# Area-efficient stormwater treatment – Where? When? How?

## INTRODUCTION

Urbanisation and increasing catchment imperviousness in urban areas cause increasing stormwater pollution and peak flows [1], the key pollutants being metals, sediment (TSS), nutrients and salt [2]. Also polycyclic aromatic hydrocarbons (PAH) have been identified as important pollutants posing a risk for receiving waters [3]. Still, stormwater is often discharged without any treatment making it a main reason for urban ecosystem degradation due to water contamination [1]. Where existent, stormwater ponds or basins, primarily aiming at flow detention, also achieve a certain treatment by sedimentation of particles. However, small particles (ca. <20 µm), colloids and dissolved pollutants, however, pass through these facilities and therewith also a large share of the pollutants. Thus, there is an urgent need to further develop stormwater treatment, especially with regard to capturing dissolved and small particulate pollutants. As densification in cities makes it increasingly important to apply treatment techniques with low land footprint, we propose to investigate six area-efficient advanced water treatment techniques that have hardly been studied for stormwater applications but have great potential to considerably decrease the concentrations of sediment and pollutants in urban stormwater. We also propose to compare different solutions for integrating stormwater treatment into existing stormwater systems focusing on the degree of decentralisation of the treatment units.

## PROPOSED RESEARCH FRAME

We propose to evaluate **six advanced techniques for stormwater treatment with low land footprint**: flocculation by air agitation and precipitation, membrane filtration, reactive filter materials, floating wetlands and bottom grids for enhanced sedimentation in ponds. The main focus lays on increasing the removal of target pollutants by enhancing the separation of small particles, colloids and the dissolved fraction. We are aiming at developing these techniques further to increase their practical applicability and to facilitate their implementation. We will develop strategies to integrate stormwater treatment units into existing urban built-up areas paying particular attention to their scale of implementation (extent of decentralization). Altogether, with this project, we expect to contribute to improving urban run- off quality prior to discharge to receiving waters.

## OBJECTIVES

The specific objectives for this project are to:

- → establish a test bed for testing advanced stormwater treatment techniques in Östersund.
- → investigate to what extent and in what way flocculation by air agitation and chemical precipitation, floating wetlands and bottom grids can improve pollutant removal in stormwater ponds.
- → adapt hollow-fibre membrane filtration to stormwater treatment applications.
- → investigate which particle sizes the different techniques capture and the importance of this for the treatment effect.
- → investigate how reactive materials can be used to remove pollutants from stormwater under different conditions by laboratory and full-scale tests.
- → develop recommendations for municipalities regarding which issues need to be considered when stormwater treatment systems are implemented
- → investigate to what extent stormwater treatment should be decentralized or centralized in order to obtain sustainable systems (e.g. in terms of operation and maintenance costs).

## WORK PLAN

The work is divided into five work packages (WP) featuring full-scale investigations (WP 2 & 4) and laboratory investigations (WP 1 & 3). **Six advanced techniques** will be tested towards their suitability for stormwater treatment: flocculation by **air agitation and precipitation, membrane filtration, reactive filter materials, floating wetlands and grids** for enhanced sedimentation in ponds. In WP 5, strategies for designing sustainable stormwater systems by integrating treatment units will be studied focusing on the degree of decentralisation.

### TARGET POLLUTANTS

The target pollutants focused on in all sub-studies (laboratory experiments as well as field investigations) are (heavy) **metals** (Mn, Cd, Pb, Hg, Ni, Cu, Zn, Cr, As), mineral oils/**hydrocarbons** and polycyclic aromatic hydrocarbons (**PAH**). Throughout the project, focus will be on the **size of the particles** treated by the investigated techniques. This is of utmost importance because in conventional stormwater treatment systems (such as ponds), usually small particles and colloids pass through and are discharged. However, heavy metals, hydrocarbons and organic pollutants are known to be attached to these particles so that an increased separation of these particles (which the investigated techniques aim for) would lead to an improved treatment. pH, turbidity, conductivity and temperature will also be measured.

### WP 1 FLOCCULATION BY AIR AGITATION AND/OR CHEMICAL PRECIPITATION

**Background:** Air agitation is known to enhance flocculation in wastewater treatment where it introduces agitation energy to the system and promotes the formation of aggregates (flocs) from the finely divided matter [4]. Air agitation as a method for stormwater treatment has not yet been investigated although it has great potential to enhance flocculation and sedimentation in common stormwater treatment facilities such as detention ponds. In the context of stormwater treatment, some flocculants have been previously tested, i.a. aluminium and iron salts [5-7], in some cases in combination with a polymeric coagulant. Biopolymer (chitosan) has been studied treating construction site run-off [8], but not stormwater. However, a comprehensive study comparing a broad range of flocculants is missing to date. At large, air agitation and chemical precipitation are promising processes for advanced stormwater treatment but there is a research need for adjusting these technologies for stormwater applications.

**Objectives:** (1) To investigate to what extent aeration and/or the addition of chemical coagulants increase pollutant removal from stormwater by coagulation of particles, colloids and dissolved pollutants and their sedimentation and (2) to find the optimum conditions with regard to flocculant dosing, contact/sedimentation time and air agitation time/intensity.

**Methods:** Air agitation and chemical precipitation will be tested at laboratory and full scale. A factorial experiment will be performed in the laboratory to investigate the effect of flocculation/sedimentation time and chemical agent dosing on the removal of pollutants from synthetic stormwater using flocculants such as iron/aluminium salts and polymeric additives (provided by Kemira AB), and also alternative flocculants such as biopolymers, flocculants from other applications (e.g. water glass) or by-products such as water treatment sludge. Air agitation experiments will be carried out in laboratory-scale containers using pumps and nozzles for air distribution (for full-scale testing see WP 2). Addition of flocculant will be tested in full-scale in a common stormwater sedimentation pond (because the test bed in Östersund is located in a natural lake).

### WP 2 FLOATING WETLANDS, BOTTOM GRIDS AND AIR AGITATION FOR ENHANCED SEDIMENTATION

**Background:** Floating wetlands are a new promising technique for stormwater treatment as recent studies show [9, 10]. These artificial floating islands consist of a porous synthetic frame in which plants are planted with their roots hanging down in the water decreasing the flow velocity and thus enhance sedimentation. The roots, substrate and frame are also inhabited by microorganisms that consume nutrients from the stormwater. Floating wetlands for stormwater treatment have not yet been comprehensively studied (there is only one such facility in Sweden), in particular not in colder climates.

In a currently on-going pre-study, Co-applicant Prof Jiri Marsalek, in collaboration with Prof Staffan Lundström, Fluid Mechanics, LTU, model the flow over bottom grids for enhanced sedimentation with the aim to optimize the grid structure. This modelling is carried out based on the results of two previous studies [11, 12]. The results from this pre-study show great potential for the grid to enhance sedimentation in stormwater ponds, however, the positive effects on the sedimentation efficiency still needs to be confirmed at full-scale.

**Objectives:** (1) To establish a test bed that will be used to test innovative techniques for stormwater treatment. To investigate in full-scale if and to what extent (2) floating wetlands can contribute to pollutant removal in stormwater ponds in cold climate and (3) aeration and grids can enhance sedimentation in stormwater ponds.

**Method:** In co-operation with the municipality of **Östersund**, a **test bed** will be established. A **shielded wet detention pond** will be constructed in the lake Storsjön. Flexible "walls" are built into the lake shielding the pond water from the lake water (by Järven Ecotech AB). The constructed pond will be divided (using shields) into three sections to test aeration (see WP 1), floating wetlands (collaboration with Veg Tech AB) and bottom grids (Järven Ecotech AB). Aeration and bottom grids will be tested in the same section but shifted in time, while one section will be a blank for comparison. The grid will be tested based on the results from abovementioned pre-study. The instrumentation of the sections includes flow meters, sensors/transmitters for online-measurements of turbidity, conductivity and pH as well as automatic samplers.

### WP 3 MEMBRANE FILTRATION

**Background:** Membrane filtration is a common technique for industrial water and wastewater treatment which has been successfully applied in large-scale and new membranes are constantly developed. The technique can be a viable option to treat heavily polluted stormwater, e.g. from industrial areas or highways. To date, only very few studies on stormwater treatment with membrane filtration are available, but with promising results [13, 14]. Research needs to focus on the effectiveness of different membrane types, importance of stormwater quality (content of organic matter, mineral oils, sediments of different sizes) on the filtration process, the development and quality of organic fouling/mineral scaling layer and practical issues such as back-flushing, aeration and/or resting frequencies, necessary operational pressure.

**Objectives:** (1) To investigate the potential of two ultrafiltration/nanofiltration membranes to remove pollutants from stormwater. (2) To study the formation of a fouling layer and its properties.

**Method:** Two different membrane filter cartridges will be tested: an ultrafiltration membrane (pore size of 20 nm) made of a blend of polyvinylpyrrolidone and polyethersulfone, and a tight ultrafiltration membrane with even finer pores towards nano-size. Membranes and bench-scale membrane test unit will be provided by Purac AB. Three different input waters will be tested: synthetic stormwater (made using sediments from a highway runoff sedimentation basin and metal salts), melted snow (sampled along a highway in Luleå) and stormwater (from a heavily trafficked highway). The most promising membrane will be fed with synthetic stormwater in a long-term experiment allowing a fouling layer to form. The properties of the fouling layer will be investigated using a scanning electron microscope (SEM).

## WP 4 REACTIVE FILTER MATERIALS FOR HEAVY METAL RETENTION

**Background:** To remove heavy metals from stormwater, filtration through adsorptive filter materials has been previously suggested. Filters design varies and include small filter units in the stormwater network (manholes) and packaged filter units (e.g. for treatment of roof run-off from copper roofs which is an important issue in Sweden). The filter materials studied include sorbents such as zeolite, wood chips, peat and opoka [15], chitosan, crab shell, peat, Sargassum, sawdust, and sugarcane bagasse [17], limestone and ochreous sludge [18], and oyta shells and olivine [5]. The few full-scale studies available investigate pure sorbents in a layered filter [18] and as a polishing step at the outlet of a pond [5].

**Objectives:** (1) To investigate how well various reactive materials sorb different pollutants under different conditions focusing on the removal of heavy metals (i.a. Cu), nutrients and organic pollutants (2) To test a zeolite filter treating copper roof run-off in full scale.

**Method:** The filter materials tested (batch and/or column experiments) will be of various types: industrial by-products, natural minerals, organic materials and commercial filter products. Focus will be on the materials' capacity to adsorb metals, nutrients and organic pollutants, on the required stormwater/filter contact time and on temperature dependency. At full-scale, a packaged zeolite filter treating copper roof run-off from the Nationalmuseum in Stockholm, built and operated by the National Property Board of Sweden (Statens fastighetsverk) will be studied using automatic sampling during rain events of different size. Flow, pH, temperature, turbidity and conductivity will be measured using online probes in the in- and outflow of the filter.

## WP 5 DESIGNING SUSTAINABLE STORMWATER SYSTEMS: INTEGRATION OF TREATMENT UNITS INTO URBAN BUILT-UP AREAS

**Background:** Currently, small decentralised stormwater treatment units are installed at many sites in Sweden, usually filtration technique such as in biofilters, adsorptive filters and infiltration systems. However, these filter units are small and treat run-off from a limited area only which means that they need to be installed in large numbers to achieve a substantial treatment effect. The high degree of decentralisation (scattering of numerous small units) currently practised increases the complexity of stormwater systems and thus the efforts needed for operation and maintenance. Another issue is ownership, treatment units in many cases being privately operated with a risk to end up with large numbers of inefficient units. In a broader planning perspective, a holistic approach to stormwater treatment is needed in order to include both stormwater retention and treatment as well as issues of ownership and responsibility, durability of treatment methods, operation and maintenance of treatment units, and the degree of centralisation or decentralisation of treatment units.

**Objectives:** (1) To identify integrated solutions for how treatment units can be incorporated in urban stormwater systems and be integrated in the urban built-up areas. (2) To develop recommendations for municipalities regarding which issues need to be considered when stormwater treatment systems are implemented.

**Methods:** To analyse different system solutions, systems analysis tools such as multicriteria analysis and cost-benefit analysis will be used. To investigate and discuss current and future practice in the municipalities today, five workshops will be organised. Information about the decision processes regarding newly implemented stormwater treatment units will also be collected in a survey and personal interviews with, e.g., environmental officers at the municipalities.

## SCIENTIFIC PUBLICATION AND SPREADING OF INFORMATION

### COMMUNICATION WITH STAKEHOLDERS/END USERS

Results will be communicated to stakeholders through the communication platform of the research cluster **Dag&Nät** (Research Centre of excellence) headed by *Urban Water* at LTU including the Swedish Water and Wastewater Association (SWWA) and several Swedish municipalities). Activities and results will be presented in Dag&Nät Newsletters published 3-4 times a year and the popular science series *Ny Forskning och Teknik*. Results will be presented at national conferences arranged or co-organised by Dag&Nät. This communication platform reaches about 1000 end-users and stakeholders. In addition, the outcomes of this research will be published in relevant Swedish **periodicals**, e.g. *Svenskt Vatten*, *Cirkulation, Bygg&Teknik* or *Byggindustrin* to which several of the applicants regularly contribute. In dialogue with SWWA results will also be presented in SWWA publications. The project partners will present their research on conferences aiming at both academia and practitioners (e.g. Novatech and NordIWA: 1/3 researchers, 2/3 end-users and stakeholders). The project will be conducted in collaboration with industry and municipalities and results will be directly communicated in meetings and workshops.

### COMMUNICATIONS WITH THE SCIENTIFIC COMMUNITY

From this project, at least seven scientific papers will emerge that will be published in peer-reviewed scientific journals. Open access is striven for and will be paid for where necessary. Furthermore, results from each WP will be presented at significant scientific conferences such as *Novatech*, Lyon, France, *NordIWA* (Nordic wastewater conference), *ICUD* (International Conference on Urban Drainage) and *IWA ICWS* (International Conference on Wetlands Systems for Water Pollution Control).

## RESEARCH ENVIRONMENT

### RESEARCH TEAM

The main applicant is **Annelie Hedström**, associate professor, LTU, with broad experience from different water treatment applications and will specifically contribute with knowledge in zeolite filtration. She is also experienced in systems analysis and multi-criteria methods that will be conducted in WP5. Co-applicant **Prof Maria Viklander**, Urban Water, LTU, is one of the leading researchers in the urban water field with focus on urban hydrology, stormwater quality and treatment as well as stormwater systems in cold climates. She will be the main supervisor of the PhD students working in the project. Co-applicant **Prof Jiri Marsalek**, LTU, Scientist Emeritus at National Water Research Institute, Burlington, Canada, will contribute with his strong competence within urban water engineering. He is possibly the most distinguished researcher in urban drainage worldwide with special focus on cold climate issues. Co-applicant PhD **Inga Herrmann**, associate senior lecturer, LTU, carries a PhD in filtration with reactive filter materials and contributes with her competence within water treatment. Co-applicant PhD **Heléne Österlund**, researcher, LTU, supports the project with her knowledge in chemistry as well as experience in instrumentation of field sites. PhD student **Fredrik Nyström**, LTU, is currently working with preparatory flocculation tests. He has previous experience in laboratory testing and will mainly be in charge of the laboratory work in the project. A **new PhD student** will be recruited to the project and will be in charge of the test bed in Östersund as well as the systems analyses in WP 5. **Kerstin Nordqvist,** laboratory engineer, LTU, has many years of experience in both laboratory and field work and supports the laboratory experiments as well as the field samplings of this project.

### COLLABORATIONS

The work in this project is carried out in close collaboration with **four partners from industry** (Purac AB, Kemira AB, Järven Ecotech AB, Veg Tech AB), several **municipalities** (i.a. municipality of **Östersund**, Environment Directorate of **Stockholm** (miljöförvaltning), and municipalities taking part in the workshops, WP 5) and the **National Property Board of Sweden** (Statens fastighetsverk). The municipality of Östersund houses the test bed that will be used to investigate the stormwater techniques provided by the companies. The National Property Board of Sweden houses the full-scale zeolite filter unit for treatment of copper roof run-off at the Nationalmuseum in Stockholm. The Environment Directorate of Stockholm (miljöförvaltning) will use the results of the project when issuing licenses to similar facilities in future. Both LTU as the academic part in the project, the municipalities and companies have an equally great interest in studying these techniques so that we expect the studies to become an inspiring and successful teamwork.

The applicants at LTU have an extensive network of international collaborators, *inter alia* Environment Canada; University of Sheffield; Monash University, Australia; NC State University, USA. Within a collaboration between the Urban Water Group and the division of Fluid Mechanics, LTU, an important pre-study for this project is currently carried out (bottom grids for enhanced sedimentation, see WP 2).

### AVAILABLE EQUIPMENT

The Urban Water Research Group accesses an environmental laboratory with **laboratory equipment** including an **experiment hall** where experiments can be set up. The group has recently acquired a **particle size analyser,** an instrument for the determination of particle size distributions also including colloid sized particles that are important in stormwater. In addition, instrumentation **equipment** needed for the **field sites** is available to some extent from other on-going and completed projects (flow meters, automatic samplers, turbidity probes).

## SOCIETAL VALUES

The techniques studied in this project have potential to lift today's stormwater treatment to a considerably higher level. An improved treatment of stormwater is crucial at many locations where stormwater is heavily polluted and/or the receiving waters are at risk. Often, space is limited and therefore it is important to develop area-efficient treatment methods. Additionally, e.g. stormwater ponds and floating wetlands significantly contribute to an aesthetically pleasing cityscape. The further investigation and development of these techniques, including their treatment enhancement, as planned in this project, will increase their implementation. Our investigations on how treatment units can be sustainably integrated into stormwater systems will support the municipalities and thereby aid their implementation. Ponds do not only treat stormwater but also detain it so that their further implementation may also contribute to climate change mitigation; the effects of increasing precipitation on sewer systems causing increasing flooding risks in future to be moderated.

The proposed research shall increase the implementation of techniques for advanced stormwater treatment and has thus potential to contribute to reaching 6 of the **16 Swedish National Environmental Quality Criteria (miljökvalitetsmålen)**: Good built environment, Non-toxic environment, Zero Eutrophication, Flourishing Lakes and Streams, Reduced climate impact and Rich Diversity of Plant and Animal Live. Clean stormwater reaching our lakes and streams as well as aesthetically pleasing local stormwater treatment and detention will help creating sustainable and livable cities.

Stormwater treatment is increasingly gaining attention in Sweden. Adapting available techniques (membrane filtration, floating wetlands, air agitation, precipitation) to stormwater applications as well as to the Swedish climatic context will help to open a market for industry delivering solutions for stormwater treatment. Due to the growing interest in stormwater treatment, this project is of significant economic importance.

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