoven that encourages an efficient economy, a better living environment and promotes innovation in the region in line with the development of Brainport Eindhoven Region. The added value of this innovative approach consists of:

- A flexible and sustainable water system (both in terms of water quantity and water quality)
- A more comfortable living environment, especially in the urban environment
- A more robust groundwater system that supports the production of drinking water
- A flexible approach to achieve the provincial nature goals for the Groene Woud area.

3.3 Future outlook

The final outcome of the pilot stage will be a closed business case that describes the combinations of functions (water storage, ecology) an analysis of effects, as well as co-ownership. The business case will be the formal product for a go/no go decision at management level. Stage 2 will consist of a concrete pilot in a distinct area. After another go/no go moment further broadening and best practice to common practice will take place.

3.4 References

Rambags, F., K.J. Raat, K.G. Zuurbier, G.A. van den Berg and N. Hartog, 2013. Aquifer Storage and Recovery (ASR). Design and operational experiences for water storage through wells. PREPARED 2013.016, 40pp.

4 Adapting water treatment to severe droughts and intense rainfall events in the Algarve, Portugal

Maria João Rosa (LNEC), Rui Sancho (Águas do Algarve, SA), Helena Lucas (Águas do Algarve, SA), José Menaia (LNEC)

<u>Additional reading</u>: *Raspati et al., 2013. Prepared Del. 5.2.4/5.2.5.*

4.1 Background

Water utilities face new challenges arising from faster and more severe raw water quality variations promoted by climate change. These are expected to lead to an overall deterioration of the water quality used for drinking water production.

Portugal forms a reference case for the adaptation of drinking water systems to cope with two of the main climate change pressures: severe droughts and intense rainfall events. In particular, the Algarve region, in the south of Portugal,is prone to both these climate extremes (Figure 4-1). The region is well-known for its summer tourism and is one of the most popular golf destinations in the world. Tourism is the most important economic activity, driving a strong seasonal water demand that peaks in summer. The water consumption of the golf industry will equal the water demand of approximately 200,000 residents in the near future.

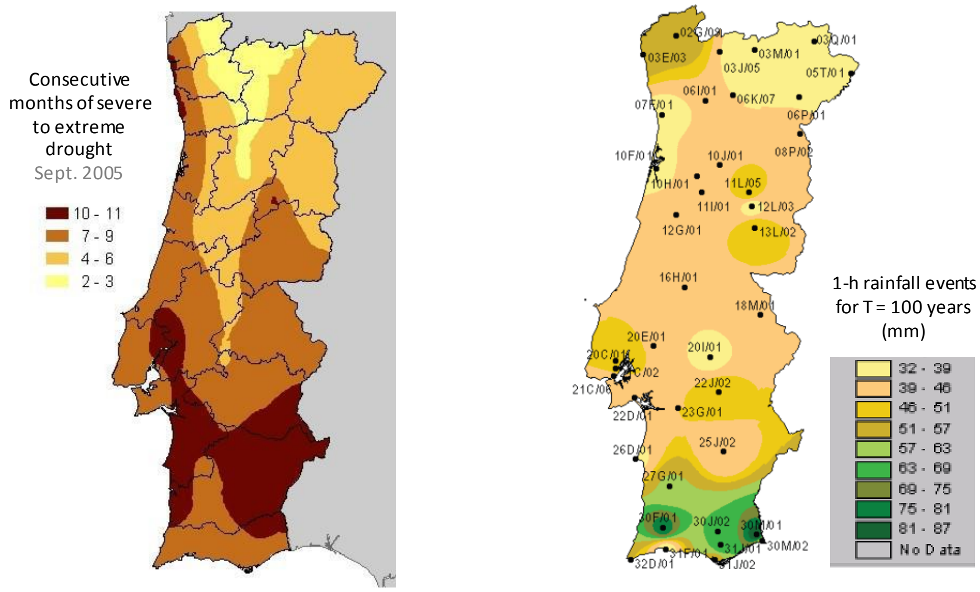

Figure 4-1 Spatial distribution in Portugal of consecutive months of severe to extreme drought during the hydrological year 2004/2005 (MAOTDR et al., 2005) (left) and of 1-h rainfall events for a 100-years return period (Brandão et al., 2001) (right).

The Algarve multi-municipal system currently covers 16 municipalities. Its concessionaire is Águas do Algarve (AdA), and in the high season water is supplied to approximately one million people. Surface water is taken from the reservoirs (dams) Odeleite - Beliche, Funcho (until 2012), Bravura, and Odelouca, which is used since 2012 and which now is the main reservoir. The system includes four water treatment plants (WTPs): Alcantarilha (design capacity of 259,000 m^3 day^{-1}) and Fontaínhas (29,000) in western Algarve; and Tavira (190,000) and Beliche (13,000) in eastern Algarve. The WTPs were designed to treat surface water using conventional treatment of pre-oxidation with ozone (chlorine dioxide at Fontaínhas), remineralization (only in eastern Algarve, where raw waters are very soft), coagulation with polyaluminum chloride and powdered activated carbon (PAC) addition (whenever necessary), flocculation, lamellar sedimentation, rapid sand filtration and final chlorination. To face the strong seasonal demand, the bigger plants have two or three parallel treatment lines.

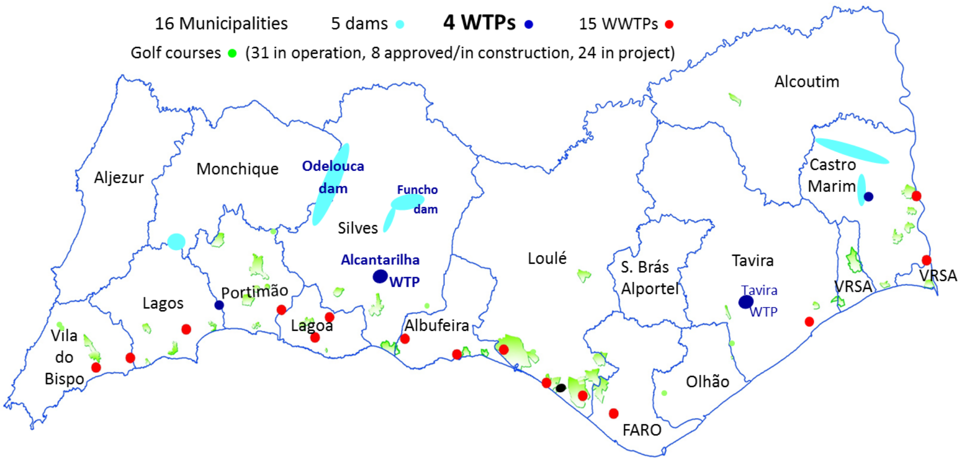

Figure 4-2 The Algarve region and the multi-municipal system (adapted from Freire, 2010)

Fast and severe raw water quality changes are an important issue in the Algarve. Seasonal variations result in two major raw water qualities at Alcantarilha WTP: clear waters (1-6 NTU) and turbid waters (25-40 NTU, sometimes up to 1000 NTU). Increases in turbidity usually occur after intense rainfall periods (winter and autumn) or are related with particle re-suspension in the WTP effluent main, due to the increase in flow rates to fulfil the water demand during the high season (June-July). High turbidities give rise to high organic carbon contents. On top of these seasonal variations, periods of severe drought, such as in 2004/2005 (Figure 4-1) and 2012, put extra pressure on the water supply in the region.

These issues prompted the preparation of a Contingency Plan for the Algarve multi-municipal system. This plan was compiled in addition to the Action Plan establishing measures and investments to reinforce of Algarve's water supply capacity.

4.2 PREPARED results put into practice

A WTP management protocol was put into practice following a 3-level strategy to ensure a safe water supply:

Level 1: (A) Optimisation of WTP unit operations and processes, and (B) identification of the limiting steps (*e.g.*, the recirculation of sludge treatment streams) and operating conditions (type and dose of oxidants, coagulants, flocculants and PAC) for controlling the identified hazards.

A novel performance assessment system was used for benchmarking the water treatment, i.e. for promoting the continuous improvement of its performance in terms of effectiveness, reliability and efficiency. For instance, the most cost-effective immediate measure to mitigate drought effects in western Algarve (before construction of the Odelouca dam in 2012) was to reactivate groundwater abstraction from the municipal wells. This required Alcantarilha WTP to adapt to different types of raw water, namely mixtures of surface and groundwater and 100% groundwater. While the lower microbial loads and NOM concentration in the groundwater made the water treatment easier, bromide concentration and the water turbidity/alkalinity challenged the pre-ozonation and the coagulation, flocculation and sand filtration steps, and required fine-tuning of the chemical dosing for successful control of bromate formation and residual turbidity and aluminium.

Level 2: Development of studies for WTP upgrade in case the monitoring program indicates limited results of Step 1 strategy.

One may expect limited performance of the conventional treatment with pre-ozonation and PAC adsorption if the occurrence of the above mentioned hazardous substances becomes frequent. In this case, it may become necessaryto apply complementary and advanced technologies such as dissolved air flotation for cyanobacteria removal; ultrafiltration for particles removal (including bacteria and protozoan cysts, virus and cyanobacterial cells); and, for further removal of low molecular weight organics (including toxins and THM precursors), PAC/ultrafiltration, nanofiltration, granular activated carbon (GAC) adsorption, and GAC filters with controlled biological activity.

Level 3: A contingency plan was developed listing the management procedures "how to act" whenever the monitoring program would indicate that the treated water is not safe for human supply. This plan includes instructions to interrupt Alcantarilha's WTP production and to manage an alternative supply water system using water produced in other plants, which use different surface water and/or groundwater sources. This option is less relevant since the year 2012, after the Odelouca dam.

4.3 Future outlook

Many utilities rely on conventional surface water treatment assisted by ozonation and PAC adsorption. Increased oxidation may enhance disinfection and the breakdown of micro-pollutants, however, it may also lead to increased formation of disinfection by-product (DBP) with adverse health effects. Hence, special care must be taken to ensure a safe disinfection and control of micro-pollutants while minimizing DBP formation.

The ability to rapidly detect water quality changes that lead to risk is a key-issue for deciding and implementing the adequate preventive and corrective actions. This will require pro-active measures to identify (1) changes in quantity and quality of water resources, and (2) the impact of raw water quality changes in the produced water quality.

Pro-active measures to identify changes in quantity and quality of water resources:

- Anticipating the water source pollution – modeling intense rainfall events (frequency and intensity), runoffs and droughts;
- Characterizing the water source pollution – monitoring (volume and water quality parameters) of intense rainfall events and wastewater discharges in the watershed;
- Characterizing the source water availability and quality – modelling the water quality in different scenarios;
- Regular monitoring/inspection of the source water quality – visual inspection, e.g. of water scums, turbidity and colour, including as much as possible parameters of rapid determination for early warning of quality changes requiring treatment adaptation (e.g. cyanobacterial blooms, muddy and clay waters);

Pro-active measures to identify the impact of raw water quality changes in the produced water quality:

- Monitoring the critical treatment steps' effectiveness and efficiency, using as much as possible reliable online measurements;
- Modeling WTP response to raw water quality changes.

4.4 References

Brandão, C., R. Rodrigues, J.P. Costa, 2001. *Análise de Fenómenos Extremos. Precipitações Intensas em Portugal Continental*. Direcção dos Serviços de Recursos Hídricos. Lisbon, Portugal (in Portuguese).

Freire, J., 2010. Plans for bulk supply of TWW for golf course and landscape irrigation in the Algarve region. *Workshop on treated wastewater use in Portugal.* Lisbon, October 13, 2010.

MAOTDR, MCTES, MADRP AND MAI (2005) *Drought in Continental Portugal. 31st December 2005*. Inter-ministerial technical group final report to the Ministries Council. RCM 83/2005, art.º 8. Ministry of Environment, Regional Policies and Planning; Ministry of Science, Technology and Higher Education; Ministry of Agriculture, Rural

Development and Fisheries; Ministry of Interior. Lisbon (in Portuguese).
Raspati, G., J. Menaia, K.J. Raat, M. João Rosa, B. De La Loma González, E. Sivertsen, 2013. Assessment of current treatment works to handle climate change related pollutants and options to make current multi-barrier systems climate change proof. PREPARED 2013.020.

5 Adaptations to the multibarrier treatment at Norrvatten, Sweden

Bjørnar Eikebrokk (SINTEF), Edvard Sivertsen (SINTEF)

Additional reading: *Raspati et al., 2013. Prepared Del. 5.2.4/5.2.5. Smeets et al., 2013. Prepared Del. 5.5.2*

5.1 Background

Climate change will impact water supply systems by altering source water availability and quality, and reducing the reliability of infrastructures. Water treatment facilities will face increased water temperatures, increased NOM concentrations (cf. Figure 5-1), increment in turbidity, taste and odour compounds, problems associated with algae, increased microbial loads in source water and faster and more severe raw water quality changes. In order to cope with these challenges water treatment facilities may need optimization of existing technologies, introduction of supplementary treatment step and even replacement of existing treatment step(s).

The key to ensure clean, safe and reliable drinking water is to understand the drinking water supply from the source all the way to the consumer's tap. This knowledge includes understanding the general characteristics of the water source and the surrounding catchments, as well as identifying all real and potential threats to the water quality. The multi-barrier approach takes all possible threats into account and makes sure there are sufficient "barriers" in place to either eliminate them or minimize their impacts. Multi-barrier approach includes selecting the best available source and protecting it from contamination, using effective water treatment, and preventing water quality deterioration in the distribution system. The approach recognizes that while each individual barrier may not be able to completely remove or prevent contamination, and therefore protect public health, together the barriers work to provide greater assurance that the water will be safe to drink.

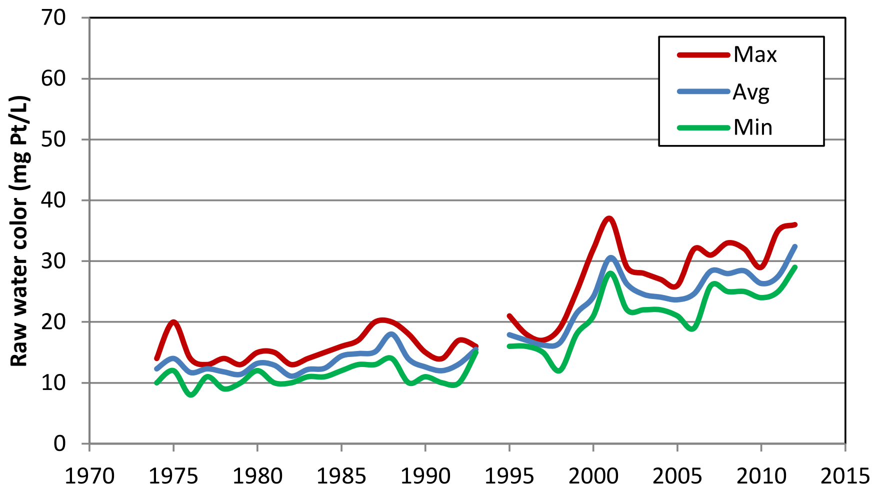

Figure 5-1 A typical example of NOM increase in surface water within the Nordic region (Eikebrokk, 2012).

5.2 PREPARED results put into practice

In the following a supplementary example from Norrvatten in Sweden is presented, clearly demonstrating the need for adaption to climate change and the interaction effects between different treatment steps.

Norrvatten in Sweden is a treatment facility supplying the northern part of Stockholm. Water treatment includes coagulation, sedimentation, rapid filtration, granular activated carbon (GAC) filtration, UV disinfection and chlorination. The GAC filters were installed as a barrier against chemicals like micro pollutants and petroleum spills from the heavy boat traffic on Lake Mälaren.

However, due to a significant increase in NOM in recent years, the coagulation and separation (sedimentation and filtration) processes are no longer capable of removing NOM down to acceptable levels. As a result, the capacity of the downstream GAC filters is rapidly exhausted by the increased NOM load. These effects are ascribed to the pore blockage ability and high affinity for AC adsorption sites from the large and reactive NOM molecules. Thus, from a practical and economic point-of-view, quite unrealistic regeneration frequencies are required in order to maintain GAC filtration as an effective barrier against chemical spills. In addition, there are significant environmental aspects of the high regeneration frequencies.

The treatment facility needs adaption to the increased NOM load in order to restore the necessary barriers. A pilot scale nanofiltration (NF) treatment step has been installed prior to the GAC filters in order to reduce the NOM concentration to acceptable levels. Experiments so far have shown a significant reduction in the NOM concentration as a result of the NF treatment.

5.3 Future outlook

In order to decrease the NOM (DOC) concentration levels and to restore the subsequent GAC filter as an efficient barrier against micro pollutants and petroleum spills, an additional NF treatment step prior to the AC filter has been proven to be a viable option. The next steps for the treatment facility will be to finalize the optimization of the NF process using the NF pilot plant and to start preparation of the installation of a full sized NF plant. The decision whether to install a NF plant or not is expected to be made in 2014.

5.4 References

Raspati, G., J. Menaia, K.J. Raat, M. João Rosa, B. De La Loma González, E. Sivertsen, 2013. Assessment of current treatment works to handle climate change related pollutants and options to make current multi-barrier systems climate change proof. PREPARED 2013.020.

Smeets, P., (ed), E. Mesquita, M. João Rosa, J. Menaia, E. Kardinaal, B. Eikebrokk, 2013. Adapted operation of drinking water systems to cope with climate change. PREPARED 2013.047.

6 NOM removal in Oset water treatment plant, Oslo, Norway

Lars J. Hem (Oslo VAV), Edvard Sivertsen (SINTEF)

Additional reading: *Raspati et al., 2013. Prepared Del. 5.2.4/5.2.5; Eikebrokk et al., 2013. Prepared Del. 5.2.6.*

6.1 Background

Climate change will result in increasing NOM concentration in many of Europe's surface waters. One of the impacts of increased NOM content is increased soft deposits, biofilm formation and regrowth in distribution systems. This increases the risk that pathogenic micro-organisms survive in the distribution system, posing a threat to a secure water supply.

Optimization of existing WTPs generally is the most cost-efficient strategy and should thus be the first step towards adaptation of water treatment systems to increased NOM concentrations. The next option may include assessments of the need for supplementary treatment steps, such as coagulation with subsequent filtration or nanofiltration. Replacement of the treatment technology should be viewed as the last resort if the above means fail or are inadequate.Further, it is not only the increasing NOM concentration levels that may impacts on treatment. NOM composition and thus its treatability and biodegradability may also change. Therefore, NOM characterization and treatability assessments are also required in order to identify best available technologies and best available operations.

6.2 PREPARED results put into practice

In 2009, Oslo municipality put the new Oset water treatment plant in operation including coagulation, sedimentation and filtration followed by UV disinfection. The old treatment plant had only 5 µm micro-straining and chlorination. In 2006, the presence of moulds with possible health effects was detected in the treated water. In PREPARED, Oslo VAV wanted performed a study of the effect of the new treatment on the quantitative and qualitative biofilm formation, the latter with focus on moulds and opportunistic pathogenic bacteria. The methodology included analyses of biodegradable organic carbon, biofilm monitoring and micro-biological analyses of the biofilm in raw water, filtered water, treated water and distributed water.

The results from the biofilm monitoring showed a 95-99 % reduction in biofilm formation as a result of the NOM removal in the new treatment plant (Figure 6-1 and Figure 6-2). Further, the biofilm formation was almost constant in the distribution system. Moulds were present with large amounts in biofilms grown in raw water, but occasional in filtered water, finally treated water or during distribution. Some opportunistic pathogenic bacteria were identified in the raw water, but not in filtered water. The results showed that the NOM removal also removed moulds and most opportunistic bacteria as well as reduced the content of biodegradable organic matter to a level where these micro-organisms did not grow in the network. However, *Legionella* was detected in biofilms from raw water, filtered water and during distribution.

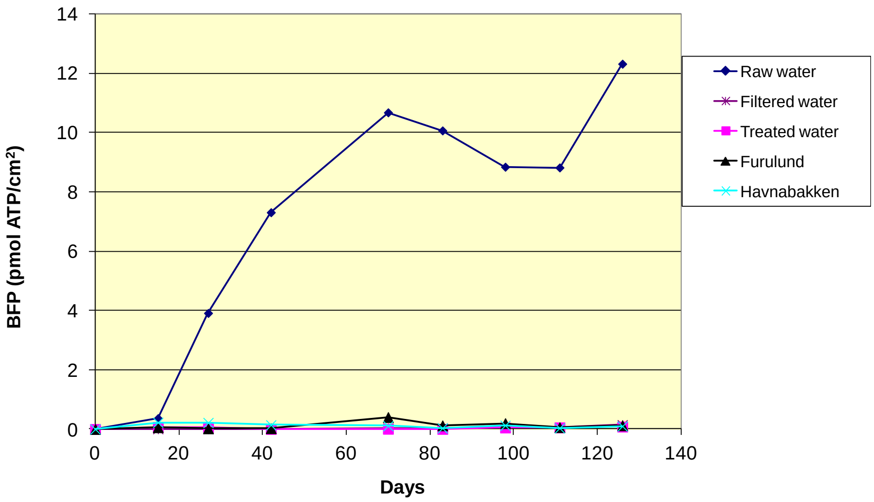

Figure 6-1 Biofilm formation in water after various treatments at the Oset plant

Figure 6-2 The effect of NOM removal on the biofilm formation: biofilm grown in raw water (left) and in filtered water (right)

The demonstration concluded that the NOM removal by coagulation, sedimentation and filtration was the main reason for the reduction in biofilm formation and the absence of moulds and most analysed opportunistic bacteria.

6.3 Future outlook

Facing a situation with increasing NOM concentration in source waters, and hence increased possibility for biofilm formation, treatment process optimization and implementation of best operation practice is a natural first step in order to remove the increased NOM load. The need for supplementary treatment steps and replacement of the treatment technology is the next steps. The above-mentioned deliverables have demonstrated the effect of NOM removal on biofilm formation and have developed guidelines ready for use in how to meet increasing NOM concentration in source waters.

In Oslo, the planning of both new water treatment plants and a new supplementary raw water source has started. NOM removal will be required for the new plants and the following alternatives are considered: coagulation and filtration; ozonation and biofiltration; and nanofiltration. The different treatment processes have different effects on the various parts of the NOM. The results from PREPARED are important in this work by showing the effect of chosen treatment on the biofilm formation in the network. The effect of the NOM removal process on the biofilm formation will be one of the parameters taken into consideration for the process selection even though this may require prolonged pilot studies and some of the analyses performed in PREPARED.

6.4 References

Raspati, G., J. Menaia, K.J. Raat, M. João Rosa, B. De La Loma González, E. Sivertsen, 2013. Assessment of current treatment works to handle climate change related pollutants and options to make current multi-barrier systems climate change proof. PREPARED 2013.020.

Eikebrokk, B., L.J. Hem, L. Monteiro, J. Menaia, S. Grobe, J. Wagner, G. Schaule, 2013. Remedial actions to prevent adverse effects of re-growth in networks at higher temperatures. PREPARED 2013.035.

7 Adapting chlorine residual modelling to Lisbon drinking water temperature and NOM

Laura Monteiro, José Menaia (LNEC)

Additional reading: *Dias et al., 2014. Prepared Del. 1.2.8; Eikebrokk et al., 2013. Prepared Del. 5.2.6; Smeets et al., 2013. Prepared Del. 5.5.2*

7.1 Background

As most water utilities worldwide, the Lisbon drinking water distribution system (DWDS) utilizes chlorine residual as a last barrier against microbial hazards. There, chlorine must be at the levels required for effective disinfection, but these should be as low as possible to minimize the formation of toxic disinfection by-products, as well as taste and odour. However, chlorine concentration decays as the water travels throughout DWDS. Hence, modelling and predicting the evolution of chlorine concentration in DWDS is crucial to manage the disinfectant levels within the required limits. However, in addition to uncertainties in the supporting hydraulic simulation, the precision of chlorine residual modelling largely depends on the accuracy of the used bulk decay kinetics and rate coefficients. The latter are commonly determined in the laboratory for a given temperature and not accounting for variations in the water´s composition, namely its NOM contents. Since chlorine mostly decays by reacting with NOM at rates that depend strongly on temperature and involved reactants (i.e. NOM), such practice often leads to inaccuracies in the modelling of chlorine residual. It is likely that such inaccuracies will become particularly critical in the present and forecasted climate change circumstances, in which increases and/or variations in DWDS water temperature and NOM are expected.

7.2 PREPARED results put into practice

With the aim at supporting the distributed disinfection control demonstration studies on the Lisbon DWDS the decay of chlorine residual as influenced by DWDS water temperature and NOM was studied for waters with different NOM levels and makeup (reported by Dias et al., 2014). Studies covered water temperatures from 5ºC to 30ºC.

As Figure 7-1 illustrates, temperature influenced significantly the reaction rate coefficient of chlorine bulk decay (kb) in the tested waters. In addition, temperature influences on kb followed the Arrhenius relationship. However, as it is detailed in D5.2.6, the intensity of temperature increment effects was dissimilar among tested waters, presumably reflecting differences in the nature of their NOM. However, as such differences could not be related with measurable water NOM characteristics, namely SUVA. Therefore, results support the two main conclusions:

1. DWDS chlorine decay rate coefficients (kb) depend on the water´s temperature according to the Arrhenius law;
2. The intensity of such temperature effect may vary with the concentration and characteristics of the waters' NOM.

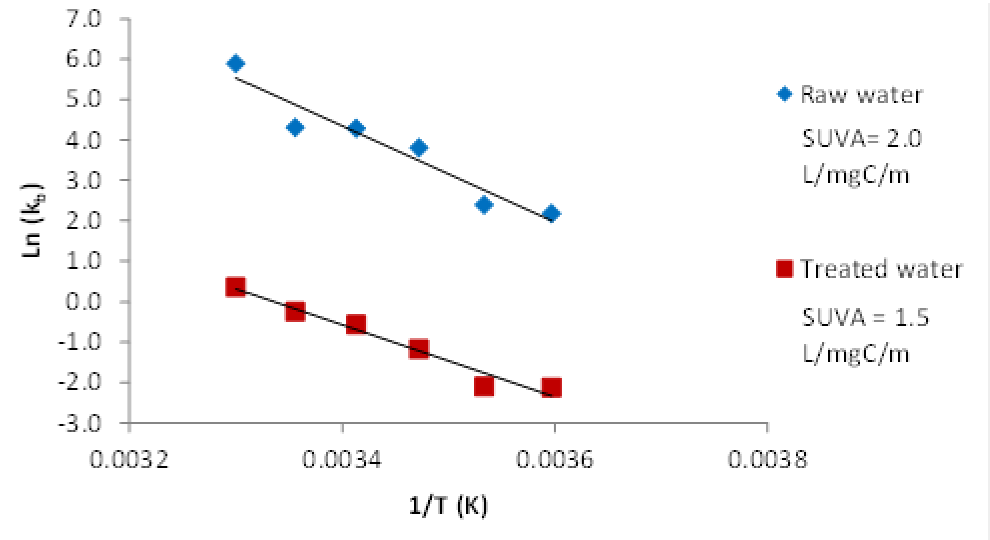

Figure 7-1 Arrhenius plot showing the influence of temperature on chlorine bulk decay coefficients

Accordingly, in order to reduce uncertainties in the modelling of chlorine residual in DWDS, the used kb values need to reflect the water temperature and reactivity against chlorine.For this purpose, whenever no significant changes occur in the DWDS water composition, a temperature adjustment factor can be found for kb by determining decay coefficients in water at pertinent temperatures and fitting them to an Arrhenius plot (Eikebrokk et al., 2013). However, such procedure needs to be repeated every time changes in DWDS water composition occur, principally with respect to its NOM levels and/or makeup.

The Lisbon-Demo activities could not be developed to the point of allowing the full demonstration and practical application of this approach (Dias et al., 2014). However, the Lisbon drinking water utility, which has closely followed the development of the research reported by Eikebrokk et al. (2013), is aware of the usefulness and methodology for determining chlorine decay coefficients for waters with varying temperature and NOM.Its application will allow the utility to reduce uncertainties in the modelling of chlorine residual in the Lisbon DWDS. Accordingly, the use of PREPARED results will improve the utility's capability to handle climate change driven variations in DWDS water composition.

7.3 Future outlook

Owing to the widespread use of chlorine as disinfectant residual, drinking water utilities may take profit of the herein outlined methodologies and guidance, worldwide. While it still needs to be demonstrated, given the similarities between the DWDS chlorine consumption mechanisms and those of other chemicals used as disinfectant residuals (i.e. monochloramine, chlorine dioxide), it is likely that such methodologies and guidance will also apply to the modelling of those alternative disinfectants. Accordingly, the implementation of PREPARED results concerning the influence of temperature and NOM on chlorine decay may have a wide-ranging usefulness for the modelling and management of DWDS disinfectant residual. Such approach is relevant for the control of DWDS water quality and safety, particularly in the present climate change circumstances.

7.4 References

Dias, N., A. Donnelly, L. Monteiro, A. Poças, J. Menaia, 2014. Demonstration of early warning and distributed disinfection control for water distribution network in Lisbon - Demonstration Report. PREPARED 2014.009.

Eikebrokk, B., L.J. Hem, L. Monteiro, J. Menaia, S. Grobe, J. Wagner, G. Schaule, 2013. Remedial actions to prevent adverse effects of re-growth in networks at higher temperatures. PREPARED 2013.035.

Smeets, P., (ed), E. Mesquita, M. João Rosa, J. Menaia, E. Kardinaal, B. Eikebrokk, 2013. Adapted operation of drinking water systems to cope with climate change. PREPARED 2013.047.