A survey of 30 Swedish stormwater ponds - evaluation of pond design, maintenance needs and implications for practice

Inspection de 30 bassins de traitement des eaux pluviales en Suède - Evaluation de leur conception, leur maintenance, leurs besoins et enseignements pratiques

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RÉSUMÉ

L'inspection de 30 bassins d'eaux pluviales Suédois a révélé qu'approximativement la moitié de ceux-ci ne respectait pas les recommandations de conception actuelles. 5 des 30 bassins n'étaient pas du tout accessibles et 4 autres n'étaient pas accessibles par engins motorisés. Il s'agit d'une menace pour le fonctionnement à long terme de ces équipements étant donné que leur conception empêche toute maintenance. La majorité des bassins n'avait pas de chambre de sédimentation et 11 des 25 bassins accessibles avaient une faible efficacité hydraulique. Durant les inspections, plusieurs problèmes mineurs ont été détectés qui pourraient pourtant être réglés facilement par les municipalités. Des dépôts de sédiments ont été observés dans tous les bassins inspectés. Les concentrations de métaux dans ces dépôts étaient relativement basses, sûrement en raison des faibles quantités de fines retenues. En accord avec des études précédentes, ces travaux montrent que négligence, manque de maintenance et conception incomplète sont des problèmes récurrents pour les infrastructures de gestion des eaux de pluie. La réglementation aurait besoin d'évoluer en conséquences pour inclure des coefficients de sécurité lors de la conception de ces infrastructures et en exigeant leur inspection régulière. Il est également nécessaire que les gestionnaires d'équipements de traitement des eaux pluviales soient présents lors de la réception de ces équipements après construction.

ABSTRACT

A survey of 30 Swedish ponds revealed that about half of the ponds was not designed according to up-to-date recommendations. 5 of 30 ponds were not accessible at all and further 4 ponds not accessible for machinery. This is a threat to the long term function of these ponds since maintenance is prevented by design. A majority if the ponds did further lack a forebay; and 11of 25 ponds showed a poor hydraulic efficiency. When inspecting the ponds on site, several minor issues were detected which, however, could be repaired easily by the municipalities. All ponds retained sediment. The metal concentrations in this sediment were relatively low, maybe due to the relatively little amount of fines retained. Similarly to other field studies which evaluate the function of SCMs in field, this study shows that neglect, under-maintenance and insufficient design is an important issue for a relatively high number of SCMs. Regulators should thus include factors of safety in SCM design, assess SCM function conservatively and require regular inspection. Stormwater asset managers should be present at the final inspection and acceptance of each construction project which includes stormwater facilities.

KEYWORDS

Stormwater control measures (SCM), wet ponds, long term function, maintenance

INTRODUCTION

One of the mostly common stormwater control measure (SCM) in Sweden and worldwide are wet sedimentation ponds (VanLoon et al. 2000). The main treatment mechanism is sedimentation, but (depending on shape, depth, vegetation etc.) also other factors can contribute to the quality treatment. Forebays enable the deposition of coarse and gross solids as well as larger soil particles in a separate treatment step.

As all SMCs, stormwater wet ponds can only work efficiently if they are inspected and maintained frequently (Blecken et al. in press). However, the (rather limited) available data indicates that maintenance is often lacking, which may jeopardise the ponds' treatment performance (Starzec et al. 2005).

Visual inspections of inlet and outlet structures should be carried out regularly or after significant storms (EPA 1999). Malfunctions of the hydraulic structures, accumulation of debris and rubbish, erosion, and uncontrolled vegetation growth or die-off may cause problems (Blecken et al. in press). Maintenance includes especially the scheduled removal of the accumulated sediment (Heal et al. 2006).

The need to gather more data on the long term functionality and/or maintenance needs of existing SCMs rather than focusing exclusively on "showcase" pilot facilities has been highlighted (D'Arcy and Sieker 2015). Therefore, the main objective of this study were to survey the status of 30 wet ponds in 5 Swedish municipalities. The survey involved also classifying the ponds' design.

MATERIAL AND METHOD

30 Swedish municipal ponds between 3 and 33 years old, located in the Swedish cities of Malmö, Örebro, Växjö, Umeå, and Östersund were visited and inspected. Key characteristics of the ponds and their catchments were identified based on municipal data-sets.

An inspection and maintenance checklist based on the WSUD Technical Design Guidelines for South East Queensland Waterways, 2006 was used to determine the ponds' general status. The pond design was evaluated by checking if the ponds had a forebay, and estimating the ration between the pond area and the (impervious) catchment area as well as the ponds' hydraulic efficiency.

To determine the latter, an approach suggested by Persson et al. (1999) using a "λ-value" to describe the hydraulic efficiency (with $\lambda \leq 0.5$ indicating poor hydraulic efficiency, $0.5 < \lambda < 0.7$ indicating satisfactory hydraulic efficiency, and $\lambda > 0.7$ indicating a good hydraulic efficiency) was used. The shapes and inlet/outlet locations of the ponds were determined from maps and aerial photos and compared to the geometries of the 13 basins layouts studied by Persson et al. (1999), and the most appropriate efficiency values were adopted (or interpolated) from this reference. The hydraulic efficiency parameter λ indicates how evenly the flow velocities and tracer concentrations are distributed throughout the pond, and the occurrence of "dead" (recirculation) zones is avoided

In August and September 2013, sediment samples were collected from bottom sediment to the inlets and outlets of 25 ponds (5 ponds were not accessible, see below). All sediment samples were analysed for particle size distribution (PSD) and total Cd, Cr, Cu, Ni, Pb and Zn concentrations using standard methods.

RESULTS AND DISCUSSION

Pond Design

Maintenance accessibility

Adequate maintenance and inspection access is a pre-requisite for securing a pond's long-term function (Larm 2000). Swedish design recommendations also highlight the fundamental importance of maintenance access (Larm 2000). However, 9 of the 30 ponds were not readily accessible to inspectors or machinery. Five of the ponds could not even be accessed on foot, and therefore could not be inspected at all (Figure 1). This is a major problem because it means that 30% of the visited ponds were designed in a way that prevented maintenance. The large number of inaccessible ponds in the group chosen for study is thus somewhat surprising.

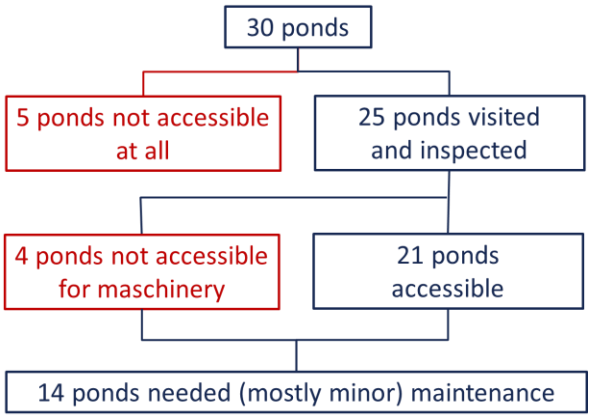

Figure 1: Accessibility of the surveyed ponds

Hydraulic efficiency

The hydraulic efficiency model of Persson et al. (1999) describes the hydraulic efficiency of a pond using lambda (λ), which depends on the pond's shape, the location of its inlet and outlet, and its flow distribution. Of the 25 accessible ponds, 11 ponds showed a poor hydraulic efficiency ($\lambda \leq 0.5$), four ponds a satisfactory hydraulic efficiency ($0.5 < \lambda < 0.7$) and 10 ponds a good hydraulic efficiency ($\lambda > 0.7$). The fact that relatively many ponds were improperly designed could reduce their effectiveness at treating sediments and associated metals. A principal component analysis indicated that the λ-values were clearly correlated with both the percentage fine sediment retained in the ponds and high metal concentrations (see below).

Sediment forebay

To fit a sediment forebay in pond designs is commonly recommended to improve their efficiency of pollutant removal because forebays effectively trap coarser (often less polluted) sediments and thereby facilitate sediment removal and disposal (EPA 1999, Larm 2000, Sansalone and Buchberger 1997). However, only 7 of the 25 evaluated ponds had a forebay. Although the lack of a forebay does not necessarily impair a pond's function, it does generally impede sediment removal.

Survey Results

Most of the accessible 25 ponds were in relatively good condition. About half of them was in need of (minor) maintenance, mainly due to sediment and litter accumulation at their inflow and outflow points. Only one major issue was detected: the outlet structure of one pond was found to be damaged and leaking. However, the municipality was aware of this leakage and it was repaired shortly after our inspection which underlines the need for municipalities to regularly inspect SCMs to detect damage as early as possible. The fact that the inspection survey revealed relatively few minor issues that could be easily corrected demonstrates the importance of relatively simple regular inspections serving to detect minor problems at an early stage, before they would seriously impact on pond functioning.

The scope of the survey was limited by incomplete data available in municipal records. Besides some of the missing basic pond characteristics, some other relevant data, e.g. design criteria (detention time, multiple peak flow controls, sediment storage volume, sediment influx to the ponds, pond geometry including bathymetry, etc.) were not readily available from the municipal records. This lack of basic pond information implies risks for successful operation of, and maintenance planning for, these facilities.

Sediment

The distribution of sediment particle sizes varied widely among the 25 ponds. In most cases (16 of 25) only minor percentages of fines (silt and clay) were retained in the ponds. In contrast, in nine ponds, the percentage of these fines exceeded 50%.

The metal concentrations measured in the pond sediment were assessed against the Swedish EPA guidelines (Swedish EPA 2000) for the protection and management of receiving water bodies and ecosystems. The Pb and Cd concentrations were in the class I range (i.e. very low concentrations), corresponding to levels that are not expected to cause adverse effects (Swedish EPA 2000).

Approximately 40% of the ponds had sediments with Cr, Cu, Ni, or Zn concentrations in the class III range, which can have adverse biological effects on the receiving waters, in the remaining ponds these concentrations were low (class I and II). It is clear that these ponds are having beneficial effects on their receiving bodies of water because they are retaining this relatively highly polluted sediment. The high number of ponds with relatively low metal concentrations may be due to the relatively coarse material given that heavy metals are most strongly associated with fine-grained fractions (Sansalone and Buchberger 1997).

Correlation of percentage fines, sediment metal concentrations and pond design

A PCA was performed to an overview of the significance and correlations of the factors affecting the ponds' treatment performance indicators, namely the metal concentrations and proportion of fines in the accumulated sediments. The factors added were age, λ-value, and ratio pond area/impervious catchment area.

The PCA reveals that the metal concentrations in the sediment close to the inlet, the ratio of pond area/ impervious catchment area, the Cr and Ni sediment concentrations at the outlet, the percentage of fines, and the λ-values are correlated (PC1). The Cd, Cu, Pb, and Zn sediment concentrations at the outlet and pond age are grouped together along the second component (PC2). The λ-values correlate with the fine sediment fractions and metal concentrations underlining the importance of careful design.

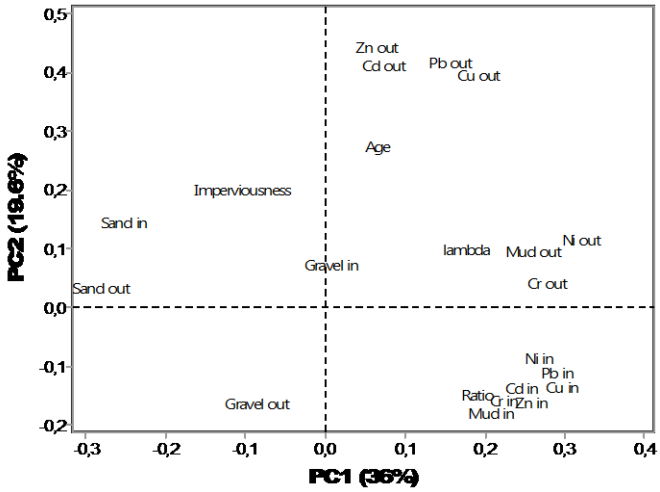

Figure 2. Loading plot for principal components 1 and 2 obtained from a PCA of sediment metal concentrations (close to the inlet and outlet), sediment PSD, pond age, ratio of pond areas impervious catchment area, and lambda (λ).

Conclusions

In conclusion, although several minor issues were detected, the surveyed ponds were in satisfactory condition and all of the detected issues could be corrected with relatively little effort. However, none of the identified issues would have been rapidly detected during standard inspections due to the general lack of regular inspection schedules and inspection access. The need to regularly inspect and evaluate the functioning of existing SCMs that have been in operation for long time should be highlighted to improve and optimize the design of these systems. However, one alarming result of this study is that 1/3 of the ponds were designed and operated in a way that would prevent detection of these or other issues during a standard inspection because there was no regular inspection regime or no maintenance access.

Given that this and other studies which show neglect, under-maintenance and/or insufficient design of SCMs (Al-Rubaei et al. 2013, Starzec et al. 2005, Wardynski and Hunt 2012, Lindsey et al. 1992), regulators should (i) include factors of safety in the SCM design allowing for partial failure of the systems, (ii) assess the SCM performance conservatively to avoid assuming too positive performance and (iii) clearly require regular (e.g. annual) inspection of the facilities (Blecken et al. in press). Stormwater asset managers should be present at the final inspection and acceptance of each construction project which includes stormwater facilities. Besides right design, long-term maintenance is crucial for SCM functionality and must be regarded if LID, SUDS or WSUD should be successful

concepts in the long run.

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