CONTROLLING ENVIRONMENTAL POLLUTION IN THE URBAN WATER CYCLE

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ABSTRACT

With the responsibility for stormwater, drinking water and wastewater, the water and wastewater sector handles a considerable amount of environmental pollution. In Sweden, the sector has developed strategies for reducing and controlling environmental pollution through a practice called 'upstream work'. 'Upstream work' consists of different strategies (e.g. mapping out industries, water sampling in the pipe system and information campaigns to the public) to hinder chemicals and other pollution from reaching the wastewater treatment plant. In this contribution, 'upstream work' is compared to the wider concept of source control to evaluate if there are any aspects of source control that can help develop 'upstream work'. Further, examples of tools, methods and approaches that facilitate source control and 'upstream work' are presented. A tool, method or approach can be used in different parts of the process of controlling environmental pollution and provide assistance with different challenges. Therefore, the efforts/measures are categorized based on which process step they address (identification, quantification, prioritization and control). Further, tools, methods and approaches that can be performed by the water and wastewater sector are highlighted. The categorization provides practical ways to work on controlling environmental pollution for organizations that currently work with source control and/or upstream work and for the organizations that have not started the process yet. Source control can provide insights to develop upstream work, especially for diffusing pollution. By developing 'upstream work' to include the entire urban water cycle, important steps towards a more sustainable urban water management are taken.

Keywords: drinking water, pollution abatement, pollution prevention, source control, stormwater, wastewater, water and wastewater sector, water management, water pollution, upstream work

1 INTRODUCTION

Environmental pollution from a wide range of sources is concentrated in urban areas [1]. With the responsibility for stormwater, drinking water production and wastewater treatment, the water and wastewater sector has to handle a significant amount of this pollution. In Sweden, the water and wastewater sector has developed strategies for reducing and controlling environmental toxins through a practice called 'upstream work'. According to the Swedish Water and Wastewater Association, 'upstream work' means to "hinder chemicals and other pollution at source in order to avoid introduction to the water cycle or cycle of nutrients" ([2], author's translation). The first 'upstream work' initiatives arose in the beginning of the 1960s and consisted of identifying and addressing releases of harmful substances from industries that damaged the pipe system and the treatment process at wastewater treatment plants (WWTP) [3, 4]. The term 'upstream work' was introduced in the beginning of the 1990s and referred to measures to increase sewage sludge quality [5] and it has had positive results [6]. In recent years, the positive effects of 'upstream work' on water quality in recipient water have obtained more attention and the first systematic attempts of 'upstream work' aimed at raw water have been introduced [7]. 'Upstream work' as a concept and practice is widely known in the water and wastewater sector in Sweden, but outside the sector and in the international community it seems fairly unknown. Source control is the most similar concept, although it is wider and can include strategies for different types of water as well as air, soil and sediments [8].

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Two ongoing EU projects are focusing on source control. NonHazCity (2016–2019) is a partnership between 18 cities around the Baltic Sea. The project will identify and prioritize sources of environmental toxins, specifically targeting households and other small emitters. The main aim is to reduce and prevent environmental toxins at source to avoid introduction to the sewer system and ultimately the Baltic Sea, with a particular focus on reducing consumption [9]. The SOLUTIONS project (2013–2018) focus on emerging pollutants and the project aim at developing a conceptual framework to support water quality policies with new approaches and tools for monitoring. The development of tools for identification as well as prioritization of water pollution is stressed in the project [10]. However, there are already established tools and approaches that can be useful for source control and 'upstream work' but it can be difficult for professionals to know when to use them [11].

In this contribution, the similarities and differences between the concepts *source control* and *upstream work* are examined, with the aim of understanding the aspects of source control that can help develop 'upstream work'. 'Upstream work' has traditionally mainly targeted wastewater (especially from industries) but this is changing. Amneklev [12] argues that 'upstream work' should be widened and applied to more areas, include more actors and tackle more substances. As source control is a broader concept, it might give some insights into how the practice of 'upstream work' can be expanded to include the whole urban water cycle. Further, I present an overview of some available approaches, methods and tools that can facilitate prevention and abatement of environmental pollution/environmental toxins in water, particularly suitable for use in the water and wastewater sector. I intend to answer the following research questions:

1. What similarities and differences do the concepts 'source control' and 'upstream work' have and what aspects of 'source control' can be used to develop 'upstream work'?
2. What efforts are available, internationally and in Sweden particularly, to facilitate control of environmental pollution that can be utilized by the water and wastewater sector?

International literature on source control and Swedish literature on 'upstream work' were examined to find definitions and examples of practical measures to be able to compare the concepts. As documentation on 'upstream work', especially the history, is rather limited, information is largely based on oral resources from professionals and grey literature. The overview of efforts to facilitate control of environmental pollution aims at being pragmatic and the categorization should be applicable both for organizations that already work with these issues and organizations that have not started to work with it yet. The ambition is not to present an exhaustive investigation of efforts for source control and 'upstream work', but to exemplify how one can go about preventing and reducing environmental pollution in an effective way and what is needed to do so. The efforts/measures did not have to be particularly developed for the water and wastewater sector to be seen as useful and hence included, but the information derived should be relevant for the sector. On this basis, several efforts/measures were discarded as they were so comprehensive that it was challenging to understand what the practical benefits and specific contribution of using it would be.

First, the development of 'upstream work' is described. Second, the differences and similarities between the concepts source control and 'upstream work' and the ways in which source control can give insights into the development of 'upstream work' are discussed. Last, categorized approaches, methods and tools for controlling environmental pollution are presented.

2 THE DEVELOPMENT OF 'UPSTREAM WORK' IN SWEDEN

The first step towards what today is referred to as 'upstream work' in Sweden was initiated in Stockholm and Gothenburg in the beginning of the 1960s. These first attempts were not called 'upstream work' but 'industrial wastewater control' in Gothenburg [4] and 'measures for treatment plants' in Stockholm [3]. In both cities, industries was the target group and the main aim was to protect pipe-system, pump stations and treatment processes [3, 4]. In 1976, the water and wastewater company in Gothenburg formed a working group to evaluate how the industrial wastewater was handled in the region [4]. The group changed its name from 'industrial wastewater control' to 'wastewater quality' in the 1980s to not denounce industries. The name was changed to the 'upstream unit' in 2008. By that time, 'upstream work' was an established concept.

During the 1980s, sewage sludge was spread on agricultural land without much regulation. When Sweden entered the European Union in 1994, the EU sludge directive from 1986 was to be implemented. However, the Federation of Swedish Farmers did not see the directive as strict enough [13]. Therefore, the so-called sludge agreement between the Federation of Swedish Farmers, the Swedish Environmental Protection Agency and the Swedish Water and Wastewater Association was formed. With the 'sludge agreement' the water and wastewater sector had to be able to demonstrate the practical measures that was taken to increase sludge quality and this marks the beginning of the term 'upstream work' [5]. The agreement was broken by the Federation of Swedish Farmers in 1999 following a debate on flame retardants [13]. After the disagreement, the Swedish Water and Wastewater Association initiated a new project to increase sludge quality, which was later developed into a certification system named Revaq. Today Revaq is a cooperative effort between the Swedish Water and Wastewater Association, the Federation of Swedish Farmers, the food industry & Swedish FMCG association [14]. The first WWTP was certified in 2008 and in 2015, 42 municipalities were certified. This translates into that slightly more than half of the Swedish population is connected to a certified WWTP [15]. With the implementation of the Water Framework Directive in the 2000s, 'upstream work' for water quality has become increasingly important [16]. In 2013, the Swedish Environmental Protection Agency recommended the Swedish government to legislate on an obligation for all WWTPs to initiate 'upstream work' [6].

3 COMPARISON OF UPSTREAM WORK AND SOURCE CONTROL

Source control and upstream work have a difference in that 'upstream work' focuses on avoiding introduction of environmental pollution in the water cycle or cycle of nutrients (i.e. sewage sludge), while source control does not particularly target water. Although the term 'source control' appears in the pollution literature, definitions are rare. An exception is Larsen and Gujer [17], who define source control as "the interaction of the consumer with industry that provides the goods and services the consumer desires" (p. 310). In this definition, the relationship between the industry and the consumer is highlighted, while upstream work focuses on the relationship between the water and wastewater utilities and industry as well as consumers and water and wastewater utilities. There are, however, several similarities in the practical application of the two concepts. Larsen and Gujer [17] give examples of substituting chemicals, on-site treatment in industries and segregated waste streams. The Revaq guidelines exemplify 'active upstream work' as mapping industries, requesting lists of chemical usage from connected enterprises, measuring pollutants in sludge and carrying out information campaigns to the public [18]. The measures are rather similar to what Larsen & Gujer exemplify with, although they focus on the industries and not the water and wastewater sector. A water and wastewater company can make use of legislation to pressure industrial companies to substitute chemicals and install treatment, but the industries have to implement the measures.

Eriksson et al. [19] use source control broadly (and calls it emission control strategies) as strategies to manage releases in different parts of the system, from the point of release to the receiving waterway. This says something important on the effectiveness of measures for reducing environmental pollution. The source (as in point of release) might not be the most effective way to control the pollution. Instead, the best alternative, seen as total reduction of pollution, can differ dependent on pollution and source. Therefore, a view of the whole urban water cycle is needed in order to find suitable places to intervene.

There are some indications that the focus on wastewater and sludge in 'upstream work' is beginning to change. The slogan for the Revaq certificate was changed in 2016 from focusing on sludge as a 'recycled crop fertilizer' to also emphasizing the benefits 'upstream work' has for water quality [20]. Further, a Swedish drinking water producer has initiated 'upstream work' for their water reservoirs [7]. To facilitate this broadened perspective, some aspects of source control can be useful. 'Upstream work' as a concept and practice was developed from needs to handle harmful substances in wastewater, which is probably why it works well for waters with clear boundaries, i.e. piped water. However, 'upstream work' for stormwater and raw water is not as widespread, although there are some initiatives. What source control can offer is systematic efforts from a widened perspective, more applicable to stormwater, such as best management practices [21] or raw water, such as source control interventions [22]. Considering the responsibility of the water and wastewater sector for the whole water and wastewater system, such a widened perspective is called for. By considering the whole system, the most suitable places to intervene can increase the effectiveness of the measure. As many environmental toxins are of persistent character, some measures only move pollution from one medium to another [8]. A widened perspective reduces the risk of measures only moving pollution between the medium.

4 APPROACHES, METHODS AND TOOLS FOR SOURCE CONTROL AND UPSTREAM WORK

In the area of environmental management in general and water management in particular, there are several approaches, methods and tools developed to ease the work. However, it can be difficult to know when to use which tool, method or approach. For effective source control and upstream work, there are some process steps that have to be taken and some approaches, methods and tools are more suitable for some process steps than the other.

4.1 Defining approach, method and tool

The use of approaches, methods and tools is often central part of a strategy/effort/initiative. These terms are regularly used in connection with environmental management, but they are rarely defined. de Ridder et al. [23] include methods, procedures and techniques in the term 'tool'. For the purpose of exemplifying practical ways to go about preventing and reducing environmental pollution, such a broad definition does not seem sufficient. van der Vorst et al. [24] instead separates approach from technique and tool, but argue that the three are connected. A *tool* is something used to perform an action. A *technique* is a tool with an added purpose, e.g. to inform decision-making. An *approach* is a technique with an intention or philosophical framing, e.g. sustainable development. These definitions demonstrate the different abstraction levels where *tool* is the most applied and describes something to be used when executing a specific task while *approach* is the most abstract and serves a greater goal. The term *technique* can, in this context, be problematic. In the water and wastewater sector, there has been a large focus and faith in technical solutions, something that has been critiqued [25]. Source control efforts and 'upstream work' can include technical solutions but is not limited to that. To avoid the risk of technique being associated to technical aspects, I instead use the term *method* to describe a process, with a specific purpose, to obtain new information. Hence, based on van der Vorst et al. [24], the definitions are as follows:

- A *tool* is something that is used to execute a certain task.
- A *method* consists of one (or several) tool(s) with a specific purpose.
- An *approach* provides a trajectory or loose structure, identified by a need, but does not provide detailed practical advice. It can consist of several methods but form a whole.

4.2 Analytical scheme

A tool, method or approach can be used in different parts of the process of controlling environmental pollution and provide assistance with different challenges. There are some general lists of harmful substances provided by, for example, the Water Framework Directive, but some substances are more prevalent in some areas than other [26]. Hence, *identifying* problematic substances in different types of water and tracing the sources are important [18]. When the problematic substances in the local context and their sources are identified, a *quantification* of sources and flows give information on where the largest sources are [12]. This information can then be used to *prioritize* between substances and sources [1]. However, as pointed out by Hörsing and Ledin [26], a prioritization should not only be based on quantities but also how harmful the substance is. Some substances do not even have to be quantified to be of high priority. This concerns, for example, the so-called 'phase-out' substances that the Swedish Chemicals Agency has decided on [27]. The water and wastewater company has the right to request an action plan from connected industries on how they plan to phase out these substances. A quantification of flows and sources also result in different source control options [1]. However, this requires that there are some source *control* options identified. In summation, the analytical scheme is as follows:

- Does the tool/method/approach help *identify* substances, sources or abatement strategies?
- Does the tool/method/approach *quantify* substances?
- Does the tool/method/approach help *prioritize* substances, sources or abatement strategies?
- Does the tool/method/approach *control* sources?

4.3 Ways to facilitate the process steps of source control and upstream work

The process steps (identification, quantification, prioritization and control) for source control and upstream work and approaches, methods and tools that can facilitate each of the steps are shown in Fig. 1. Some of these efforts can be executed by the water and wastewater company, while for some the results can support source control or 'upstream' initiatives.

4.3.1 Identification

Identifying what substances are present where and the sources is a prerequisite to be able to control environmental pollution. Two approaches to identify substances that can be used by the water and wastewater sector, preferably on a WWTP or water resource level, are *water characterization* and *source mapping*. It is important to characterize raw water in a drinking water reservoir or influent to a WWTP in order to receive information on what substances that have to be handled. Source mapping include identifying activities in a catchment area of a drinking water reservoir and in-water activities that may have an impact on water quality. For wastewater, identifying connected enterprises and their chemical usage is one way of mapping potential sources. EnvoMap is a tool specifically developed for the water and wastewater sector with the aim to aid the task of mapping enterprises. The programme is map-based and can visualize the connected enterprises in relation to the pipe system. The enterprises can further report their chemical usage directly into the system, whereby the chemical usage is scanned against priority lists of harmful substances [28].

Although enterprises might use harmful substances in larger quantities, households can together be responsible for a significant amount of the pollution through used products [26] and these contributions can be more difficult to identify. *Life cycle assessments (LCA)* is a method to assess environmental impact of products, services or other activities [24]. The chemical footprint (ChF) tool developed by Hitchock et al. [29] is based on LCA and can be particularly relevant for the sector when identifying sources. The chemicals in each ingredient in a product is investigated and the ingredient is scored based on parameters such as if it

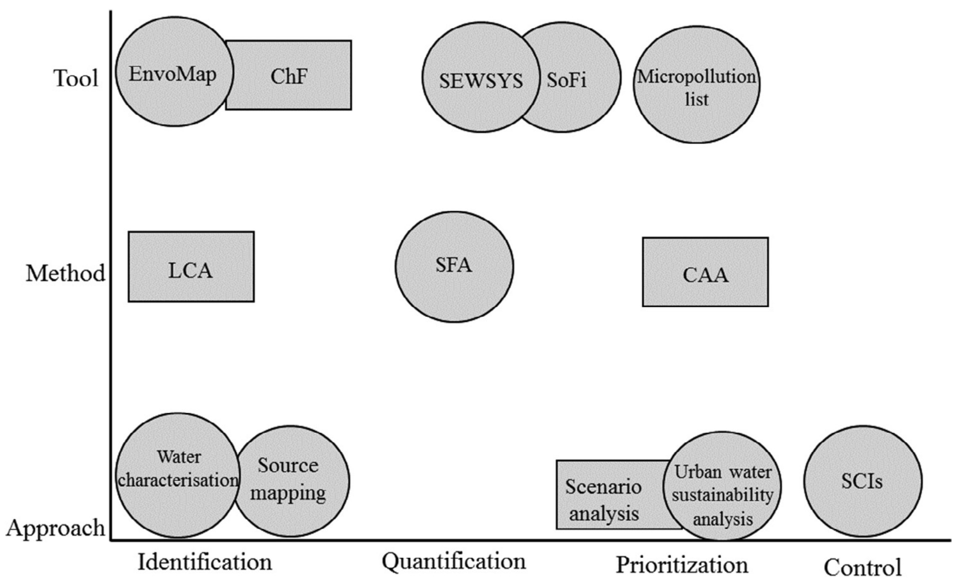

Figure 1: The efforts plotted as a result of type (y-axis) and which part of the source control facilitation process it operates on (x-axis). Circles indicate that it can be used by the water and wastewater company and rectangles indicate that the results can benefit the source control or upstream practice. Abbreviations: ChF (chemical footprint), LCA (life cycle assessment), SCIs (source control interventions), SFA (substance flow analysis), SoFi (Source Finder) and SEWSYS (Sewage System).

is carcinogen, toxic to aquatic organisms, and bioaccumulative, to make up the toxicity of the product. This information can be important to produce an overview of the potential threats to water or sludge quality from products used in households.

4.3.2 Quantification

After the substances and sources have been identified, the next step is to quantify them to get an understanding of significant flows. Substance flow analysis (SFA) is a widely used method for quantifying flows (i.e. sources, transport routes and recipients) of environmental pollution in a defined system [21]. It has been used to quantify, for example, silver flows [30], heavy metals from road traffic [31] and pharmaceuticals [32]. An SFA requires resources, both financial and in terms of competence, which can make it difficult for a small municipality to carry out SFAs themselves. Some general conclusions can be drawn from an SFA in one municipality to another, particularly concerning stocks, sources and involved actors, while measures to handle the flows is more difficult to make general conclusions about [33].

SEWSYS (SEWage SYStem) and *Source Finder* (*SoFi*) are tools based on SFA developed for the water and wastewater sector. SEWSYS simulates flows of some common substances in sewer systems [34]. Other factors that may influence quantity, such as corrosion rates and atmospheric deposition, are also included in the model [21]. SoFi is a calculation tool for heavy metals in influent water to WWTPs. This Excel-based tool uses a mixture of template- and measured data and can separate sources into household, stormwater (from combined systems), small and large enterprises, drainage water and leachate. A feature allows the user to test how certain efforts perform in reducing the overall quantity of the heavy metal pollution to the WWTP [35], which is why it is categorized as somewhere between the category quantification and prioritization.

4.3.3 Prioritization

Quantification of substances and flows allows for prioritization. Prioritization could be on a substance or sources level. It can also concern a prioritization among abatement strategies to get the most effective control.

On a substance level, there are several priority lists of substances that are perceived as particularly harmful. The *micro-pollution list* is a Swedish tool developed by Hörsing and Ledin [26] to help practitioners with their 'upstream work'. The list consists of organic micro-pollution present in sludge that poses the risk of being transferred to ground water or crops. The substances are based on the WFD-list, the SIN-list and the 'phase-out' substances decided by the Swedish Chemical Agency. The micro-pollution list can assist WWTPs when prioritizing what substances to focus on and develop control strategies for.

Chemical alternative assessment (CAA) is a method that can support water and wastewater companies with substitution [36]. A main aim of the method is to avoid the so-called 'regrettable substitution' where one toxic substance is substituted for an equally bad or worse one [37]. The assessment also considers if the substances are needed at all, such as with antimicrobial content in hand soap [36] or if the substances achieve what they are supposed to in a sufficient way, for example, if flame retards improve fire safety or increase escape time [37]. Although the water and wastewater company will not perform a CAA itself, insights from CAAs can be used by the water and wastewater company. This too, for example, prioritizes what substances to highlight in guideline, lobby for substitution of and substitute in their own facilities.

Scenario analysis is an approach that can be used to describe possible future developments [38]. By creating scenarios, different source control solutions and efforts can be tested. Scenarios for source control purposes generally need some type of input-data, and SFAs can be used as a basis for the scenario development (see, e.g. [21, 39]). The so-called prescriptive scenarios [40] are most relevant for practical source control efforts as they aim to give opportunity to plan for the future. Prescriptive scenarios are divided into 'forecasts' and 'what-if' [40]. The 'what-if'- type has been used for source control purposes in the EU project Score- PP (Source Control Options for Reducing Emissions of Priority Pollutants). The project used both technical (e.g. best available technology) and management-oriented scenarios (e.g. implementation of EU directives) in different medium, such as sewage sludge, groundwater, surface water, air and soil [19]. The study indicates that implementing EU directives should be prioritized. Carrying out a large-scale scenario analyses might be too time-consuming for an individual water and wastewater company, but the information derived from projects such as Score-PP can help prioritize between abatement strategies. When investigating different possible abatement strategies and prioritizing between them, there are several sustainability aspects to consider, such as available technology, economical feasibility, acceptance by the public and that the environmental benefits are secured. The urban water sustainability analysis is an approach aimed to address these issues, specifically developed for the water and wastewater sector. The analysis is based on a conceptual framework with three subsystems, namely technology, user and organization [41]. The framework also includes five criteria: hygiene, environment, sociocultural aspects, technical function and economy (for details, see [42]). This comprehensive approach will aid in choosing the most efficient and sustainable strategy.

4.3.4 Control

Controlling the identified, quantified and prioritized substances and sources is the last step of the process. Some general ways to control pollution is prohibition and substitution (legislative and voluntary) and de-centralized treatment in, for example, stormwater and by industries following best available technology (BAT) [19]. Prohibition can be on substance level such as with 'phase-out' substances or that certain activities (such as leachate from landfills) are not permitted to be connected to the WWTP [18]. However, there seems to be rather few examples of systematic approaches, methods and tools to be used in the control step.

Source control interventions (SCIs) is an example of a systematic approach. It is focusing on controlling pollution from farming practices to water reservoirs. SCIs are based on cooperation between farmers or land managers and the water and wastewater company. Four kinds of practical efforts are included in SCIs. 'Liaison', which is the most commonly used, consists of different types of collaboration such as data sharing. The other categories are 'lobbying', attempts to influence increased water protection, 'advice & support', such as investments on farms or compensation of land, and 'education' which include, for example, information brochures and communication efforts with the farmers. SCIs have mainly been used to handle pesticide problems as they pose a large problem to the drinking water quality and there is, at present, no feasible treatment option. Further, the approach has more often been used for surface water than for groundwater. When SCIs have been used for groundwater, it has been connected to nitrate abatement [22].

5 CONCLUSIONS

In this contribution, I have categorized approaches, methods and tools that can facilitate control of environmental pollution aimed at the water and wastewater sector. Different steps of the facilitation process require different efforts, which is why the approaches, methods and tools have been categorized based on if it assists in identification, quantification, prioritization or control. Dependent on where the organization is at with their own work, they can start at different levels. In addition, approaches, methods and tools that can be executed by the water and wastewater sector are separated from those where the results can inform the source control or 'upstream' practice. Moreover, source control and 'upstream work' as concepts and practices were compared and although there are several similarities, source control is a broader concept than 'upstream work'. Since 'upstream work' as a concept and practice is widening, there are some lessons to be learnt from source control, especially regarding stormwater and raw water. 'Upstream work' has a good foundation in the water and wastewater sector in Sweden. By expanding 'upstream work' to include more measures in the watercycle, important steps towards a more sustainable urban water management are taken.

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