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Urban drainage and highway runoff in cold
climates: Conference overview

By:

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M. Viklander, J. Marsalek, P.-A. Malmquist and W.E. Watt

Abstract

Overview of research findings presented at the conference on urban drainage and highway runoff in cold climates starts with generation of urban runoff and snowmelt, followed by snowmelt and winter runoff quality, best management practices for urban snowmelt and winter runoff, and snow management in urban areas. Research on the urban hydrological cycle is lagging behind the needs in this field, particularly in terms of data availability. The current studies of winter urban runoff quality focus on road salts in the urban environment and their environmental effects. The needs for better source controls in salt applications, improved management of chloride-laden runoff, and selective adoption of environmentally safer alternative de-icers were reported. Adaptation of the conventional stormwater best management practices (BMPs) for winter operation remains a challenge. The first step in refining the existing BMPs for winter operation is to advance the understanding of their operation, as reported for some cases at the conference. Finally, snow management in urban areas may require local storage of fresh (unpolluted) snow and disposal of more polluted snow at central snow disposal sites.

Key Words: urban snowmelt, winter runoff, snowmelt generation, water quality, environmental effects.

Drainage urbain et ruissellement des routes dans les climats froids : aperçu de la Conférence

M. Viklander, J. Marsalek, P.-A. Malmquist et W. E. Watt

Résumé

Aperçu des résultats des recherches présenté à la Conférence sur le drainage urbain et le ruissellement des routes dans les climats froids. On a examiné successivement les questions de la production des eaux du ruissellement urbain et de la fonte des neiges, de la qualité des eaux de fonte des neiges et de ruissellement d'hiver, des meilleures pratiques de gestion pour les eaux de fonte des neiges et de ruissellement d'hiver, ainsi que de la gestion des neiges dans les régions urbaines. La recherche sur les cycles hydrologiques urbains accuse un certain retard par rapport aux besoins dans ce domaine, notamment pour ce qui est de la disponibilité des données. Les études actuelles sur la qualité du ruissellement urbain en hiver examinent les effets des sels de voirie en milieu urbain, ainsi que dans l'environnement. On a indiqué qu'il faut limiter plus efficacement la pollution due aux applications de sels de voirie, mieux gérer les eaux de ruissellement riches en chlorure, et favoriser l'adoption sélective d'autres composés de déglacage moins nocifs pour l'environnement. L'un des défis à relever est l'adaptation aux conditions hivernales des meilleures pratiques de gestion (MPG) des eaux pluviales. Au cours de la conférence, plusieurs intervenants ont dit que, à cette fin, il faudrait d'abord mieux comprendre le fonctionnement de ces pratiques. Enfin, pour la gestion de la neige dans les régions urbaines, il peut être nécessaire de stocker sur place la neige fraîche (non polluée) et de transporter la neige polluée dans des sites d'élimination centraux.

Mots-clés: fonte des neiges dans les régions urbaines, ruissellement d'hiver, production d'eau de fonte des neiges, qualité de l'eau, effets sur l'environnement.

NWRI RESEARCH SUMMARY

Plain language title

Urban drainage and highway runoff in cold climates: conference overview

What is the problem and what do scientists already know about it?

Cold weather imposes special requirements on urban and highway drainage, caused by storage of snow and pollutants in the catchment snowpack, snowpack processes, and changes in runoff and snowmelt flows brought about by snow and ice. Such processes are particularly strong on urban roads and highways subject to high deposition of pollutants. Consequently, the resulting runoff and its poor quality differ from those observed in warm weather. Thus, snowmelt and winter runoff discharged from urban and highway drainage structures require further study with respect to advancing the understanding of these sources of pollution and developing best runoff management practices for winter conditions.

Why did NWRI do this study?

NWRI has been working on improving the understanding of stormwater and highway runoff pollution, and the best management practices (BMPs) for controlling such pollution sources. Collecting new knowledge on stormwater and highway runoff quality during winter months will supplement the earlier research findings and contribute to better management practices taking into account winter conditions.

What were the results?

The overview paper summarized the findings of a specialty conference addressing this topic. The important findings include the following: (a) research on the winter urban hydrological cycle is lagging behind the needs in this field, (b) road salts were reported as the most significant pollutant found in winter runoff, (c) better controls of salt applications are needed, (d) further research on environmentally safer (than road salt) de-icers is needed, (e) conventional stormwater management practices need to be better adapted to winter runoff conditions, and (f) used snow management in urban areas may require new strategies comprising local storage of fresh (unpolluted) snow and central disposal of polluted snow.

How will these results be used?

These results will be used by urban planners and municipal engineers in controlling winter snowmelt and highway runoff pollution.

Who were our main partners in the study?

This overview was prepared in cooperation with three external collaborators - Maria Viklander (Lulea University of Technology, Sweden), Per-Arne Malmquist (Chalmers University of Technology, Sweden) and Ed Watt (Queen's University, Canada).

Sommaire des recherches de l'INRE

Titre en langage clair

Drainage urbain et ruissellement des routes dans les climats froids : aperçu de la Conférence

Quel est le problème et que savent les chercheurs à ce sujet?

Les climats froids imposent des exigences spéciales pour le drainage des eaux urbaines et routières, à cause du stockage des neiges et des polluants dans la zone de captage de la neige accumulée, des processus qui s'exercent sur la neige accumulée, ainsi que des changements dans les écoulements alimentés par le ruissellement et la fonte des neiges, sous l'effet de la neige et des glaces. Ces processus sont particulièrement importants sur les routes urbaines et sur celles qui reçoivent de forts dépôts de polluants. Pour toutes ces raisons, les caractéristiques du ruissellement produit et de sa pollution sont différentes de celles qu'on observe dans les climats chauds. Ainsi, pour mieux comprendre ces sources de pollution et pour développer de meilleures pratiques de gestion du ruissellement dans des conditions hivernales, il faut effectuer des études supplémentaires sur les eaux de fonte des neiges et de ruissellement d'hiver déversées par les ouvrages de drainage urbains et routiers.

Pourquoi l'INRE a-t-il effectué cette étude?

L'INRE travaille à l'amélioration des connaissances sur la pollution des eaux pluviales et de ruissellement des routes, ainsi qu'à celle des meilleures pratiques de gestion (MPG) pour la limitation de ces sources de pollution. La collecte de nouvelles données sur la qualité des eaux pluviales et de ruissellement des routes pendant l'hiver devrait compléter les résultats des recherches antérieures et contribuer à améliorer les pratiques de gestion en prenant en compte les conditions hivernales.

Quels sont les résultats?

Cet aperçu résume les résultats d'une conférence spécialisée sur ces questions. Les conclusions les plus importantes sont notamment les suivantes : a) la recherche sur le cycle hydrologique urbain hivernal accuse un certain retard par rapport aux besoins dans ce domaine; b) les sels de voirie sont les polluants les plus importants observés dans les eaux de ruissellement d'hiver, c) il faut améliorer les mesures de limitation de la pollution des applications de sels, d) il faut effectuer des études supplémentaires sur des agents de déglacage moins nocifs pour l'environnement (que les sels de voirie); e) il faut mieux adapter aux conditions de ruissellement d'hiver les pratiques ordinaires de gestion des eaux pluviales et f) de nouvelles stratégies peuvent être requises pour la gestion des neiges polluées dans les régions urbaines, notamment le stockage sur place de la neige fraîche (non polluée) et l'élimination de la neige polluée dans un site central.

Comment ces résultats seront-ils utilisés?

Ces résultats devraient servir aux planificateurs urbains et aux ingénieurs municipaux pour la limitation de la pollution des eaux de fonte des neiges et de ruissellement des routes en hiver.

Quels étaient nos principaux partenaires dans cette étude?

On a rédigé cet aperçu en coopération avec trois chercheurs de l'extérieur, Maria Viklander (Université technologique de Lulea, Suède), Per-Arne Malmquist (Université technologique Chalmers, Suède) et Ed Watt (Université Queen's, Canada).

Urban drainage and highway runoff in cold climates: Conference overview

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Abstract

Overview of research findings presented at the conference on urban drainage and highway runoff in cold climates starts with generation of urban runoff and snowmelt, followed by snowmelt and winter runoff quality, best management practices for urban snowmelt and winter runoff, and snow management in urban areas. Research on the urban hydrological cycle is lagging behind the needs in this field, particularly in terms of data availability. The current studies of winter urban runoff quality focus on road salts in the urban environment and their environmental effects. The needs for better source controls in salt applications, improved management of chloride-laden runoff, and selective adoption of environmentally safer alternative de-icers were reported. Adaptation of the conventional stormwater best management practices (BMPs) for winter operation remains a challenge. The first step in refining the existing BMPs for winter operation is to advance the understanding of their operation, as reported for some cases at the conference. Finally, snow management in urban areas may require local storage of fresh (unpolluted) snow and disposal of more polluted snow at central snow disposal sites.

Key Words: urban snowmelt, winter runoff, snowmelt generation, water quality, environmental effects.

Introduction

Planning, design and operation of urban drainage has evolved greatly over the last 30 years. During this period, good understanding of stormwater runoff impacts on the environment has been developed and led to the introduction of stormwater management, which attempts to mitigate such impacts by runoff controls. Towards this end, various non-structural and structural best management practices (BMPs) have been developed and used extensively for effective control of runoff flows and somewhat less effective control of stormwater quality. It should be noted, however, that much of this progress has originated and been achieved in the areas of fast population growth, which typically exist in warm and temperate climates, usually without significant snowfalls or freezing temperatures (Marsalek *et al.*, 2003a).

Recently, more attention has been paid to the differences in urban drainage design and operation in various climates, and it was noted that such differences can be rather significant and should not be ignored. In particular, it was reported that drainage in cold climates operates rather differently from

that in snow and ice free climates and not enough attention has been paid to this fact (Marsalek, 1991). Specifically, during cold weather, precipitation in the form of snow and ice may accumulate on the catchment surface and store water, sediment, litter and various chemicals associated with urban land use. The rates of chemical accumulation seem to exceed those corresponding to warm weather, because of heating, less efficient operation of vehicles, and application of de-icing and antiskid materials. During snowmelt, or rain-on-snow, the accumulated water, sediment, chemicals and other materials may be quickly released and exert impacts on the receiving waters. The resulting runoff may cause acute and chronic impacts on aquatic ecosystem in the receiving waters.

To partly close the gap between the knowledge base on urban drainage in cold climates and the needs for such information, and to stimulate further research in this field, the Division of Sanitary Engineering of Luleå University of Technology, in cooperation with many other agencies, including IAHR and IWA, held an international conference on urban drainage and highway runoff in cold climates, in Riksgården, Sweden, from March 25 to 27, 2003. The conference attracted almost 70 participants from 10 countries. The conference program comprised 31 presentations dealing with issues such as winter impacts of urban drainage on water quality and the environment, effects of chloride on receiving waters and toxicity of metals in highway runoff, the fate of aircraft de-icing fluids, urban hydrology and snowmelt in cold and alpine climates, management and planning for impact mitigation, and treatment facilities for storm water quality enhancement, including green roofs, roadside ditches, and ponds. The main purpose of this overview paper is to review the new findings presented at the Riksgården conference. Where required for the sake of continuity, references are made to other papers outside of the conference. The material discussed is divided into four major sections – urban runoff and snowmelt, quality of snow and snowmelt, best management practices for urban snowmelt and winter runoff, and snow management in urban areas.

Urban Runoff and Snowmelt

Urban areas in cold climate regions experience drainage problems and riverine flooding that differ from those in more southern regions because of snowmelt and rain-on-snow events. Thorolfsson (2003) documents urban drainage problems in North European Atlantic regions associated with a cold climate. He notes that runoff conditions during winter are strongly affected by five factors: 1) frozen ground, 2) snow on the ground, 3) rain on snow, 4) snow drifting and 5) snow redistribution. Examples of extreme floods in urban areas were provided for three northern cities: Trondheim, Vestmannaeyjar and Reykjavik. In each case the flood was caused by concurrent rainfall and snowmelt on frozen ground. Often the flooding is exacerbated by reduced capacity of inlets due to clogging by snow and ice. Thorolfsson (2003) also discusses the problems associated with both stormwater discharges (higher concentrations of suspended sediment and chloride) and combined sewer discharges, which are higher during snowmelt periods, and can occur in mid-winter because of rain-on-snow and snowmelt. The winter problems in combined sewers include combined sewer overflows and low temperatures of wastewater reaching the treatment plant. He concludes by calling for new procedures for urban drainage specifically for cold climate regions.

Not all cold climate regions are consistently cold for the entire winter. Indeed, as noted above, it is the warmer spells that often cause drainage and flooding problems. Because most urban drainage infrastructure has a long service life, the question of a changing climate is quite relevant. Semadeni-Davies (2003) addresses the issue of a changing climate in northern urban areas. Using the example of wastewater inflows related to sewer infiltration for a small town in Sweden, Lycksele, she presents the range of plausible changes in inflow for three climate scenario envelopes, the 2020s, 2050s and 2080s, which were derived from a number of Global Circulation Model (GCM) runs. She uses the tool of response surfaces to present the results that winter flows are currently sensitive to

temperature, but if temperature rises, inflow will become more sensitive to precipitation. Spring inflows are sensitive to winter snow accumulation and melt. For the case study selected, inflows could decrease by 10 % or increase by 5 % depending on the gas emission scenario and GCM selected.

Knowledge of the urban hydrological cycle in cold climate regions is essential for the planning, design and operation of urban drainage infrastructure. Long-term data collection networks are essential in order to acquire this knowledge. Thorolfsson *et al.* (2003) describe the year-round data collection system at the Risvollan urban hydrological measuring station in Trondheim, Norway. Year-round, short time-resolution data for short-term precipitation, stormwater flow, air temperature, and rainfall-snowmelt rate have been collected since September 1986 using two independent data collection systems. One system is operated by the Norwegian Water and Energy Administration. The other, which is operated by the Department of Hydraulics and Environmental Engineering, also collects data on wastewater flow, solar radiation, humidity, wind speed, wind direction and ground temperature. In addition, data on snow water equivalent for three snow courses in the catchment have been collected once a week in the winter since 1993. They present details on the measurement of all variables and discuss their experiences on operating the system since its inception, including the value of having two systems and principal causes of data losses (extreme floods and very low temperatures).

One variable in the urban hydrological cycle is the amount of water in snow storage on the catchment, which is usually calculated as the product of snow water equivalent at selected "points" and the area of snow cover that this point represents. This variable is an essential input to snowmelt runoff simulation models. Snow pillows, snow gauges or snow surveys can determine the snow water equivalent. For larger watersheds, the area of snow cover can be determined by satellite imagery. Matheussen and Thorolfsson (2003a) present a method to estimate the snow covered area for small catchments using images taken with a digital camera located on the top of a tall building and using artificial neural networks (ANN) to calculate fractional snow cover within three land cover types: roads, parks, and roofs. The method was tested for a small urban catchment in Trondheim, Norway (Risvollan). Snow covered areas determined using the digital camera ANN method were compared with those determined from air photos: the results showed strong correlation.

One problem with the development of urban runoff models in cold climate urban areas is the spatial variation of the snowmelt (compared to the spatial variation of rainfall in southern areas). This spatial variation is due to the spatial variation of snow depth (due to snow redistribution and variable melt rates) and the resulting spatial variation of snow covered area as discussed above. Matheussen and Thorolfsson (2003b) describe the development and application of a Gridded Urban Hydrological Model to simulate snow water equivalent, snow covered area, and runoff for the Risvollan Urban Catchment. The model has a temporal resolution of 1 hour and a spatial resolution (grid cell) of 2x2 metres. Grid cells are assigned one of five possible land use types (road, roof, wall, park, and shoulder). The model results are promising in that it is able to reproduce the water balance of an urban catchment.

Semadeni-Davies and Matheussen (2003) review the progress in urban snow hydrology in the 13 years since the International Conference on Urban hydrology under Wintry Conditions, which was held in Narvik, Norway in March 1990. Their review concentrated on their own research at Lund University in Sweden and the Norwegian University of Science and Technology in Trondheim. They identified the following challenges for the future: better representation of snowpack heterogeneity, snow energy balance and surface characteristics; and, improved spatial and temporal

resolution. A sobering conclusion is that whereas snow hydrology is at the heart of cold region urban drainage, there are few researchers working in this field. We might add the distressing observation that Canada and the United States, with their many northern cities, have very few researchers active in this field and most of these are not at the beginning of their careers as are the authors of this paper.

Quality of urban and road snowmelt and winter runoff

The quality of urban snowmelt and winter runoff has been discussed in a review paper by Marsalek *et al.* (2003a). This discussion focused on pollutant sources, including airborne fallout, roadway and roadside deposits, and de-icing and anti-skid agents; pollutant release from snowpacks, including preferential elution, delayed elution and in-situ residuals after the snowmelt; pollutant transport with runoff and removal with used snow; and, the assessment of snowmelt/runoff quality and environmental effects. The authors concluded that cold climate strongly affects the design and operation of urban drainage systems; urban snowmelt and winter runoff convey disproportionately high loads of specific pollutants at potentially acutely toxic levels; and ultimately, discharges of urban snowmelt and winter runoff may lead to reduced biodiversity in waters receiving such discharges. These findings indicated the need for development of new, and adaptation of the existing, management practices for cold climate conditions.

In terms of new research, the Riksgården conference program indicated great interest in road salts in urban snowmelt and winter runoff. Among the six papers reviewed in this section, one was devoted to seasonal variations in road runoff quality (Westerlund *et al.*, 2003), and the remaining five dealt with road salts in snowmelt and winter runoff.

Road runoff quality

Westerlund *et al.* (2003) reported results from two-month measurements covering both snowmelt and rain generated runoff events at a road site in Luleå, Sweden, with the traffic density of 7400 vehicles/day. The samples collected at the site were analysed for suspended solids and heavy metals (Pb, Cu, Cd, Ni and Zn). It was observed that the highest concentrations of suspended solids and particulate heavy metals occurred during the rain-on-snow events, followed by snowmelt and rain-on-snow-free catchment events. For the dissolved metal fractions, the results were inconclusive. Finally, the results also showed that during snowmelt events, the heavy metals were particle-bound to a higher degree than in the rain events. Similar results were reported by Sansalone and Buchberger (1996) in a study in Cincinnati, Ohio.

Road salts in winter urban and highway runoff

Early concerns about road salts in winter urban runoff and snowmelt appeared in the literature about 30 years ago in connection with road salting for winter road maintenance and its impacts on the environment (Field *et al.*, 1974). Indeed, during the past 50 years, large quantities of salt have been used for road maintenance and found to impact on soil structure and fertility (Amrhein *et al.*, 1992), vegetation (Field *et al.*, 1974), surface water and groundwater water quality (EC&HC, 2001), receiving water ecosystems (Crowther and Hynes, 1977), and the built environment (Lord, 1989). Five papers at the Conference were devoted to some of these issues, including transport of road salts in urban streams (Ruth *et al.*, 2003), a lake (Thunquist, 2003), and several stormwater/snowmelt BMPs (Marsalek, 2003); salting impacts on groundwater quality (Ojala *et al.*, 2003); and, source control of road salt applications by substitution of less harmful de-icers (Hellsten and Nysten, 2003).

Ruth (2003) studied road salt transport in three urban streams in Helsinki (Finland) and estimated that about 35-50% of road salts applied on Helsinki roads is transported away with surface runoff and into the sea. This transport causes high concentrations of road salt in urban streams (up to 1300 mg/L, or about 500 mg/L of sodium and 800 mg/L of chloride) and conveys in an average winter about 4000 tonnes of salt from the City of Helsinki to the sea. With respect to salt ion concentrations in streams, the reported values were comparable to those cited by Marsalek (2003) for Toronto urban creeks (chloride concentrations ranging from 250 to 1390 mg/L; e.g., Howard and Hayes, 1997) and reported by Marsalek *et al.* (2003b) for an on-stream stormwater pond (chloride concentration of 1000 mg/L). Ruth (2003) further surmised that the observed salt concentrations would cause adverse environmental effects in urban streams. Specific concerns were expressed about the observed high levels of zinc (and possibly of other heavy metals as well) associated with high salt concentrations; however, the origin of zinc (traffic or leaching of urban soils and sediments) could not be determined. Similar environmental concerns about the risk of metal leaching by chloride-laden runoff were also expressed by Thunquist (2003) and observed by Hellsten and Nysten (2003) in their study of de-icer transport through laboratory filter columns and at a field site. Practically all inorganic and organic de-icers contributed to metal leaching from soils, but only manganese and sodium concentrations exceeded the values of drinking water requirements of EU (Hellsten and Nysten, 2003).

Thunquist (2003) proposed a relatively simple yet effective mass balance model for estimating chloride influx into two lakes (Lake Böksjön and Lake Glottern) serving for municipal water supply. The first lake with a volume of almost $2 \times 10^6 \text{ m}^3$ is impacted by runoff from a four-lane European Highway E4. The second lake is smaller ($V = 1.5 \times 10^6 \text{ m}^3$) and there are no major roads in its catchment area. Chloride concentrations in the influx to the lakes were estimated from the recorded road salt applications and estimates of runoff volumes. In the lake abutting on highway, the observed and estimated chloride concentrations agreed well for the range of chloride concentrations from 25 to 50 mg/L; only the spring 1999 observations (up to 83 mg/L of chloride) were underestimated by up to 40% during a period of 2-3 months. It was suggested that the estimates of these peak concentrations would require detailed numerical modelling reflecting lake dynamics.

Marsalek (2003) analysed operation of BMPs in cold climate and noted that some stormwater management practices may increase road salt impacts on the environment. The main impacts discussed included contamination of groundwater by chloride and leached chemicals caused by infiltration of chloride-laden runoff and snowmelt; chloride accumulation in oil and grit separators, interfering with solids settling and potentially causing chloride shock loading; chloride accumulation in stormwater ponds, causing toxic effects in ponds and inhibiting vertical mixing and aeration of bottom layers, and potentially causing release of chemicals from bottom sediments; and, adverse effects on wetland vegetation.

Concerns about transport of road salts into Swedish groundwater supplies were described by Ojala *et al.* (2003). The Geological Survey of Sweden and the Swedish National Road Administration started a joint project focusing on monitoring chloride concentrations at selected sites, where road salt impacts on municipal water supplies were reported. Similar concerns about road salting impacts on groundwater quality were reported by Marsalek (2003) who cited road salt impacts on water utility wells in Madison Wisconsin (Madison Department of Public Health, 2000; chloride concentrations up to 54.4 mg/L), chloride concentrations in water table wells in the Minneapolis / St. Paul area of USA (Andrews *et al.*, 1999; up to 330 mg/L), chloride leaching from salt storage into the Heffley Creek community source water in British Columbia, Canada (EC&HC, 2001;

chloride concentrations more than 3000 mg/L), and chloride levels in 23 springs in the Toronto area (Williams *et al.*, 2000; chloride concentrations ranging from 2 to 1200 mg/L).

Because of the harmful effects of road salts on the environment, the means of salt impact mitigation were studied as early as 1965, focusing on reducing de-icing chemical usage and looking for less harmful substitutes. The main directions taken in these efforts included studies of alternative de-icers, reduced chemical usage, improved operation practices, pavement heating, pavement modification, and mechanical approaches (Lord, 1989). While there has been some success in these efforts and salt usage has been reduced from the historical highs reached in the late 1970s (Lord, 1989), the current concerns about the levels of salt usage in Canada, Scandinavia and USA confirm the continuing large usage of salt for winter road maintenance and the resulting environmental problems (EC&HC, 2001). Only one conference paper dealt with salt impact mitigation by alternative de-icers. Hellsten and Nysten (2003) studied migration of road salt and five alternative de-icers (calcium chloride, magnesium chloride, calcium-magnesium-acetate, potassium acetate and potassium formate) in aquifers. The main topics addressed included heavy metals leaching from roadside soils and an in-vitro study of de-icer degradation. It was noted that sodium chloride extracted more heavy metals from contaminated soils than acetate and potassium formate. Furthermore, chloride does not degrade in soil and groundwater, whereas formate and acetate do. Formate biodegradation in the unsaturated zone caused fewer changes in the quality of water than chlorides. Bioremediation indicated that toxicity of alternative de-icers varied greatly and the organic de-icers were more toxic than the inorganic salts. Further field studies of these phenomena are planned. Preliminary study results indicate that potassium formate may be the de-icer of choice – it caused fewer changes in the infiltrated water quality than all the other de-icers and readily biodegraded in sand and gravel. Future studies include verification of laboratory results in the field and economic evaluations of alternative de-icers.

Best management practices (BMPs) for urban snowmelt and winter runoff

Recognising the potential impacts of stormwater discharges on receiving water ecosystems, various stormwater measures have been introduced into drainage practice during the past 30 years. Such measures have been typically developed for warm or temperate climates without significant snowfall and proved to work fairly effectively under such conditions. However, their performance under cold climate conditions is less well understood, and in many aspects, cold climate BMPs represent a challenge in effective protection of aquatic ecosystems (Oberts, 2003). As noted by Oberts (2003) for BMPs in cold climate, frozen conduits, ice layers, low biological activity, altered chemistry, and saturated or frozen ground conditions all work against effective treatment of urban snowmelt and winter runoff. Some guidance for adjusting the conventional BMPs to cold climate conditions has been offered by Oberts (2003), including promotion of infiltration of suburban, cleaner meltwater into the ground, storage and settling of more polluted winter runoff in ponding facilities, and dilution or diversion of the highly polluted first flush. Although it might be impossible to dramatically reduce snowmelt/winter runoff pollution loads, the approaches listed above should help in doing a better job. In any case, the choice of BMPs should be guided by the problem at hand, which may be protection of streams and lakes against toxic substances, protection of groundwater quality, and avoidance of interference with wastewater treatment processes in combined sewer systems.

In terms of new research, six papers at the Riksgränsen conference dealt with BMPs in cold climate and are briefly discussed below.

Oberts (2003) advocated infiltration of meltwater with a high content of dissolved solids (mainly from less densely populated suburban areas) in situ or by diversion to permeable areas, such as infiltration swales or porous pavement. His experience from the Minneapolis-St. Paul (USA) area did not indicate substantial impacts on the groundwater quality, although this issue always should be considered. The need for such caution is supported by Andrews *et al.* (1999) data from this region (cited in Marsalek, 2003), who reported chloride concentrations of 4-330 mg/L in water table wells located in unconfined sand and gravel aquifers in the same area. Meltwater from more densely populated areas may rather be treated in a pond or a settling tank, where the particles may settle. The risk of flushing the particles from the pond or tank during high-intensity storms later in the year should be considered in design and monitoring of such facilities. Only small benefits may be achieved by introducing biological treatment. A combination of different BMPs in "treatment trains" may in some cases be necessary.

Marsalek (2003) reviewed the effects of road salts on different stormwater management facilities. Several studies, mostly from Canada and USA, reported accumulations of chloride and chemical stratification in oil and grit separators, stormwater ponds and wetlands. The elevated chloride concentrations may worsen facility performance, reduce DO levels in bottom layers (through impeded vertical mixing), cause toxicity in ponds, contribute to release of trace metals from bottom sediments, and cause chloride shock-loads to the receiving water in the springtime. Partial mitigation of such effects by chloride dilution and regular displacement was recommended.

Bäckström (2003) investigated the retention of suspended solids and heavy metals in grassed swales in Luleå, Sweden during rain runoff and snowmelt-generated runoff. The swales retained substantial amounts of the solid particles transported by melt water, but only low to moderate amounts of heavy metals and dissolved substances. When receiving relatively clean runoff with low pollutant concentrations, swales were found to release rather than retain pollutants. The study concluded that swales may be used for primary treatment of snowmelt and stormwater. Design parameters include the mean hydraulic residence time and the surface loading rate. Additional benefits of swales include providing storage for snow cleared from roads and retaining solids in stored snow.

Aldheimer and Bennerstedt (2003) studied various facilities for the treatment of snowmelt and stormwater from highways in Stockholm, Sweden. The selection and design of such facilities follows a procedure which considers the quality of receiving waters (very sensitive, sensitive and less sensitive to the input of pollutants) and the level of pollution of stormwater classified into three categories (little, moderately, and highly polluted). In Stockholm, stormwater is commonly treated in settling tanks, which are designed to store runoff from a 15 mm rainfall for a period of 36 hours. For a specific treatment facility studied by the authors, the treatment results varied considerably. Although the suspended solids concentrations in winter were significantly higher (10 – 60 times) than in the autumn, the solid removals were about the same, ranging from 66 to 84 %. The authors also reported on the treatment efficiency of catch basins fitted with geotextile filters. The reduction of heavy metals attributed to such catch basins ranged from 3 to 9 %. These filters were susceptible to clogging, which then resulted in street flooding. Thus, catch basin filters would require further development before they could be recommended for use in practice.

Marsalek *et al.* (2003b) observed winter operation of an on-stream stormwater pond in Kingston, Canada. Field measurements and model simulations indicated low-intensity flow circulation in the pond, with a fast flow region, a dead zone and a recirculation zone. During a snowmelt event, bottom velocities were as high as 0.05 m/s, but not sufficient to scour sandy bottom in the area of these velocities. Pond water temperature increased with depth from 0.5° to 3.5° C, and stable

aerobic conditions were observed in the pond, except for a brief period of anoxia during a cold spell. pH ranged from 7.1 to 8.9, reflecting the local limestone bedrock geology. Conductivity readings indicated high levels of total dissolved solids, mostly attributed to chloride from de-icing agents. These solids then contributed to chemostratification of the pond. Trace metal concentrations were mostly below the detection limits. In summary, no significant problems were observed during the winter months.

German *et al.* (2003) modelled operation of a stormwater pond in Gothenburg, Sweden, and noted that winter conditions with long periods of no runoff followed by large snowmelt events strongly affected pond performance in pollutant removal. Temperature effects on such removals were minimal, but the presence of ice cover had significant impacts. Ice cover prevented oxygenation of the pond and contributed to lower removals of biodegradable organics (BOD) and some forms of nutrients (N and P). The simulations indicated that the DO levels did not decrease as much at low temperatures as under warmer conditions – at 0° C the DO level was typically above 3 mg/L.

Roseth *et al.* (2003) studied the treatment of wash-water from road tunnels in Norway. In this process, surfactants are used and represent about 0.1-1% of the wash water. Microtox tests indicated that the wash water was acutely toxic, and this could be fully explained just by the presence of surfactants. To reduce impacts on receiving waters, the treatment of wash-water in constructed wetlands was implemented. The wetland proved to be effective in reducing suspended solids in the wash-water, by 80-90 %. The toxic surfactants were effectively degraded in the wetland, as further confirmed by laboratory experiments.

Snow management in urban areas

Winter maintenance of urban streets includes snow removal and transport to special snow disposal sites. This approach offers management options with respect to the ultimate fate of snow pollutants and their control. Snow disposal strategies include storing snow where it fell, transporting it short distance to local snow storage sites, or transporting it to central snow disposal sites specially designed for this purpose. There are many considerations in selecting the best snow disposal management option, including environmental effects, costs of removal and transportation, and impacts on the community. The early studies of snow disposal indicated higher pollution of used snow from downtown areas (Viklander, 1997), high concentrations of traffic and road maintenance related chemicals (chloride and lead – LaBarre *et al.*, 1973), and high concentrations of trace metals and solids in the black crust layer forming on snow pile surface (Droste and Johnson, 1993). Thus, the issues of used snow disposal and disposal strategies remain of high interest to municipal and highway engineers. Two papers at the Riksgransen conference addressed snow disposal issues.

Reinosdotter *et al.* (2003) examined pros and cons of local vs. central snow disposal sites by conducting a survey of Swedish municipalities and analyzing specific conditions in Luleå, Sweden. In assessing various management strategies, they considered the following aspects: (a) environmental effects (air pollution/greenhouse gas emission associated with snow transport; pollution of receiving waters by trace metals, oil and grease, and solids; and, local effects on vegetation and biodiversity in general), (b) costs (both capital and operational), (c) disposal site acceptance by the public, (d) institutional arrangements and responsibilities, (e) environmental legislation (both national and European Union directives), and (f) other aspects related to easy site access, traffic safety, and health risks. A survey of Swedish municipalities indicated many similarities in their approaches to snow removal and disposal – snow is cleared from streets when its accumulation exceeds a certain threshold (0.03-0.12 m), disposal sites with short transport distances are preferred, the public often complains about poor aesthetics of disposal sites (black

snow, litter), and the municipalities are required to operate and maintain snow disposal facilities. In Luleå, the central disposal site is located six kilometres from the city centre and this contributed to high transportation costs and CO₂ emissions, in comparison to local, distributed snow storage. In both cases the snow had to be first stored in swales and ditches along the roads, before it was transported to the disposal sites. The best solution might be a combination of both approaches: storing fresh, clean snow locally and transporting only the heavily polluted snow to the central disposal site.

Wheaton and Rice (2003) studied the site selection, design and operational controls for a snow disposal site in Anchorage, Alaska. On the basis of field investigations and assessments of the melt processes in a snow deposit, the authors recommended designing the snow-melting pad as a V-shaped swale. This design reduced the turbidity of meltwater by an order of magnitude. It was also observed that chloride runoff can not be controlled at the site; it needs to be controlled at the source by using smaller quantities. Recommendations for the design and control of the site are given.

Conclusions

The first International conference on Urban Drainage and Highway Runoff in Cold Climates indicated continuing interest in operational and environmental requirements on urban drainage in cold climates. Urban snow and ice, freezing temperatures, increased pollutant emissions in winter and applications of de-icing and anti-skid agents contribute to environmental impacts of urban drainage and reduced effectiveness of conventional stormwater management facilities in cold and alpine climates. The future research efforts in this field should focus on the refinement of stormwater management design and operation in cold weather.

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