SYNERGIES WITH TECHNOLOGIES

DRINKING & WASTE WATER

The most important technologies in the context of ANCS are sensor technologies, particularly sensors that use different types of communication systems (such as fieldbus or OPC). They are necessary for implementing ANCS, but they can also be improved by the technology of ANN. Virtual analysers, a device that calculates virtual signals based on simple and robust measurements and can thus substitute laboratory measurements, are particularly interesting for signals that are expensive to produce via analytics such as the biological or chemical oxygen demand (BOD/COD). From substitute signals that correlate (non-linearly) with the needed signal, estimations can be calculated within the ANN that are often more precise than the laboratory analytics.

CASE STUDIES

OPTIMISATION OF THE BIOLOGICAL TREATMENT STEP FOR THE WASTE WATER TREATMENT PLANT (WWTP) COLOGNE, STAMMHEIM

The WWTP Cologne Stammheim is one of the largest sewage treatment plants in Germany with a capacity of 1.3mn population equivalents. The plant treats a mixture of urban and industrial sewage. The biological treatment stage consists of high-load sludge activation, intermediate clarifiers, low-load aeration and biological treatment. The nitrogen removal is carried out via the pre-denitrification method in the low-load activation by pressure ventilation. Light load activation and biological treatment are situated in basins each with different boundary conditions.

The optimisation task

Low-load activation and final sedimentation were selected for optimisation. The optimisation strategy targets the control variables, including air, re-circulation volume flow, and precipitant agent dosage. The operating condition should be attuned such that the minimal use of the respective resources (energy, chemicals) is achieved. For this task, an ANCS was implemented aligned to the local conditions. As a special function, a simulator was programmed to test "what-if" scenarios with the possibility to manually enter values for the mentioned control variables.

Results

The optimisation yielded 15% energy savings for the WWTP under dry weather conditions. Under stormy weather conditions, the optimisation strategy was switched to complying with limiting values (regardless of energy consumption).

IWaNET – INTELLIGENT WATER NETWORK: LEAKAGE DETECTION IN THE WATER SUPPLY NETWORK IN BELM, GERMANY

The municipal utilities (Gemeindewerke) Belm operate a comparatively small distribution network for drinking water. The total length of the network is 110 km, stretching over 10 x 8km with the annual water supply at about 0.72mn m^3. 3,600 households with about 14,000 inhabitants are supplied by the system. Central water supply systems have complex requirements for operational monitoring and optimised operation control as they need to ensure:

- the supply of high quality drinking water with sufficient pressure and amount at each sampling point
- the energetically optimal operation of the entire system, and
- the control of incidents to ensure high customer satisfaction with high customer confidence. Monitoring the entire system at all times is currently impossible, and thus requires a new approach.

The optimization task

The reaction of the system at several sampling points can be used as a basis for approximating the behaviour of the whole system. Therefore, the implemented ANCS uses monitoring data of few sampling points for the simulation of and optimisation recommendations for the operation of the water supply network.

Results

The IWaNet system is able to indicate, which incidents and failures are likely to occur. When applied first, the system was able to detect a leakage and to localise it within few hundred meters with limited information on pressure and throughput. The system warns the user before user-set thresholds will be exceeded. It is possible to achieve optimisation of the processes with regards to energy consumption.

http://demeau-fp7.eu/

BARRIERS AND SOLUTIONS

OPPORTUNITIES FOR UPTAKE

- **Upscaling**: Membrane filtration processes show very reproducible behaviour. Therefore, experiences derived from research projects such as DEMEAU support the application of the ANN approach to a diverse range of sizes of (drinking) water treatment plants.
- **Process optimisation**: The implementation of ANN in established membrane filtration processes can enhance process productivity between 4–15%. Among existing membrane filtration plants in Europe, there is a large potential to achieve increased environmental and economic sustainability.
- **Flexibility**: As ANN are applicable to many different technology set-ups, the opportunities for uptake are diverse.

BARRIERS TO UPTAKE

- **Legal and/or regulatory barriers**: Drinking water companies must comply with the Drinking Water Directive by ensuring that the water quality of the treated drinking water fulfils the requirements of the directive. The ANN technology supports company compliance with standards, as the system continuously monitors and steers the process based on current environmental data provided.
- **Economic barriers**: The size of the plant for ANN application determines the return on investment; larger plants are hence more cost efficient than smaller plants. The potential impact of ANN application can be estimated accurately and cases for a reasonable investment (e.g. with regards to the projected payback period) can be determined in advance.
- **Maintenance**: Optimisation is a long-term task and models tend to become outdated, particularly when living (biological) systems are involved. Therefore, maintenance is an important aspect to consider as part of ANN implementation. The systems require so called "re-trainings". Re-trainings can be pursued either by aquatune, the operator or automatically by the system itself. The solution applied depends on several technical and economic parameters. aquatune offers attractive service level agreements that cover all possible options for ensuring ongoing maintenance.

WW Roetgen with the worldwide largest two-stage UF: 1st stage for drinking water production (X-Flow, 7,000 m^3/h)

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DEMEAU

DEMONSTRATION OF PROMISING TECHNOLOGIES TO ADDRESS EMERGING POLLUTANTS IN WATER AND WASTE WATER

ANCS

AUTOMATIC NEURAL NET CONTROL SYSTEMS

WW Roetgen with the worldwide largest two-stage UF: 2nd stage: backwash water treatment (Multibore®, 630 m^3/h)

Artificial Neural Networks and Genetic Algorithms can make a significant contribution to energy and economic optimization of operating water treatment plants. According to the current state of the art, control and regulation of plants is based mostly on simple concepts such as switches with a fixed time interval or based on the achievement of set limits (e.g. pressure values). The energy costs caused by the operation may be significantly higher than necessary.

PREDICTING TARGETS WITH ARTIFICIAL NEURAL NETWORKS

Many process variables, such as the permeability of a membrane for the treatment of drinking water, depend in a complex manner on many different parameters. The Artificial Neural Networks (ANN) technology allows the prediction of such process variables. Based on those predictions, procedurally and economically optimal settings of the process can be determined.

CALCULATION OF OPTIMAL SETTINGS FOR PROCESS VARIABLES WITH GENETIC ALGORITHMS

The search for an optimum solution is extremely complex due to the high number of effects that simultaneously affect process quality and efficiency. For such situations, genetic algorithms, which were developed based on natural functionalities, have proven their effectiveness. The DEMEAU project, financed within the 7th Framework Programme for Research and Technological Development of the European Union (FP7), demonstrated possibilities for savings in the operation of a membrane water treatment plant.

ecologic · WAG · aquatune · IWW

This project has received funding from the European Union's Seventh Framework Programme for Research, Technological Development and Demonstration under the Grant Agreement no. 308339.

INTRODUCTION

Artificial Neural Networks (ANN), a technology based on observations of the human brain, has become increasingly important in the operation of drinking water plants or waste water treatment facilities. Over the last sixty years, scientists have advanced simple mathematical models to powerful software tools that cannot only "learn from data" but also deal with nonlinearity. The greatest advantage of ANN is precisely its ability to learn and therefore develop on solutions to problems. ANN works in combination with an algorithm that seeks the best process configuration. The two components together are called Automatic Neural Net Control Systems (ANCS).

AUTOMATED NEURAL NET CONTROL SYSTEMS TO OPTIMISE WATER TREATMENT PLANTS

Primarily, ANCS is a computer-based system searching for process optimisation that is fed with input signals from a technical process, such as for example the sensor-data of a drinking water plant. In this way, the ANCS uses input information to determine the optimal performance of the process. In the case of a drinking water plant, such a process could be a membrane filtration process, where the system aims to optimise its target parameters. Parameters can include permeability, energy consumption, or cost efficiency, for example. The ANN, which effectively consists of calculation patterns, describes how input signals derived from a sensor are transformed into output data (Figure 1). During the learning phase, the output data is compared with measured output values to calibrate the ANN. The technology connects causes to effects using its algorithm-changes in input signals cause therefore changes in the output (target) signals, mapped by the ANN. Once the

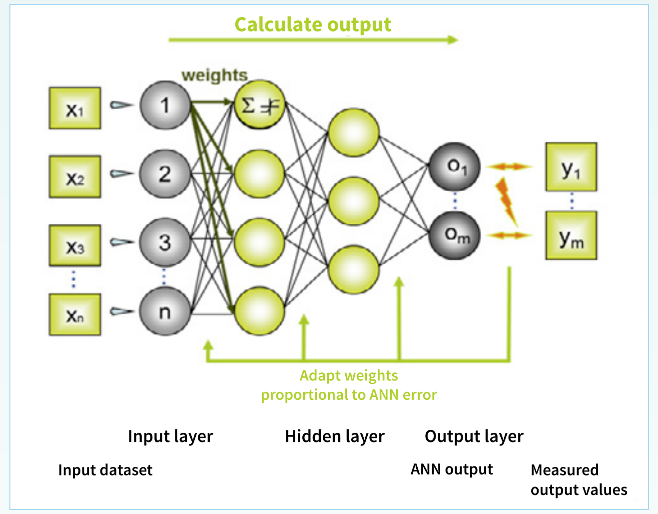


Figure 1: *ANN-Structure: Mapping of input data (e.g. flux, temperature, pH) to target data (permeability, efficiency)*

system is mature, its predictions are used within an optimisation algorithm to find optimal settings for the process parameters. ANCS was developed during the EU LIFE funded project "Purifast".

AUTOMATED NEURAL NET CONTROL SYSTEMS APPLIED TO FILTRATION PROCESSES

The membrane filtration process consists of altering periods of filtration and backwashing. The overall process performance is dependent upon the quality of the raw water and the various settings of operating parameters. Process data obtained from a completed filtration cycle is utilised to identify the optimal operative settings for the subsequent cycle.

Membrane permeability represents as the only parameter the effectiveness of the filtration and backwash cycle. Constantly high membrane permeability indicates high yield conditions as well as the absence of irreversible membrane fouling. For both filtration and backwashing, operational conditions and physicochemical processes are essentially different. Therefore, two specialized ANN-models are necessary to reproduce and predict the filtration process effectively. Those individually trained models are recombined to build a composite model, which can be considered as a single ANN structure that still provides two output parameters.

By applying ANCS membrane filtration, process performance stability is maintained by applying optimally adjusted operation parameters. The optimisation is based on the assumption that the raw water quality encountered during a filtration cycle also applies to the next filtration cycle with significant accuracy.

- Filtration and backwash flux, in addition to filtration and backwash duration, are common parameters to describe the operating status of the filtration plant.
- Water quality parameters that can be used to define the physiochemical raw water composition include: temperature, pH, redox-potential, conductivity and turbidity. The latter may differ from site to site, depending on which type of measurement is provided.

OPTIMISING A TECHNICAL PROCESS FOLLOWING THE RULES OF EVOLUTION: THE GENETIC ALGORITHMS

DEMEAU, a project funded under the 7th Framework Programme for Research and Technological Development of the EU (FP7), is currently working to demonstrate optimisation algorithms, Genetic Algorithms (GA). Genetic Algorithms are inspired by Darwin's evolution theory, in particular by his theory on the survival of the fittest. GA is an efficient way to find an operable solution, which would be a time consuming task when determined conventionally. GA provide solutions for optimisation problems with several variables approximate to mathematically optimal solutions. Possible process settings like throughput or temperature are coded and act within the algorithm as chromosomes.

The GA searches the fittest solution of the optimisation problem within a defined number of generations (rounds of comparison). Chromosomes survive a generation if the setting that they represent delivers better results in the ANN, which represents the system to be optimised, than the respective other chromosome. Throughout the process, the chromosomes are inherited by the next generation or drop out of the process. The functions of mutation and crossover simulate non-linear thinking, adding an additional level of complexity to the selection process. The functions add new features to the process and make GA more efficient. During the optimisation process, many possible operating points can be tested in a very short time to determine the fittest chromosome, and thereby also the optimal system settings within a given parameter range. A diagram of the process is shown in Figure 2.

Using ANN together with a genetic optimisation algorithm, the input parameters are divided into two types of variables, constants (or disturbance) and manipulable, and are then optimised for the problem at hand. For optimisation, a target function is defined and includes the manipulable variables. The manipulable variables can be altered in a fixed range. Therefore, the data range should be selected to lie within the area of training parameters, assuring that no extrapolation is possible. Consideration of logical or operational barriers should be included as barriers for the search area. Each time a greater fitness is generated, the chromosomes are decoded back to the original process settings.

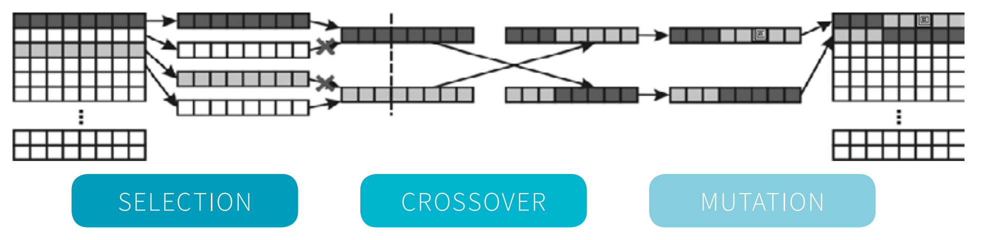
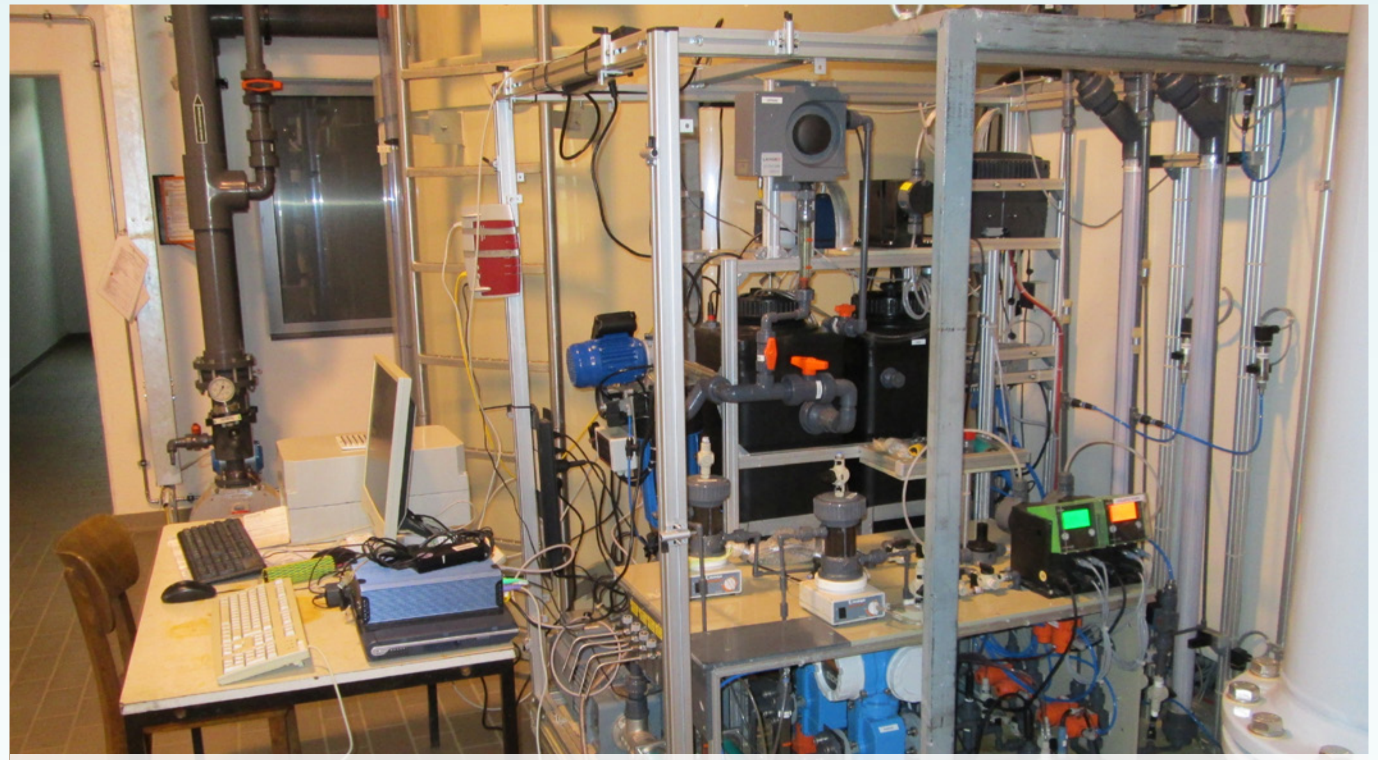


Figure 2: *Adoption of Darwin´s principle of "survival of the fittest" for the search of values for optimal parameter settings (Genetic Algorithms).*



Piloting the backwash water process (Sep. 2014–Feb. 2015) with two treatment lines, UF-modules Lab 1.5 MB 1.0 (Multibore®), membrane area 1m²(small area/full length), capillaries per fiber 7, inner diameter 1.5mm, outer diameter 6.0mm, pore size ca. 0.02µm, material: PESM

ANCS IN PRACTICE

REQUISITE CONDITIONS FOR APPLICATION

- To cost efficiently apply ANN, the process to be controlled or optimised should possess a certain degree of complexity. Processes for which ANN can be applied include the activated sludge reactors of municipal wastewater treatment plants or the purification processes in waterworks. In addition, a minimum production volume needs to be considered. For the average waste water treatment plant, the minimum size is roughly 30.000 population equivalents.
- The advantages of the technology increase with the complexity of the processes controlled and/or optimised. Availability of data is a necessary requisite. However, as modern automation systems require sensor data for correct operation, data availability is usually not a barrier.
- ANCS can be combined with many different systems of measurement as well as control technologies, and thus is very adaptable.

SCALABILITY

- Generally, ANCS can be applied to systems of all sizes. However, the size of the system influences the economic viability as time for the return of investment, shorter for bigger systems, is an important consideration for such an investment.
- The scalability depends on the process and the design of the solution in which ANN are deployed. Processes in wastewater treatment plants are dependent on the functioning of the microorganism colony. As microorganisms show usually a very individual behaviour, every model has to be custom designed. Despite this, it is still possible to scale the overall design principals.
- The filtration process as demonstrated in the DEMEAU project functions with membrane modules whose behaviour is reproducible. Therefore scaling up the results from a pilot plant to the full scale operating plant does not present any major problems. For scaling up, the formulation of the signals used as input and outputs of the model needs to be size-independent.

EXAMPLES FOR URBAN APPLICATION

- Drinking water processing (e.g. dosage of flocculating agents, filtration)
- Drinking water supply (e.g. management of storage tanks, energy recovery with turbines, consumption forecasts, leak detection)
- Control of urban drainage systems
- Waste water treatment (e.g. activated sludge plants, anaerobic reactors, process water treatment)
- Management of digestion towers, biogas plants, dosage of co-substrates

IMPACT

- ANN can be used for multi-parameter control, an important advantage over conventional control algorithms.
- ANN have the ability to tackle non-linear signals. Conventional control and statistics systems are linear systems. This limits their performance in many non-linearly behaving environmental processes.
- ANN can be "trained" on historical process data. This is cost efficient compared to engineered solutions, as training is a machine automated process. As such, ANN offer cost and time savings compared to conventional model based control systems.
- Genetic Algorithms are very efficient in finding solutions, when the search space is very large. This is already the case when the number of controlled variables in the process exceeds 3. For example, for filtration processes, the parameters throughput, filtration time, backwash volume and backwash time need to be optimised in order to minimise the total energy consumption and maintain productivity at 95%.
- Applied in conventional processes, the application of ANN can achieve high cost savings through reduced maintenance costs and lower environmental impact due to savings related to cleansing chemicals. With regards to filtration processes, ANN can decrease the backwash frequency, while simultaneously increasing the productivity of the plant and decreasing the use of chemicals for the backwash process.

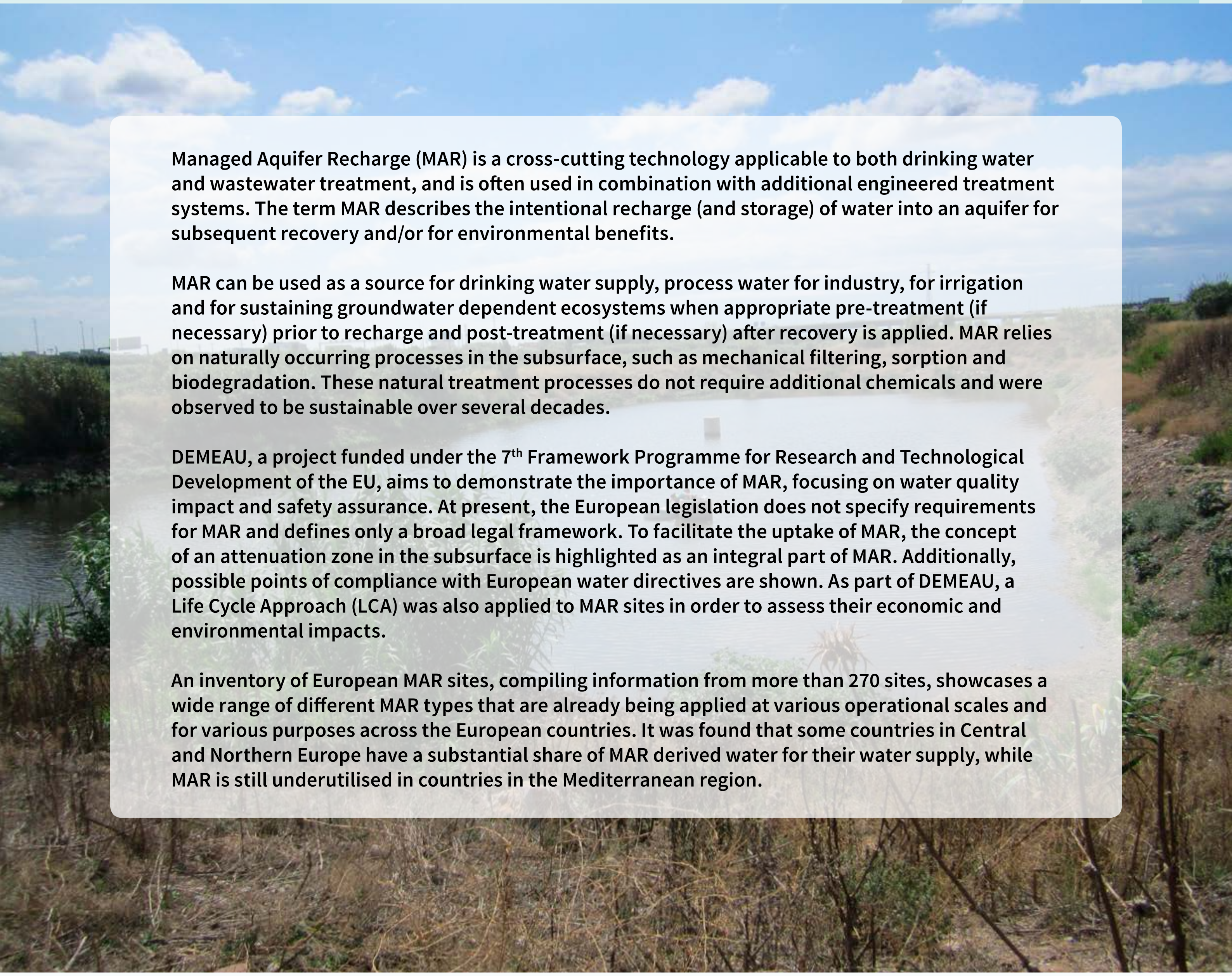
DEMEAU

DEMEAU

DEMONSTRATION OF PROMISING TECHNOLOGIES TO ADDRESS EMERGING POLLUTANTS IN WATER AND WASTE WATER

MANAGING AQUIFER RECHARGE

SUBSURFACE TREATMENT, STORAGE AND RECOVERY



Managed Aquifer Recharge (MAR) is a cross-cutting technology applicable to both drinking water and wastewater treatment, and is often used in combination with additional engineered treatment systems. The term MAR describes the intentional recharge (and storage) of water into an aquifer for subsequent recovery and/or for environmental benefits.

MAR can be used as a source for drinking water supply, process water for industry, for irrigation and for sustaining groundwater dependent ecosystems when appropriate pre-treatment (if necessary) prior to recharge and post-treatment (if necessary) after recovery is applied. MAR relies on naturally occurring processes in the subsurface, such as mechanical filtering, sorption and biodegradation. These natural treatment processes do not require additional chemicals and were observed to be sustainable over several decades.

DEMEAU, a project funded under the 7th Framework Programme for Research and Technological Development of the EU, aims to demonstrate the importance of MAR, focusing on water quality impact and safety assurance. At present, the European legislation does not specify requirements for MAR and defines only a broad legal framework. To facilitate the uptake of MAR, the concept of an attenuation zone in the subsurface is highlighted as an integral part of MAR. Additionally, possible points of compliance with European water directives are shown. As part of DEMEAU, a Life Cycle Approach (LCA) was also applied to MAR sites in order to assess their economic and environmental impacts.

An inventory of European MAR sites, compiling information from more than 270 sites, showcases a wide range of different MAR types that are already being applied at various operational scales and for various purposes across the European countries. It was found that some countries in Central and Northern Europe have a substantial share of MAR derived water for their water supply, while MAR is still underutilised in countries in the Mediterranean region.

This project has received funding from the European Union's Seventh Framework Programme for Research, Technological Development and Demonstration under the Grant Agreement no. 308339.

INTRODUCTION

BACKGROUND

Various MAR types have already been in use for decades. However, in the light of the increasing number of new chemicals entering the water bodies, these natural treatment systems similarly require a reevaluation. MAR has the potential to effectively attenuate a number of undesired substances, including pathogens, thus improving source water quality. However, the complex dynamics of subsurface conditions, such as flow regime and redox conditions make interpretation of contaminant attenuation a daunting task. Ongoing and renewed research of MAR is working to better understand such complexity.

UNDERSTANDING MAR

MAR is used to store and treat water from a variety of sources, including river water, reclaimed water, desalinated seawater, rainwater or even groundwater from other aquifers. As elaborated in *Figure 1*, water from MAR systems can be used as a drinking water, as process water for industry, for irrigation and for sustaining ground-water dependent ecosystems when appropriate pre-treatment (if necessary) prior to recharge and post-treatment (if necessary) after recovery is applied. In addition, the MAR system must be adapted to local hydrogeological conditions, to the water source type and to the required end-use. MAR must also be implemented within the existing legal and water management framework.

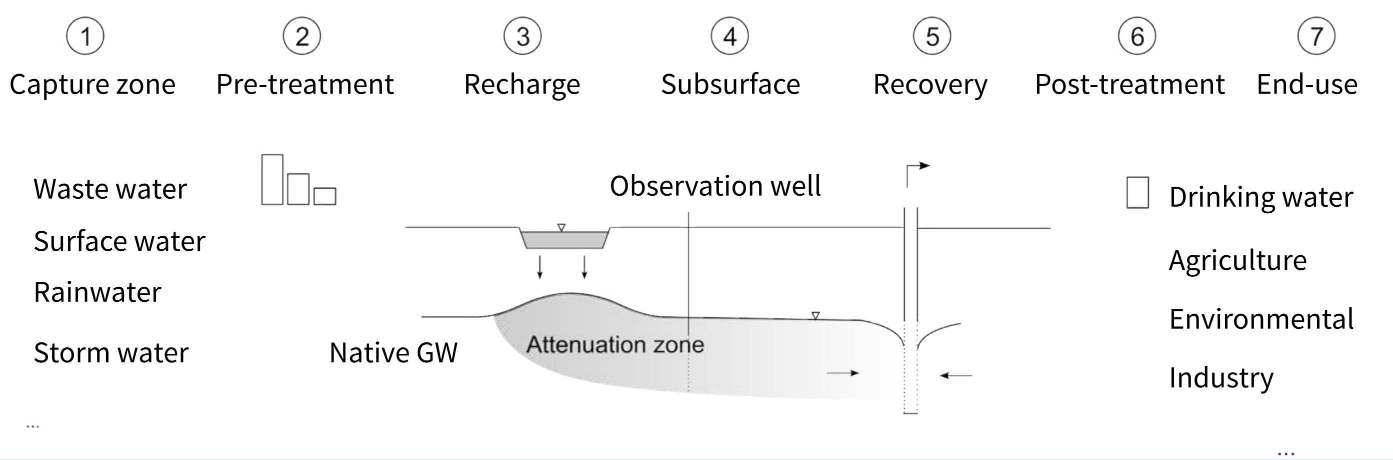


Figure 1: *An overview of the seven main components of a MAR system from source to end-use for an infiltration pond in an unconfined aquifer (modified from Dillon et al. 2010).*

MAR IN PRACTICE

CLASSIFYING MAR

MAR can be classified into four major groups based on recharge and storage technique applied *(Table 1)*.

(1) Enhanced infiltration relies on gravitational infiltration and percolation, and includes surface spreading, point or line recharge and in-channel modifications. Surface spreading methods are among the simplest and most widely applied MAR techniques. In such methods, source water is spread over a land surface and allowed to percolate to the target aquifer. Most of the existing large scale recharge schemes in European countries make use of this technique, and typically utilise infiltration ponds to enhance the natural percolation of water into the subsurface. During point or line recharge, source water is infiltrated either in elongated (e.g. shafts, drains) or punctual (e.g. abandoned dug wells, bore holes) structures. In-channel modifications are structures found in stream or channel beds (e.g. check dams).

(2) Induced bank filtration, another MAR technique, describes the infiltration of surface water induced by pumping from a nearby well. During bank filtration water quality improvement (treatment) of induced surface water is commonly the main objective. Bank infiltration schemes commonly consist of a well gallery or a line of abstraction wells parallel to the bank of a surface water body. Induced bank infiltration systems are typically installed near perennial streams and lakes that are in hydraulic contact to the adjacent aquifer.

A third MAR technique, **(3) well injection** techniques are used where thick, low permeability strata overlie the target aquifers. Aquifer storage and recovery (ASR) is the direct injection of water by a well for subsurface storage and recovery from the same well. Water storage to bridge seasonal gaps in water supply is often the primary goal when applying this technique.

Sub-surface dams, which are rarely used, do not lead to additional recharge but **(4) enhanced groundwater storage** where required. Other techniques include rooftop water harvesting (also called rainwater harvesting), a method for collecting source water in the capture zone. Rooftop water harvesting can be combined with injection or infiltration techniques as per local conditions and requirements, and therefore, is not considered a MAR technique.

Table 1: Classification of MAR types.

Recharge technique	Main MAR type	Specific MAR type
(1) Enhanced infiltration	Surface spreading methods (Areal recharge)	Infiltration ponds
		Soil-Aquifer treatment
		Excess irrigation, ditches, trenches
	Point or line recharge	Well/borehole infiltration
		Reverse drainage, shaft recharge
	In-channel modifications	Check dams
		Riverbed scarification
		Sand dams
(2) Induced bank filtration (IBF)		Riverbank filtration
		Lakebank filtration
(3) Well injection		Aquifer storage and recovery
		Aquifer storage, transfer and recovery
		Aquifer storage (hydraulic barriers)
(4) Enhanced storage		Sub-surface dams

HYDRAULIC IMPACT AND ATTENUATION ZONE

The purification capacity depends on several factors that include: the water quality of the source water, travel time of infiltrated or injected water to the abstraction well, and the design of the MAR field site. Impact zones of MAR structures can be divided into a hydraulic impact and attenuation zone (*Figure 2*).

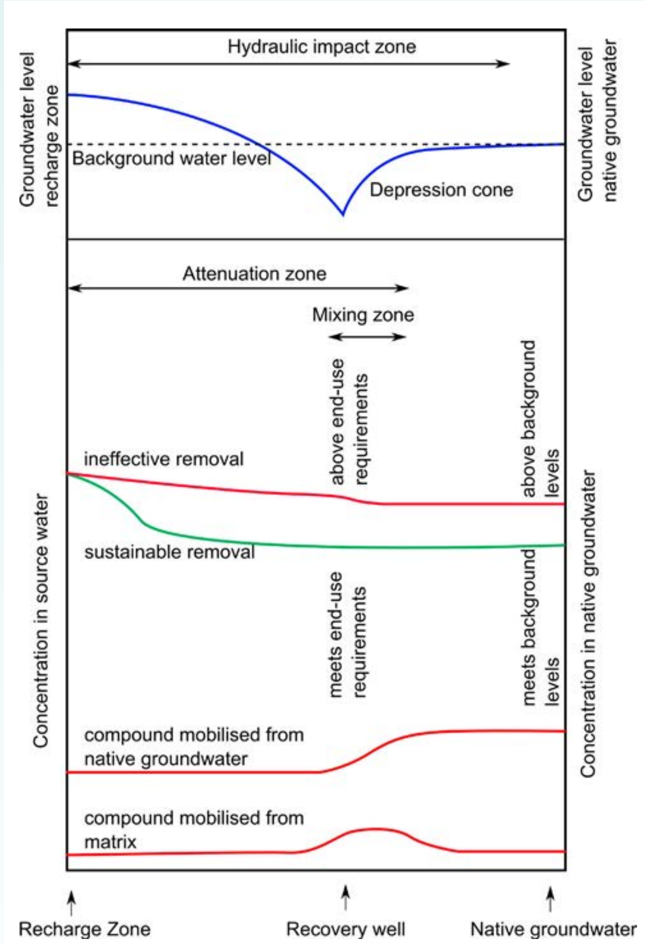


Figure 2: *Concept of hydraulic and attenuation zonation during MAR (Red lines indicate ineffective removal or mobilisation of undesired compounds, green line indicates sustainable removal) (Sprenger et al. 2015).*

The infiltration of water into an aquifer results in increased hydraulic pressure at the recharge zone. The **hydraulic impact zone** is characterised by measurable hydraulic changes derived from the MAR system. The hydraulic impact zone is usually many times larger than attenuation zone, especially for confined aquifers.

The **attenuation zone** is the area surrounding the recharge zone where changes of the infiltrated water quality take place due to natural processes in the aquifer. These natural attenuation processes may vary in time and space within the aquifer, particularly along the flow path from the area of recharge to the recovery well. Most attenuation processes in the subsurface occur at or close to the recharge zone. Part of the attenuation zone is the mixing, where native groundwater and the recharged source water mix.

MAR AND EMERGING POLLUTANTS

During subsurface passage of source water, several attenuation processes occur. These processes can be broadly divided in biotic and abiotic processes. Abiotic processes that occur in MAR include: sorption, dilution and photolysis (only occurring in surface spreading methods). Biodegradation also contributes significantly to the elimination of undesirable substances in groundwater. Temperature and redox conditions along the groundwater passage produce different degradation rates of undesirable compounds and also affect the chemical structure of the substances. Removal of emerging pollutants during MAR results primarily from sorption and biotransformation processes. Based on a literature study the percentage of removal of selected emerging compounds is classified in relation to the predominant redox condition and the residence time in the subsurface (*Figure 3*).

Due to the redox dependant degradation of some contaminants, only MAR systems comprised of an oxic to anoxic redox sequence ensure maximum attenuation efficiency. Long soil-aquifer passage and high residence time favours interaction with sediments and the communities of microorganisms in the porous media, allowing for removal of pollutants through natural processes.

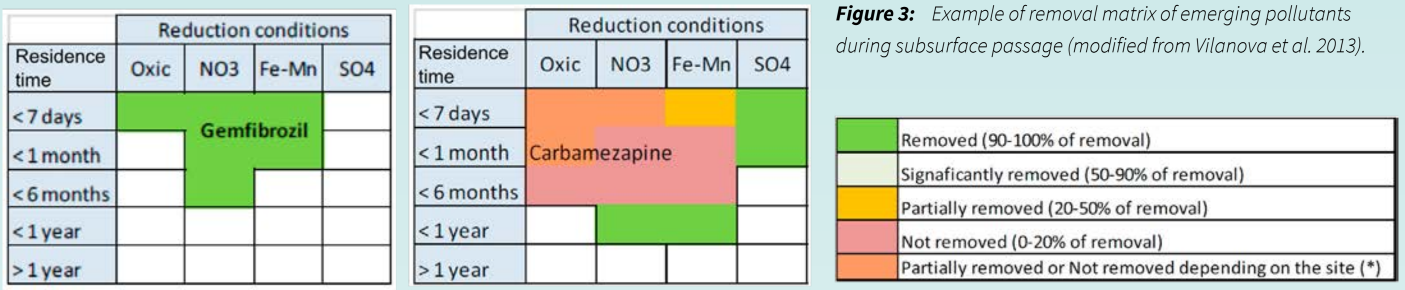


Figure 3: Example of removal matrix of emerging pollutants during subsurface passage (modified from Vilanova et al. 2013).

IMPACT

MAR IN EUROPE

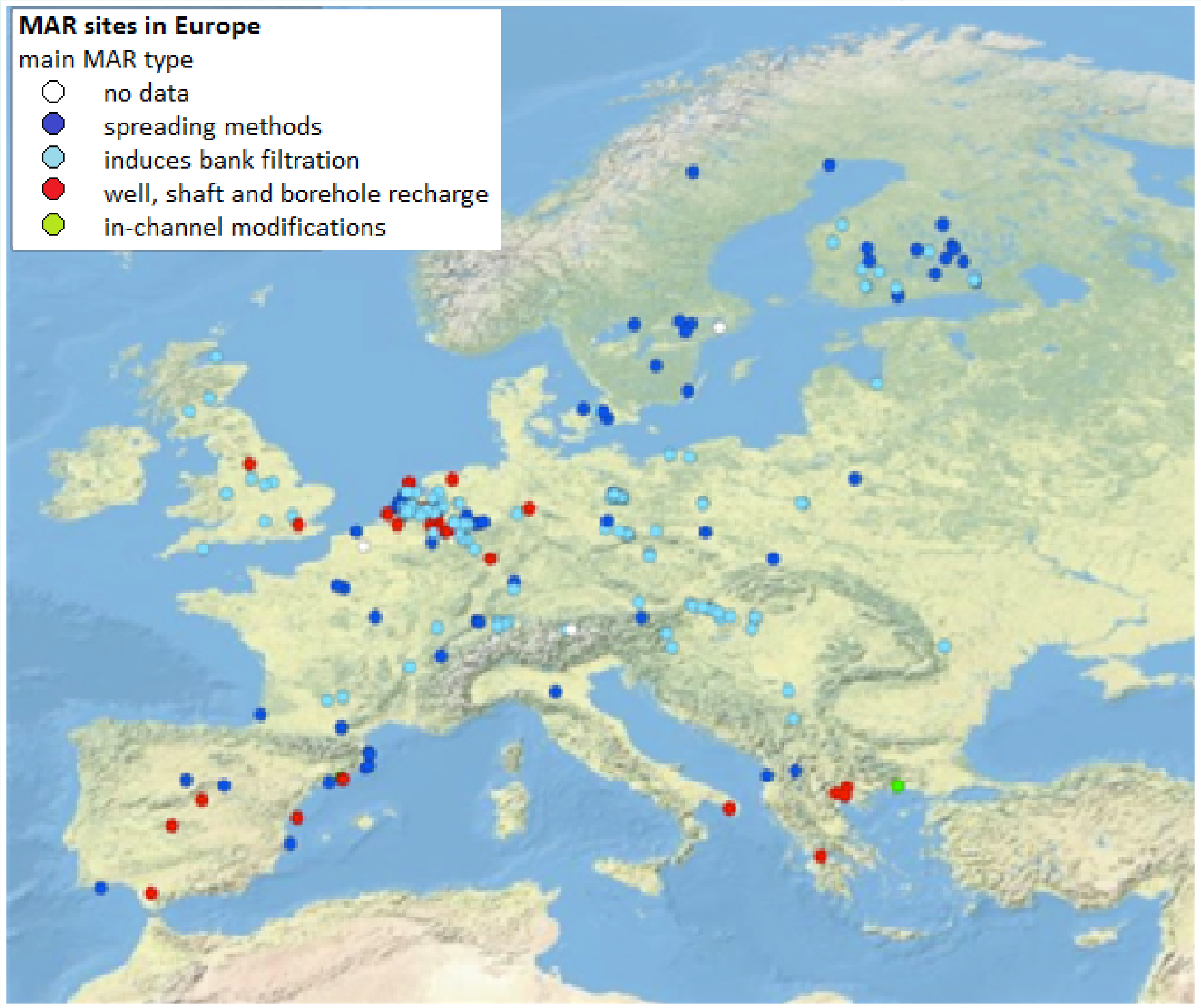
The European MAR catalogue, developed within DEMEAU, is the first systematic categorisation and compilation of information for all MAR types. This catalogue includes current information from more than 270 active MAR sites in more than 20 European countries (*Figure 4*).

Figure 4 shows that the most common types of MAR are induced bank filtration and surface spreading. Clusters of MAR sites can be seen in the Netherlands, in Germany along the rivers Rhine and Elbe, as well as in Berlin and along the Danube River in Austria, Slovakia and Hungary.

In Central European countries (but also in the northern countries) MAR plays an important role in the water supply, and is mostly used for drinking water purposes. In Mediterranean countries, mostly surface spreading sites are found, but in-channel modifications and point or line recharge facilities are also used to a lesser degree. Compared to Central and Northern Europe, MAR in the Mediterranean region is underutilized, as the map shows. Consequently, there is a large potential for MAR in this region (*Figure 4*). MAR has also a large potential in areas with dominant hardrock aquifers, such as the Iberian Peninsula or parts of Scandinavia. In these areas, MAR utilizes utilises small local aquifers which are not visible in the scale of the aquifer type map (scale 1:1,500,000).

***Figure 4:** Overview of MAR sites in Europe active during 2013.*

source: Hannappel et al. 2014
Please note, the image is a teporary replacement and will be updated when the original source has been published.



Several years of research and experience have shown that MAR is a competitive technique for water quality improvement as well as for attenuation of certain emerging pollutants. The major advantages and challenges of MAR are summarized in *Table 2.*

***Table 2:** Summary of advantages and challenges of MAR.*

Advantages	Challenges
▸ Ability to store water in aquifers for later use, which allows balancing out supply and demand gaps (except for Induced Bank Filtration (IBF)).	▸ Requires suitable water source and appropriate hydrogeological conditions.
▸ Replenishment of groundwater levels where currently over exploited and counteracting salinity ingress (except for IBF and enhanced storage techniques).	▸ 'Clogging' (physical, chemical and/or biological) of infiltration/percolation surfaces, can reduce recharge rates drastically and is often the major limiting factor to infiltration.
▸ Improving water quality by natural attenuation processes in the subsurface and balancing out seasonal fluctuations in water quality.	▸ Site specific hydrogeological exploration, wide range of information is required (monitoring, hydrogeological investigation etc.) and feasibility/pilot projects are often necessary.
▸ Applicable to drinking water and wastewater treatment and can be combined with engineered treatment systems.	

BARRIERS AND SOLUTIONS

To foster the implementation of MAR, it is important to ensure that it does not compromise the protective goals or threshold values given in European and national legislations. The present European water directives (e.g. the Water Framework Directive, the Groundwater Directive, etc.) do not specify requirements for MAR schemes and only define a broad framework in which MAR may be developed.

A principal requirement of the Groundwater Directive (GWD) is to assess the actual or potential impact of MAR on groundwater in the vicinity of the site. An important element of the risk screening process is the choice of the points at which compliance with the GWD will be evaluated. Points of compliance (POC) can be applied to MAR facilities, as shown in *Figure 5*.

In the case of MAR schemes, the receptor at risk can be defined by the groundwater beyond the attenuation zone at POC 3. The attenuation zone is the area surrounding the recharge area where groundwater quality changes takes place due to natural processes in the aquifer (e.g. straining, degradation, sorption, dissolution/precipitation, inactivation (die-off), decay or mixing).

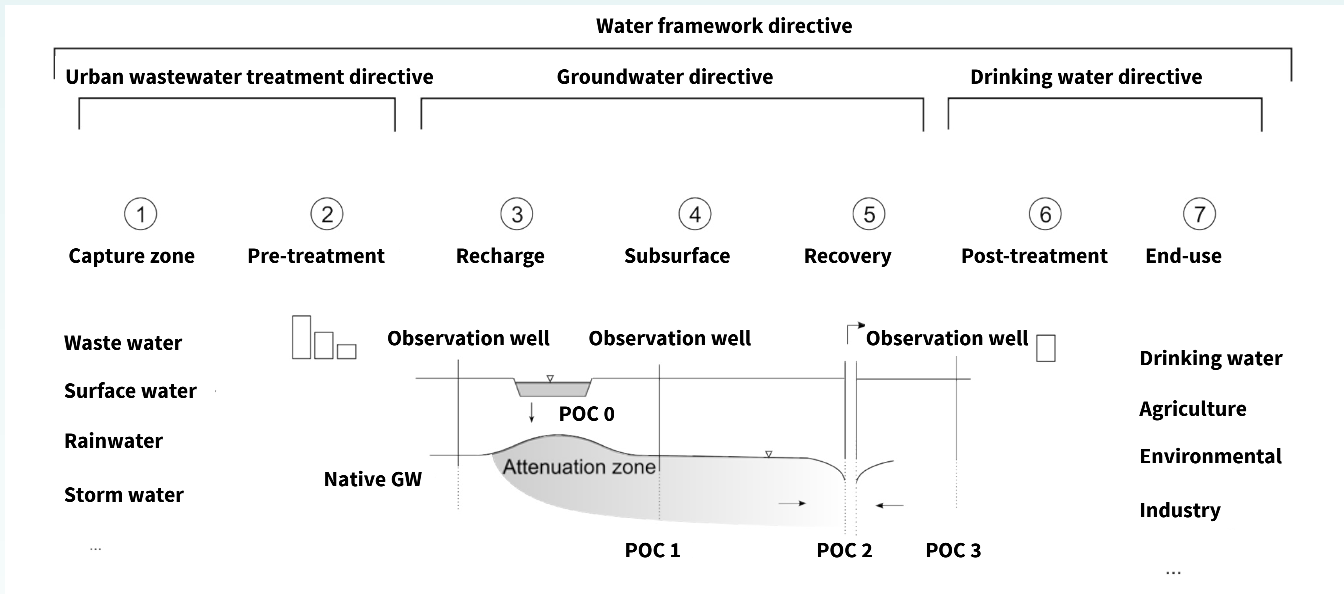


***Figure 5:** Components of MAR and possible points of compliance (POC) with most relevant European legislation (Vilanova et al. 2015).*

LIFE CYCLE ANALYSIS AND ENVIRONMENTAL IMPACTS

MAR can provide a variety of benefits, such as increasing the volume of stored water and improving water quality through natural aquifer treatment processes. However, the implementation of MAR is often hampered by uncertainty relating to economic and environmental profiles.

Within the DEMEAU project, several MAR sites have been evaluated in their economic and environmental impacts, following the methodology of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC).

These tools are based on a set of indicators selected for environmental impacts (e.g. carbon footprint, primary energy demand, ecotoxicity) and costs (e.g. annual operational costs per m^3) that show how the respective MAR site performs in comparison with other technologies for water treatment.

Life Cycle Assessment	Life Cycle Costing
▸ direct impacts on water quality (e.g. removal of nutrients and emerging micropollutants) ▸ indirect impacts from efforts for construction and operation (e.g. fuel consumption for machinery, excavation of ponds, and maintenance)	▸ operational costs for MAR feasibility, construction and maintenance ▸ investment costs for MAR feasibility, construction and maintenance

MAR LCC AND LCA IN THE LLOBREGAT AREA (SPAIN)

LCA analysis was conducted for different MAR scenarios with similar operational goals which are already in use or could be implemented in one of the case study sites in the Llobregat area close to Barcelona. The LCA case study of Llobregat consists of a variety of different MAR techniques (***Figure 6***) which have been analysed for their carbon footprint and annual costs.

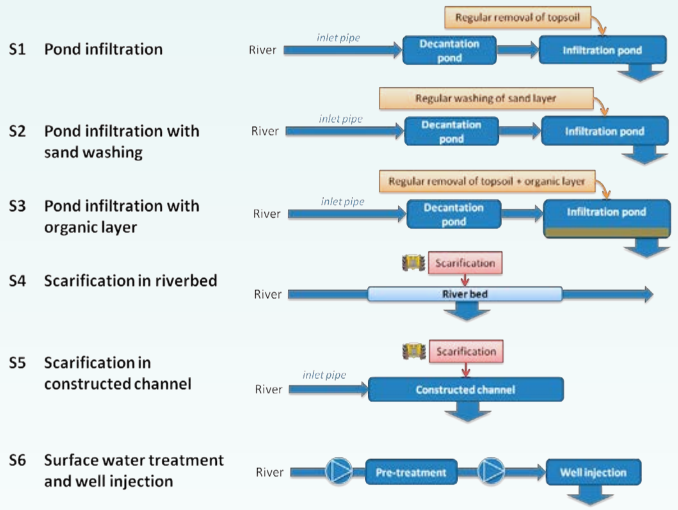


Figure 6: *Different MAR scenarios for the Llobregat area evaluated with LCA and LCC (Deliverable 51.1, unpublished). (S1) base line scenario. (S2) pond layer made of technical sand along with regular washing and refilling of the sand (S3) base line scenario with additional organic layer for improving the removal of organic micropollutants, (S4) traditional riverbed scarification, practiced for several decades in the area (S5) infiltration channels as a new technique for the area, (S6) well injection of pre-treated river water (coagulation/rapid sand filtration/disinfection).*

RESULTS OF LCA AND LCC FOR THE LLOBREGAT AREA (SPAIN)

The assessments shows that groundwater recharge by MAR infiltration ponds in the Llobregat area has low primary energy demand which also makes it a water treatment technique with a relatively low carbon footprint (***Figure 7***). Compared to pond infiltration, traditional riverbed scarification, which has been practiced for decades in the area, causes much higher CO_2 emissions per m^3 infiltrated water and is also associated with the highest annual costs (***Figure 8***).

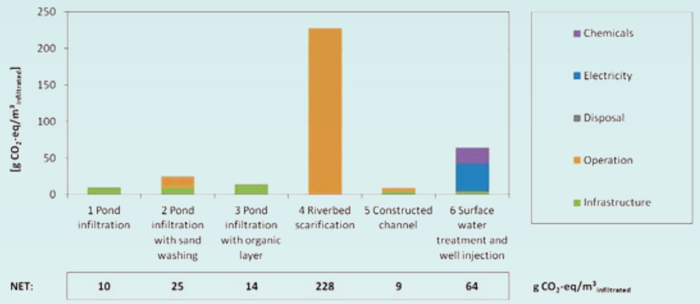


Figure 7: *Carbon footprint in CO_2-equivalents per m^3 infiltrated water for different options of MAR (pond systems at Sant Vicenç dels Horts (SVH) (1–3), traditional riverbed scarification (4), constructed channel for infiltration (5), and surface water treatment + well injection (6)) (Deliverable 51.1, unpublished).*

Adding an organic layer to the infiltration pond enhances the removal capacity for organic micropollutants. With a low additional carbon footprint, this MAR modification is an environmentally friendly option for water treatment. For a long-term sustainable operation and infiltration performance of the MAR ponds, a sand layer with defined quality and regular washing will control the clogging layer in order to maintain a high infiltration rate. Another technical MAR option with low environmental impacts is a simple channel in parallel to a river, where infiltration is maintained by regular scarification.

Assessing the economic profiles of the different technologies gives a similar picture for the different MAR options in the Llobregat area: natural pond systems are associated with costs of 8–19 €-ct/m^3 infiltrated water depending on the long-term infiltration rate that can be realised during operation (Figure 8). In comparison, riverbed scarification is more costly to operate, while surface water treatment and direct well injection is comparable to pond systems in total costs. The constructed channel is the most economical option in this comparison (3 €-ct/m^3), but its long-term, full-scale operability remains to be determined, as it is not yet implemented.

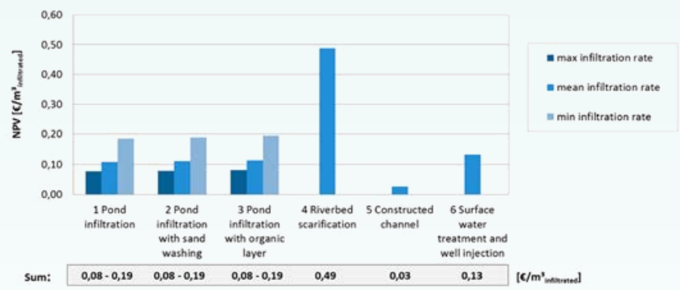


Figure 8: *Total life cycle costs (net present value, NPV) in € per m^3 infiltrated water for different options of MAR (pond systems at SVH (1-3), traditional riverbed scarification (4), constructed channel for infiltration (5), and surface water treatment + well injection (6)) (Deliverable 51.1, unpublished).*

CASE STUDIES

BERLIN - TEGEL (GERMANY)

This site is located in the northwest of Berlin, where three infiltration ponds in the catchment of Tegel Water Works are surrounded by approximately 40 production wells. The site is operated by the local water utility (Berliner Wasserbetriebe) and aquifer recharge started in the late 1950s. Beginning in the 1960s, three infiltration basins have been continuously used for infiltration. Surface water from the nearby Tegel Lake is used as a water source, pre-treated during summer via filtration through a microstrainer to prevent clogging by algae. Total annual abstraction from this site is about 21 Mm^3/a.

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DEN HAAG (THE NETHERLANDS)

The Meuse River is the drinking water source utilised by Dunea. A typical multi-barrier treatment approach ensures that the drinking water meets the high Dutch quality standards. Dunea's multi-barrier consists of three main treatment steps: pre-treatment (coagulation) of surface water, infiltration in and recovery from the dune aquifer system (MAR), and a post-treatment that includes dosing of activated carbon. As a result, the drinking water is distributed chlorine-free to consumers. The MAR systems were implemented around 1950, consisting of 36 infiltration ponds and 22 injection wells that started producing water later on, in 1980, as a response to increased demands. Today, the plant provides approximately 48 Mm^3/a of drinking water.

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SANT VICENÇ DELS HORTS – BARCELONA (SPAIN)

The Sant Vicenç dels Horts (SVH) MAR system is one of the most active aquifer recharge systems in the Llobregat area. Recently constructed in 2007, it consists of a decantation pond (5600 m^2) and an infiltration pond (4000 m^2). The purpose of this aquifer recharge system is to increase groundwater resources at the local scale. 4 Mm^3 of raw Llobregat river water have been recharged thus far. In 2011, an organic layer of vegetal compost was installed on the bottom of the infiltration pond to enhance adsorption and degradation processes along the recharge, the first of its kind worldwide at such a large scale.

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VALL D'UXÓ – CASTELLÓN (SPAIN)

The recently constructed reservoir in la Vall d'Uixó allows the storage of 2 Mm^3 of surplus water of the Belcaire River to be injected into the aquifer during drought periods. Public and private entities joined efforts to carry out the first pilot test by injecting 310,000 m^3 of river water in 2013 and 2014 using two injection wells of 100 m depth. The DEMEAU project collaborated on assessing the use of reclaimed water from the local waste water treatment plant as an alternative source of recharge water to be implemented in a future stage of processing.

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UNIQUE SELLING POINTS OF MAR

Natural pond systems are a low-cost and low-energy option for groundwater recharge, provided that a suitable long-term strategy for clogging prevention is implemented, backed up by the LCA and LCC assessment. In addition, these ponds can be upgraded or combined with other process steps (e.g. advanced oxidation processes) to enhance their capacity for removal of organic micropollutants. Similar technical processes based on conventional technology (i.e. coagulation, filtration, and injection) are comparable in life cycle costs, but show higher environmental impacts due to electricity and chemicals demand for treatment.

More information on MAR, all deliverables and reports can be found in the DEMEAU tool box: **http://demeau-fp7.eu/toolbox/**

References:

1. BGR & UNESCO (eds.), 2014, International Hydrogeological Map of Europe 1:1,500,000 (IHME1500), Digital map data v1.1, Hannover/Paris
2. Deliverable 51.1 (unpublished), Unique selling proposition, DEMEAU deliverable
3. Dillon, P., Toze, S., Page, D., Vanderzalm, J., Bekele, E., Sidhu, J., and Rinck-Pfeiffer, S., 2010, Managed aquifer recharge: rediscovering nature as a leading edge technology, Water Science & Technology, 10, 2338-2345
4. Hannappel, S., Scheibler, F., Huber, A., and Sprenger, C., 2014, M11.1 - Characterization of European managed aquifer recharge (MAR) sites – Analysis, accessed: May 2015, http://demeau-fp7.eu/results/mar
5. Sprenger, C., Grützmacher, G., and Sperlich, A., 2015, Comparison of quantitative and qualitative data during MAR with aquifer baseline data – generic approach and site application.
6. Vilanova, E., Miret, M., and Molinero, J., 2013, Decision trees for MAR impact evaluation. DEMEAU deliverable, accessed: May 2015, http://demeau-fp7.eu/results/mar
7. Vilanova, E., Miret, M., Molinero, J., and Sprenger, C., 2015, Overview of Managed Aquifer Recharge legislation.

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Cover design and layout:
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CASE STUDIES

OXIDATIVE STRESS RESPONSE AS A NOVEL ENDPOINT IN WATER QUALITY MONITORING

Recently, the AREc32 bioassay was presented as a novel tool to determine effects mediated via the oxidative stress response pathway. The latter pathway is an important part of cellular defense against different reactive chemicals, such as disinfection byproducts. A similar assay is also included in the CALUX panel.

The AREc32 bioassay has been validated and applied as a pilot installation of Waternet, a Dutch drinking water utility. The pilot installation resembles the full scale plant and includes treatment of raw water with ozone and activated carbon. The results illustrate that the AREc32 assay is highly reproducible and sensitive to a number of reference compounds. After validation, a number of raw water samples from the various treatment barriers at the pilot installation of Waternet were tested.

The results show that ozone treatment increases the oxidative stress response as measured with the AREc32 assay. In addition, activated carbon can reduce the oxidative stress response to a marginal level. It was observed that after an extra activated carbon step, the oxidative stress response increased again. This can possibly be explained by release of certain compounds that subsequently cause a bioassay response. The results below indicate the thresholds that are a human health concern. Moving forward, a comparison with analytical chemical results will be required to demonstrate the added value of the AREc32 bioassay.

BIOSCREENING OF MAR WATER SAMPLES

Managed aquifer recharge (MAR) involves building infrastructure and/or modifying the landscape to intentionally enhance groundwater recharge under controlled conditions for water storage. There are many potential sources of recharge water including storm water (excess or redirected), treated wastewater and water from watercourses or

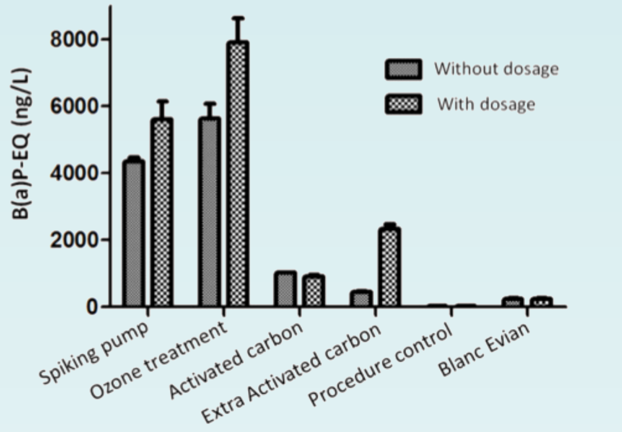

Figure 3. Induction of various water samples expressed in B(a)P equivalents

aquifers (structures such as ponds, basins, galleries and trenches) that add to the aquifer by. Various types of MAR sources (ground-, surface- and effluent- water), investigated as part of the DEMEAU project, were bioscreened in selected in vitro reporter gene assays (CALUX-panel), in the yeast estrogen screen and in the combined algae assay assessing both photosystem II-inhibition and effects on algae growth for risk assessment.

The screening pointed out relevant toxic endpoints and also distinguished between clean and polluted sites (See Figure 4 for a summary of results with the CALUX panel). For estrogenic anti-androgenic and glucocorticoid activities, the data are modified according to the currently available trigger values. Trigger values for the other endpoints, as well as the comparison of the chemical and biological data, are currently being established. Such studies greatly demonstrate the usefulness of effect-based methods to identify samples where further chemical analyses are needed to reveal the identity of the compounds causing the measured effects.

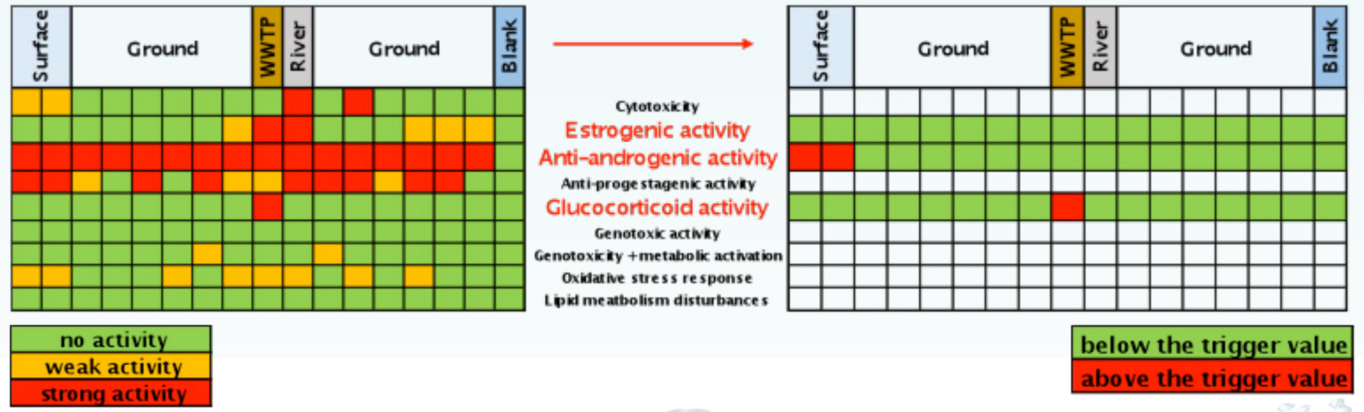

Figure 4. Summary activity profile of the tested water samples in the in vitro CALUX bioassay panel (on the left) and the modified profile (on the right) considering available trigger values (for estrogenic, anti-androgenic and glucocorticoid activity). Samples that showed lower activity than the pertinent trigger value, became "green" in the table on the right indicating low risk despite of the measured (quantifiable) activity.

BARRIERS AND SOLUTIONS

Typically, regulatory acceptance of emerging technologies is a slow process, and currently hampers the use of such modern bioassays for compliance testing and regulatory purposes. To address this barrier, **demonstration and validation** studies are being carried out in an effort to bring bioassays under increased movement toward **regulatory acceptance**. In addition to validation, another step to improve regulatory acceptance of effect-based bioscreening is the derivation of human- and ecosystem health- based **guideline values**. Such thresholds serve to act as a filter mechanism where detailed evaluation is only performed in samples exceeding the predetermined trigger value.

Beyond regulatory acceptance, increased **public (end-user) and governmental acceptance** is also desired. While some scientists and end-users view bioassays as a potential replacement of more costly techniques, such as chemical analysis, there is still a knowledge gap among many scientists, policymakers, and end-users in the applied field. In addition, a general precaution with regard to novel techniques often prohibits application of such emerging technologies, especially where investment in lab infrastructure and/or personnel training is a prerequisite to implementation.

Discussing and clarifying these critical issues and misconceptions are extremely critical in order to promote widespread application of bioassays. Moreover, in order to facilitate the operational use of these tools for decision-makers, **dissemination techniques** are also essential..

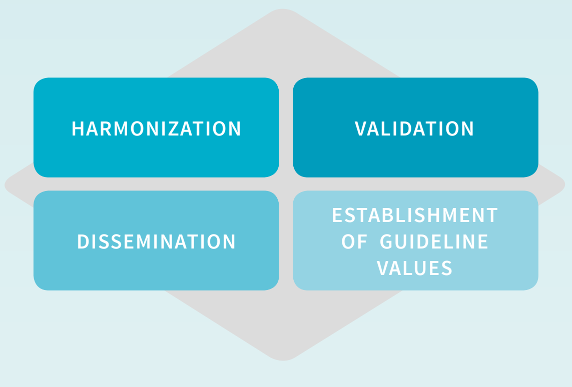

Figure 2. Crucial steps towards the better regulatory- and end-user acceptance of the bioassay technology in water quality monitoring

DISSEMINATION EVENTS

A tailored workshop on "***In-vitro* bioassays, as innovative tools for water quality assessment**" (29 January 2015; Paris, FR) in conjunction with practical demonstration of the above-mentioned workflow (Figure 1) will enable experts and decision makers from reference laboratories, water lab utilities, regulatory bodies, and from organisations in charge of risk assessment to become familiar with the added value of bioassays in safeguarding of water quality.

Another workshop is organised for spring 2015 (Utrecht, NL), where **regulatory acceptance and barriers of the bioassay technology** will be discussed in depth. This workshop aims to target policy makers, regulators, end-users, as well as standardisation institutions.

SYNERGIES WITH TECHNOLOGIES

In addition to providing cost-effective means for safety evaluations and water quality assessments of emerging and unknown pollutants, synergistic application of bioassays can also be extended to other promising DEMEAU technologies, including:

- **Managed Aquifer Recharge (MAR)**, which enables the storage of water in periods of good resource quantity and uses natural degradation of pollutants. A selected panel of Bioassays can be used for MAR samples as constant monitoring tool for (1) safeguarding good water quality and (2) investigating temporal trends in toxic activities that can be influenced by either accidental or biological sources of pollution;
- **Hybrid ceramic membrane filtration (HCMF)**, which combines ceramic membranes with processes such as coagulation, pre-coats of powdered activated carbon or ion exchange pretreatment and can remove a broad spectrum of pollutants; and
- **Hybrid advanced oxidation processes (HAO)**, which are good candidates to treat surface water and municipal wastewater effluents (the main source of emerging pollutants) and offer flexible solutions to treatment processes for water purification. For both HCMF and HAO, bioassays can be used to evaluate their proper functioning. This is done by screening the total toxic potency of the released product (i.e. drinking water or wastewater effluents).

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Figure 1: Ivan Pel and Hamilton Robotics
Figure 2 and 4: Dr. Eszter Simon
Figure 3: Dr. Merijn Schriks

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DEMEAU

DEMONSTRATION OF PROMISING TECHNOLOGIES TO ADDRESS EMERGING POLLUTANTS IN WATER AND WASTE WATER

BIOASSAYS

NOVEL EFFECT-BASED MONITORING APPROACHES IN WATER QUALITY MONITORING

Efficient monitoring and adequate treatment of water sources for potentially harmful emerging pollutants are essential for avoiding direct health risks to consumers. Current monitoring strategies rely exclusively on chemical analysis. However, chemical analysis only identifies specific, targeted compounds, and provides no information on the biological effects of the pollutants. As such, chemical analysis is rather limited in scope.

MEASURING THE TOXICOLOGICAL EFFECT OF ENVIRONMENTAL SAMPLES

Bioassays have emerged as a new, promising technology to address this gap in monitoring strategies. Specifically, bioassays offer the ability to measure biological effects of individual compounds present in water samples, and thus are particularly useful for assessing the harmful effects of complex mixtures of unknown pollutants. Bioassays hold the potential to serve as an additional, complementary technology for use in conjunction with chemical analysis, and therefore present a promising opportunity for introduction and integration into current water monitoring strategies.

MONITORING OF WATER QUALITY: FOR FUTURE USES AND EVALUATION OF WATER TREATMENT TECHNOLOGY

Recommendations from DEMEAU, a project funded under the 7th Framework Programme for Research and Technological Development of the EU (FP7), suggest that bioassays could play an important role in prescreening water sources to help identify polluted sites. According to DEMEAU, bioassays also have the potential to be used to evaluate the effectiveness of water treatment technologies already applied.

eco logic · BDS BioDetection Systems · KWR Watercycle Research Institute · VEOLIA · oekotoxzentrum centre ecotox

This project has received funding from the European Union's Seventh Framework Programme for Research, Technological Development and Demonstration under the Grant Agreement no. 308339.

INTRODUCTION

In light of the increasing number of chemicals entering water bodies, as well as recent advances in (bio)analytical measurement strategies, new technologies for improving and optimising conventional monitoring programs offer the potential to increase the rigor and scope of current water quality monitoring. Though targeted chemical analysis is routinely used in water quality monitoring and well-accepted in regulatory frameworks, its scope is restricted to a relatively small selection of compounds. **Integration of (bio)analytical techniques, such as bioassays, into novel monitoring programmes** present opportunities for measuring the integrated (eco)toxicological effects of chemicals found in aquatic ecosystems and/or sources of drinking water—regardless of the structure, concentration and identity of such chemicals.

One of the aims of the DEMEAU project is to demonstrate effect-based monitoring strategies and the usability of effect-based bioanalytical tools. As such, DEMEAU's work package on bioassays focuses on implementation of bioassay technologies in the context of water quality and safety assurance.

BACKGROUND

Bioanalytical tools offer the potential to effectively (pre) screen for chemical pollutants, while also offering important complementary tools to use in combination with chemical analysis. Bioassays, in particular, allow the identification of the observed biological effects caused by environmental chemicals and the mixtures that contain them. Recent technological developments have provided powerful quantitative *in vitro* bioassays to effectively measure a wide range of major classes of toxicants (i.e. acutely toxic compounds, endocrine disrupting substances and genotoxic agents) in the water cycle. Bioassays utilise living animals, plants (*in vivo*), tissues or cells (*in vitro*) to determine the biological activity of a substance or environmental sample containing a mixture of both known and unknown substances.

CONTAMINANTS

These modern bioassays are capable of effect-monitoring of a broad range of known contaminants exerting the following toxic endpoints reported as relevant to assessment of aquatic environments. These contaminants include polycyclic aromatic hydrocarbons (PAHs), phenol derivatives, detergents, pesticides, pharmaceutical residues and, personal care products, plasticizers, etc.

Toxic endpoints	Possible adverse health and/or ecotoxicological effects
Endocrine disruption Agonistic and antagonistic - Estrogenic - Androgenic - Progestagenic - Glucocorticoid effects	Tumor development Birth defects (Sexual) developmental disorders
Xenobiotic metabolism	Reproductive and developmental problems, interfere with hormone action and cancer
Oxidative stress	Inflammation, sensitisation and neurodegenerative diseases
Genotoxicity / DNA damage	Tumor development
Cytotoxicity	General toxicity
Inhibition of the photosystem II	Photosynthesis inhibition linked to reduced algae/plant survival and growth
Acetylcholinesterase inhibition	Neurotoxic effects of a certain group of insecticides(organophosphates and carbamates)

BIOASSAYS IN PRACTICE

COST-EFFECTIVENESS: SIMPLE AND RAPID ASSESSMENT OF THE SAFETY OF WATER SAMPLES, HIGH-THROUGHPUT SCREENING CAPACITY

In practice, bioassays follow relatively simple protocols and **allow for a rapid, high-throughput screening of adverse effects** that can occur in waste streams and in the environment. As the biological response of different living organisms confronted with a novel chemical substance is diverse and depends on their sensitivity to toxicants, the selection of bioassay(s) predetermines the type of toxicants eventually identified.

When **selecting the suitable assay panel for water quality monitoring**, the following criteria should be thoroughly considered: (1) the availability of standardised protocol, (2) the support and services desired; (4) short/realistic analysis time; (5) measure of accuracy (sensitivity and specificity); (6) reproducibility and repeatability, (7) straightforwardness of readouts; (8) cost effectiveness and (9) applicability to complex samples. The latter is especially important to address, as most of the currently available in vitro bioassays work most effectively when screening pure compounds, but may fail when screening more complex environmental samples.

The workflow of a bioassay analysis of an aqueous sample is illustrated in *Figure 1*. In the first step, the aqueous sample is transferred to a solvent that is suitable for the selected bioassay(s) technique. Next, the concentrated extract is used to expose the cell-based assay. Read-out modern bioassays, such as CALUX assays, use quantitative methods to assess activation of toxicity pathways, including for example, measurement of activation of luciferase activity. The activity of the tested extract is expressed as reference compound-equivalent concentration per sample unit.

Figure 1. Generic workflow of water bioscreening

In order to perform **rapid and cost-effective water quality assessment**, the high-throughput (HTP) screening capacity of the assays is very important. Using robotics, automated sample workup, miniaturised assay formats, liquid handling devices, sensitive detectors, high-speed plate readers, data processing and control software facilitates, the generation of large number of individual assay data points allows for more efficient screening, while also reducing the costs associated with chemical analysis. However, HTP screening is only applicable/cost-effective in laboratories with a certain sample throughput.

CALUX BIOASSAY PANELS: BIOASSAYS FOR EFFICIENT ANALYSIS

Because a number of emerging chemical compounds are polar and/or occur mainly in surface waters at very low concentrations (ng/L), consideration of the selection and the efficacy of the applied extraction/concentration method, in addition to the sensitivity of the applied bioassay, are crucial to address prior to the screening process. In response to this, as part of the DEMEAU project, scientists recently developed the CALUX cell panel, a type of bioassay panel **with the ability to run in an efficient and automated way** (Van der Linden et al., 2008; Van der Burg et al., 2013).

In order to avoid possible contamination and loss of analytes of interest during the sample preparation process, the applicability of "direct exposure" is currently being investigated within the CALUX technology. To do so, water samples are directly exposed to the CALUX cells without preparing an organic extract in advance. The CALUX reporter gene assays (as well as the exposure) are performed in an aqueous cell culture medium. As such, adding the water samples directly to the cells, thus far, appears to work. However, special care should be taken to avoid microbial and/or bacterial contaminations. In addition, the sensitivity of the assay is of much higher importance if this method is selected.

IMPACT

Bioassays provide the unique possibility to investigate water quality (and other matrices) based on the toxic activity of the pollutants that are present, as opposed to their specific structural nature. Bioassays are wide in their scope of water quality monitoring, and can be tailored to and adjusted for testing a range of water sources, from general toxicity tests to very specific biological activities.

The major advantages of the application of novel quantitative Bioassays include the following:

- Improved safety assessment through measurement of the effect(s) of untargeted (unknown) water contaminants, including contaminants that are the result of metabolic conversions at low concentrations (ng/L);
- Provision of antagonistic, synergistic, and/or additive effects of complex contaminant mixtures by measuring the total biological activity of a water sample;
- Cost-effective, when compared to instrumental chemical analysis;
- No use of experimental animals; and
- Relevance to human toxicity, if a human cell-based assay is applied. For example, in vitro toxicity tests conducted in human cells can help identify specific biomarkers of exposure, biologic change, or susceptibility that can be investigated directly in human populations. If e.g. fish cell-based assays are used or experiments on algae or yeast cells are conducted, also conclusions with regard to aquatic species can be drawn.

Potential users of the technology and applications include the following:

Potential users	Applications for
WATER QUALITY CONTROL AGENCIES	▸ The generation/validation/control of water quality objectives related to ecosystem and human health ▸ Assessment of the presence of toxic compounds ▸ Tracing hidden sources of pollution ▸ Setting permit criteria for the discharge of effluents ▸ Checking the compliance of effluent dischargers ▸ Determining the efficacy of pollution control measures ▸ Defining and standardising the interpretation of results gained within monitoring studies using bioassays ▸ Future implementation within the Water Framework Directive (using the derived toxicological dataset)
INDUSTRY	▸ Toxicity screening of waste streams before releasing them into the environment ▸ Pollution control measures (evaluating the effectivity of technology) ▸ Alarm notification for process failure
DRINKING WATER COMPANIES	▸ Safety assessment of source water ▸ Treatment technology effectiveness evaluation ▸ Efficient and comprehensive safety assessment of drinking water ▸ Failure notification alarm

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