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National storm water quality regulations and standards

Règlements et normes nationaux en matière de la qualité des eaux d'orage

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ABSTRACT
This paper reviews the storm water quality regulations of six major industrialized nations: The United States, Canada, United Kingdom, Germany, Australia and Japan, the order being set by the principal authors (both North America) who consider this to be a logical geographical order. The main purpose of the paper is simply to introduce the interested reader to these rules as a matter of broadening his/her knowledge base. Due to space limitations much detail is left out, but hopefully the essence of the laws and regulations are presented. No attempt has been made to compare and contrast these different rules with the objective of determining which are the best rules or what the "best rule" might be. The reader will observe that the differences are great, and to a large degree reflect the culture of the individual country.

RÉSUMÉ
L'Article fait la synthèse des règlements en matière de la qualité des eaux d'orage dans 6 grandes nations industrialisées: USA, Canada, UK, Allemagne, Australie et Japon, lórdre de ce classement étant donné par les auteurs principaux (tous deux américains) qui considèrent cela comme une ordre logique du point de vue géographique. L'objet premier de cet article est seulement de familiariser le lecteur intéressé à ces règlements dans le but d'élargir sa culture générale. Le manque de place a contraint à négliger de nombreux détails, mais heureusement les principes des lois et règlements concernés sont présentés. Il n'a pas été tenté de confronter ces différents règlements dans le but de rechercher quel serait le meilleur ou ce qui devrait être le règlement le mieux adapté. Le lecteur pourra observer que les différences sont grandes et que ces règlements sont le reflet de la culture propre à chaque pays.

Key words: Laws, regulations, storm water, storm water pollution, storm water quality, combined sewer overflows, urban drainage, United States, Canada, United Kingdom, Germany, Australia, Japan

Introduction

During the late 1960s and early 1970s most of the industrialized countries of the world undertook the serious development of legislation to regulate wastewater discharges to their national waters. In North America, this period of regulatory development was largely catalyzed by the developing environmental consciousness of the 1960s, and perhaps by the increasing recognition of damage to fisheries and other resources that had arisen from historically unchecked pollution of surface waters. The regulatory impetus outside North America may have been similar in origin. Whatever the reason, the result was a new generation of legislative responses to the problem of pollution control. These acts and laws primarily targeted control of gross and evident surface water pollution point sources, that is, industrial discharges, and municipal wastewater treatment plant discharges and largely ignored or deferred the attention to storm water control. Through the enforcement of these laws, acts and regulations, the quality of these nations surface waters has greatly improved.

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During the mid-1970s and early 1980s, adjustments to the initial regulation of point source pollution began to emerge. It became increasingly apparent that pollution in wet weather discharges from industries, municipalities, and agriculture was significant, and researchers and regulators began to pay more attention to the water quality impacts and regulation of pollutants from these sources. Industry and combined sewer overflows (CSOs) have received the most attention world-wide, but in the United States, attention and regulation has, since 1990, also focused on the pollution in the surface runoff from urban areas. Interestingly, while agriculture is a major contributor of storm water pollution, it has managed to remain unregulated in most of the world.

In this article, the storm water quality regulations in the United States, Canada, United Kingdom, Germany, Australia, and Japan are reviewed. These countries were selected primarily for their broad geographical coverage, but also because of the recognized variation in their individual regulations.

Storm Water Quality Regulations in United States

In the United States, the legislative foundation for the Water Pollution Control Act was created by the United States Congress in 1968. The Water Quality Act Amendments of 1972 significantly tightened this Act requiring secondary treatment as a minimum for municipal wastewater and "Best Available Technology" for waste discharges from industries. Then in 1987, the U.S. Congress again amended the Act, requiring municipalities with populations greater than 100,000 to acquire an National Pollutant Discharge Elimination System (NPDES) permit to discharge storm water from their drainage systems and to reduce the pollutants in these discharges to the "Maximum Extent Practical" (MEP). A national program targeted specifically at CSO control was devised as well. Both are discussed below.

Municipal Storm Water NPDES Permit Requirements

On November 16, 1990, in response to the mandate of the US Congress, USEPA published its final rules for the regulation of storm water discharges for municipalities with populations over 100,000 (USEPA, 1990). These rules require that the municipalities, which have separate wastewater and storm drainage systems, obtain a NPDES permit for their storm water discharges, in addition to the permit for discharges of treated wastewater. The application is to be filed in two parts. Part I is a description of the existing storm water management system and of current storm water quality management programs. Part II comprises the development of a comprehensive program to reduce pollution from the storm water system.

Part 1 – NPDES Permit Application. A major requirement of Part I application is location and mapping of known municipal storm drain outfalls that discharge to waters of the United States. Part 1 involves the collection and analysis of existing data including: 1) existing rainfall/runoff data (volume and quality); 2) identification of receiving water bodies and existing information on their water quality; and 3) field screening of major outfalls (up to 250 for medium systems and up to 500 for large systems) to detect possible illicit connections. Illicit connections are non-storm water connections that are not allowable such as floor drains, wash water drains, household wastewater connections, etc. The field screening comprises collection and field analysis of two grab samples over a 24-hour period from all dry weather flows. Management Programs that are currently underway for control of pollutants in storm water discharges are to be described in Part 1 of the application. Also required is a description of procedures to control pollution from construction activities, requirements for floodplain management and measures for wetland protection. Municipalities must also demonstrate that they have, or can acquire legal authority to control the quality of storm water discharges and prohibit non-storm water discharges from its system. Legal authority is a major problem for many of the municipalities because the enabling acts of the authority responsible for a drainage usually has no provision for managing water quality.

Part 2 – NPDES Permit Application. Part 2 is the more extensive portion of the NPDES permit application. It comprises essentially three main elements: 1) the wet weather sampling program to characterize the pollutant characteristics of storm water discharges; 2) a technical plan to reduce pollutants in storm water runoff to the "maximum extent practicable"; and 3) a financial institutional plan to support the technical plan.

Storm water runoff must be sampled at 5 to 10 representative outfalls for three significant storms (greater than 0.1 inches or 2.54mm), with antecedent dry periods of 72 hours. Samples are to be analyzed for organic pollutants, toxic metals, cyanide, oil and grease, and total phenols plus a number of nutrients and indicator bacteria, and flow weighted "event mean concentrations" computed. Based on these samples, the total annual storm water pollution load for the municipality is to be estimated. Subsequent steps of the program refine load estimates.

A further major element of the Part 2 application is the proposed Management Program. The emphasis of the program is: 1) Source controls and illicit connection prohibition in developed areas; 2) Structural treatment controls for new development, and 3) Sediment and pollution control on construction sites. The main elements of the management program are identified in Table 1. The Management Program must estimate the reduction in storm water pollution load expected by implementation of the Program, and include a financial/institutional program for the permit period (5 years) comprising a capital and O&M budget, and the source of funding for these expenditures be identified.

Table 1. Activities to be Addressed in Municipal Stormwater Management Programs.

For Residential/Commercial Activities:
- Roadway and drainage facility operations and maintenance programs
- BMP planning for new development and redevelopment projects
- Retrofitting existing or proposed flood control projects with BMPs
- Municipal waste handling and disposal operations
- Pesticide, herbicide, and fertilizer use controls

For Improper Discharge Activities:
- Prevention, detection and removal program for illegal connections to storm drains
- Spill prevention, containment, and response program
- Program to promote proper use and disposal of toxic materials
- Reduce storm water contamination by leaking/overflowing separate sanitary sewers

For Industrial Activities:
- Inspection and control prioritization and procedures
- Monitoring of significant industrial discharges

For Construction and Land Development Activities:
- Water quality and BMP assessments during site planning
- Site inspection and enforcement procedures
- Training for developers and contractors

Source: CDM et al., 1993

Clearly, the process is highly specific in terms of the problems, measures, and solutions to be considered.

The Cost of the Program to develop permit applications and the cost of *implementing* the storm water management programs developed in Part II of the application has been of significant concern to local communities. Regarding the cost of preparing the permit application, Gebhardt and Lindsey (1993) surveyed 59 large municipalities (more than 250,000 population) they found that Part 1 application costs ranged from $50,000 US to $1,150,000 US, with the average cost of $420,000 US. Part 2 costs ranged from $71,400 US to $2,000,000 US, with a mean value of $555,326 US.

National Combined Sewer Overflow (CSO) Control Policy

USEPA's Combined Sewer Overflow Control Policy was finalized in April of 1994 (USEPA, 1994). This policy is somewhat of a landmark policy in two respects: First, the policy was created through joint collaboration of USEPA, environmental groups, and municipalities; and second, the policy contains a presumptive clause with respect to meeting water quality standards. The policy provides guidance to regulators and CSO permittees (cities with combined sewer systems) on coordinating the planning, selection, sizing and construction of CSO controls and allows for public involvement during the decision-making process. The major requirements of the policy are: 1) an accurate characterization of the CSO permittee's combined sewer system, 2) demonstration of implementation of nine minimum controls, and 3) development and implementation of a long-term CSO control plan.

Implementation of the Nine Minimum Controls

The so-called "nine minimum controls", which are identified in Table 2, are actions that can be undertaken by a community at minimal cost to reduce CSOs. Documentation of the nine minimums controls program must be submitted to USEPA and may include operation and maintenance plans, revised sewer use ordinances for industrial users, sewer system inspection reports, infiltration/inflow studies, pollution prevention programs, public notification plans, and facility plans for maximizing the capabilities of the existing collection and treatment systems, as well as contracts and schedules for minor construction programs for improving the existing system's operation.

Table 2. Nine Minimum Controls Required by USEPA.

1. Proper operation and regular maintenance programs for the sewer system and the CSO points;
2. Maximum use of the collection system for storage;
3. Review and modification of industrial pretreatment programs to assure CSO impacts are minimized;
4. Maximization of flow to the POTW for treatment;
5. Prohibition of CSO discharges during dry weather;
6. Control of solid and floatable materials in CSOs;
7. Pollution prevention programs that focus on contaminant reduction activities;
8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts; and
9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls

Long-Term CSO Control Plan

The long-term CSO control plan is required for municipalities with populations greater than 75,000. This plan comprises nine elements.

1. *Characterization, Monitoring and Modeling* of the combined sewer system is required to develop an understanding of the combined sewer system including, the response to various rain events, the characteristics of the overflows, and the water quality impacts from the CSO discharges.
2. *Sensitive Areas* are the highest priority for controlling overflows. These include designated Outstanding Natural Resource Waters, National Marine Sanctuaries, waters with threatened and endangered species and their habitat, waters with contact recreation, public drinking water intakes or their designated protection areas, and shellfish beds.
3. *Evaluation of Alternatives* examines a reasonable range of alternatives. In addition to considering sensitive areas, the long-term CSO control plan should adopt one of the following approaches:
   a. "Presumption" Approach. A program that meets any of several basic effluent control based performance criteria would be "presumed" to provide an adequate level of control to meet CWA requirements without further receiving water analysis. The criteria are basically: 1) four or less overflows per year, or 2) capture of 85 percent of the combined wastewater on an annual basis. Captured wet weather flows must receive a minimum of primary treatment.
   b. "Demonstration" Approach. A permittee may demonstrate that a selected control program, though not meeting the criteria specified in the "presumption approach" is adequate to meet CWA requirements. This approach is arduous and results are open to subjective conclusions with respect to meeting or not meeting CWA requirements; this has made it initially less attractive to the affected municipalities.
4. *Cost/Performance Considerations* require the permittee to develop appropriate cost/performance curves that correspond to the different overflow ranges defined in Item 3.
5. *Operational Plan* is required to revise the operation and maintenance program developed as part of the nine minimum controls to accommodate the long-term CSO controls.
6. *Maximizing Treatment at the Wastewater Treatment Plant* is a key element. In many communities, the wastewater treatment plant has primary treatment capacity greatly in excess of its secondary treatment capacity. One effective strategy to abate pollution promoted by the policy is to maximize the delivery of wet weather flows to the treatment plant for primary treatment, bypassing the secondary treatment units with the excess flow.
7. *The Implementation Schedule* includes all pertinent information necessary to develop the construction and finance schedule for implementation of long-term CSO controls. Construction phasing should consider: 1) Eliminating overflows that discharge to sensitive areas as the highest priority; 2) Use impairment; 3) Permittee's financial capability including consideration of such factors as: Median household income/total project cost per household, unemployment, grant and loan availability, and residential, commercial and industrial user fees.
8. *Post-Construction Compliance Monitoring Program* is adequate to verify compliance with water quality standards and protection of designated uses.
9. *Public Participation*: EPA expects that the permittee, in developing its long-term CSO control plan, to actively involve the affected public in the decision-making. This includes rate payers, industrial users, persons down-stream, and other interested persons.

The CSO program is intended to be comprehensive, but feasible and achievable both in terms of immediate action requirements, and in terms of the long term control program.

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Storm Water Quality Regulations in Canada

Responses to economic challenges have created an environment of change in Canadian law and practice with respect to environmental regulation. It is thus somewhat difficult to be definitive about the current state of affairs in this area and some significant details are necessarily omitted. Nevertheless, there are certain basic features of regulation that are likely to be applicable over the present and near future.

Federal Mandates

Canada does not mount Federal Regulations comparable to the U.S. Clean Water act. Instead, Canadian Federal law tends in practice to provide direction to large, federal and international boundary water projects. The Canadian Environmental Assessment Act provides for the comprehensive evaluation of works prior to implementation; projects are tested in a formal evaluation process that ensures the various facets of public interest, aesthetic values, environmental values and so on are addressed in terms of potential impact and mitigation. This does not specifically target storm water, but does provide a basis for evaluation of large works, and by its nature with thereby encompasses storm water as a subset of the total problem. The Canadian system also makes use of the Canadian Fisheries Act, which deals with aspects of protection and maintenance for fishable waters. Again, storm water impacts can and are dealt with in the context of larger issues, namely the protection of fisheries resources. Instances of particular agreements can also be cited, as in the Canada-Ontario agreement, which provide a mandate for provincial and federal interaction, or the Canada-U.S. agreements related to Great Lakes protection, which provide a basis for management of joint resources.

Provincial Mandates

Province by province, regulation tends to vary. To respect space limitations in this paper, Ontario is taken as an example of practice at this level. The system in Ontario is for the most part founded on three types of legislation: 1) legislation which requires planning on a comprehensive basis; 2) legislation which provided for the management of floodways, and 3) legislation providing for the protection of natural resources. Although these areas overlap substantially both technically and procedurally, practice in Ontario is basically regulated as follows.

Land Use and Landform Management: The Official Planning Act required that all municipalities put in place a plan which defines the total scope of development for their service areas, including planning for roadways, land use, sanitary and water services, etc. Subsequent amendments to these plans are possible, but the evolution of practice has led to a very detailed scrutiny of storm water issues as land uses are determined. A formal hearing before the Ontario Municipal Board (OMB) is required to achieve a variance from the Official Plan. Testimony and argument is conducted before the OMB in a format comparable to that applied to criminal court, with expert testimony and legal representation sometimes at a very intense level.

Floodway Management: Following major flooding and damage associated with a regionally rare hurricane, Conservation Authorities were defined, each dealing with flood protection of a specific watershed area in the Province. These Authorities were originally focused on storm water conveyance and storm water management, but have recently shown a more interest in a comprehensive approach to watershed management. Although this is a natural evolution, given the geographic nature of their mandate and the emergence of blue-green technologies as a part of the storm water management arsenal, the legislative foundation for this tendency is not clear. It seems to be the result of interest on the part of the Authority, compromise on the part of municipalities, and delegation on the part of the Ministries which might otherwise serve this purpose.

Resource Management: The Ministries themselves are fundamental divisions of government in Ontario. In this case, the ministries of Environment and Energy (MOEE), and Natural Resources (MNR), are the major agencies providing guidance. MOEE focuses on traditional requirements of water quality control, while MNR focuses on equally traditional requirements of resource management. These agencies are the arms of provincial government most closely associated with the problems of storm water management, but again approach the problem from a global perspective rather than as a primary mandate.

The mandates of these two Ministries do overlap, but in essence, the MOEE provides guidance to water quality requirements in surface and natural waters, and regulates the discharge of pollutants to those waters. Authorization for wastewater treatment plant discharges, for example, are dispensed by the MOEE. The MNR provides for resource conservation, and has a principal interest in fisheries, and therefore is concerned with minimum flow quantities, sediment loads, and morphological change. In practice, teaming and reciprocal delegation based on cases-by-case delegation tends to characterize ministry interaction where storm water is concerned. In recent years, there has been an approach that promotes watershed/subwatershed planning that provides integrating guidance to stormwater management plans undertaken at a site level. On the horizon is the completion of a draft policy for CSO control, patterned similar to the recent USEPA regulation, that will provide guidance for the mitigation of CSO sites remaining around the province.

It seems that in the face of economic pressure, there are trends, province by province, to a more and more deregulated approach. To a significant extent, scrutiny is devolving to the municipality. This partly reflects maturing interests on the part of the municipalities, and partly the expedient need for decentralized (not funded by the Provinces) control mechanisms. Beyond that, industrial sectors in Ontario and Alberta have moved more to self regulation and self monitoring with some sort of auditing function. Future trends seem to be even more in this direction. Associated with a shift in government from a socially focused provincial government to a government focused on fiscal restraint and recovery, funding for soft issues and infrastructure is under attack. The Conservation Authorities are being fiscally starved, MNR funding has been cut significantly (40% budget removal has been cited), as has MOEE (budget cuts of 1/3 have been cited). This has a significant impact which will be protracted because research and technical planning/evaluation have been seriously reduced as a result. The trend to nominal regulation and decentralized delegation would seem to be a reality for some time to come.

Municipal Mandates

Aside from the apparent trends noted above, practice at a Municipal level has included a number of vehicles that implicitly or explicitly regulate storm water controls. There are significant instances of master plans and policy documents, developed by and enforced at a municipal level, that have provided a basis for development and practice as regards storm water management. These have partly been prompted by the various forces cited above, in particular the Conservation Authorities. They are typically integrated and focused documents that stop short of actual design, but define in relatively rigid detail the various forms and magnitudes of storm water control devices that will be associated with development. The plans typically define preferred design standards (design storms, acceptable models and techniques etc.), the locations of major system floodways, the locations and tributary areas for storm water control facilities, and the anticipated pre and post development peak flows. These plans can become integral with the Official Plans for the area, or can represent details of design practice inherent to the Municipality. In addition, some municipalities put forward design standards that promote the use of specific sizing techniques, construction details, or specific storm water control devices practices.

EEC (European) Standards for Storm Water Management

In common with a variety of industrial, economic and policy areas, this aspect of law in the EEC is in a period of evolution. Since 1989, within the European common market, the European Standard Organization (CEN) has been working through technical committees to develop a common standard within the European countries. Within TC165 "Wastewater Engineering" the Working Group 22 has developed common basic standards for drainage and sewer systems identified as European Standard prEN7t2 "Drain and Sewer Systems Outside Buildings".

Part 4 "Hydraulic design and environmental consideration" gives general statements related to storm water treatment. In this Standard (Chap. 9.3) combined sewer overflows are mentioned ,and general statements concerning the need for control works are made. In the annex of these European standards are the relevant documents of all 18 European nations. This voluminous source provides significant information on the EEC in its present state, however it appears that changes may be in the offing in this area.

Storm Water Regulations and Standards In The UK

In England, Wales and Scotland, the United Kingdom parliament establishes the Acts which provide laws for pollution control in inland and coastal waters. The Acts give the general framework and authority to the Secretary of State to issue regulations. These regulations are in the form of "Statutory Instruments" which provide more detail for the implementation of the laws. Where regulations are not made, as in the case for discharges specifically into and from surface water sewers, then the interpretation of the law is more difficult.

In Northern Ireland, legal provisions are made in Orders in Council. These Orders can not be amended during the passage through Parliament. Therefore, to prevent excessive redrafting, Orders in Council are usually proposed only when the final text of the legislation enacted in the rest of the UK is confirmed. This results in a 2-3 year delay on the publishing of equivalent legislation in Northern Ireland. It does suggest a commonality of approach throughout the UK, however.

The principal Acts and Orders concerned with discharges to and from public sewers are:

England and Wales	Water Resources Act 1991
	Water Industry Act 1991
Northern Ireland	Water and Sewerage Services (Northern Ireland) Order 1973
	Water (Northern Ireland) Act 1972

Scotland	Water Act 1989
	Control of Pollution Act (COPA) 1974
	Sewerage (Scotland) Act 1968
	Rivers (Prevention of Pollution) (Scotland) Acts 1951 and 1965

Responsibility for administering the provisions made in these Acts lies with the sewerage undertakers and the environmental regulatory authorities. The UK must also comply with EC Directives which are relevant to water quality. These Directives are incorporated into UK law usually in the form of Statutory Instruments.

The sewerage undertakers in the UK are: 1) The ten Water Service Companies in England and Wales, 2) the three Water Authorities in Scotland, and 3) the Water Executive of the Department of the Environment for Northern Ireland.

The environmental regulatory authorities operating in the UK are: 1) The Environment Agency (EA) in England and Wales, 2) the Scottish Environment Protection Agency (SEPA), and 3) the DoE (NI) in Northern Ireland.

Provision of Storm Water Drainage. The general responsibility of the sewerage undertakers is to provide an adequate sewerage system to protect properties from flooding. Moreover the undertaker has a duty to accept and dispose of wastewater from public and private properties. Sewerage undertakers are responsible for the maintenance and discharges from public sewers. Where developers have laid a private sewer, this may be adopted by the undertaker after satisfactory completion of the work. The sewerage undertaker is not responsible for domestic, site or highway drains or drainage unless or until the effluent enters the public sewer. Section 95 of the Water Act enacts the general duty of sewerage undertakers to:

"provide, improve and extend such a system of public sewers (whether inside its area or elsewhere) and so to cleanse and maintain those sewers as to ensure that the area is and continues to be effectually drained." Properties should not be at risk of flooding from sewer systems more often than twice in ten years.

This duty includes the requirement to collect and dispose of surface water, which, as defined in Section 219(l) of the Act 'includes water from roofs'.

In the UK urban drainage has and continues to be developed in a piecemeal fashion. Older urban centers tend to be drained on a combined sewer system, with storm water flows conveyed in the same pipe as the foul domestic flow. However, new developments should be provided by a dual pipe system, with surface water flows conveyed in a separate system to the foul flow, except where the undertaker specifies otherwise (Water Services Association/WRc, 1995).

Control of Pollution from Combined Sewer Systems

The UK policy for the protection of the aquatic environment is based on Environmental Quality Objectives (EQOs) which specify the desired uses of a water body. Environmental Quality Standards (EQSs) are then defined such that, when achieved, the EQOs are protected. The primary focus of WQOs is likely to continue to be based on percentile compliance and absolute limits in terms of

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various specified chemical determinants for spot samples, taken on a routine basis. A supplementary requirement for WQOs is that the provision of the relevant EC Directives should be met.

All legitimate uses recognized for surface waters can be affected by wet weather discharges from sewer systems. However, river aquatic life, bathing and general amenity have been specifically identified in the AMP2 guidelines for England and Wales (National Rivers Authority, 1993) and appropriate Environmental Quality Standards have been developed.

Over and above any requirements arising from compliance with standards, there is a general requirement for all new or unsatisfactory sewer systems to carry flows without spilling from combined sewer overflows until the incoming flow exceeds that calculated by Formula A (FWR, 1994). This formula was derived to replace multiples of dry weather flow for overflow settings, and is based on the dry weather flow, population and trade effluent flow of the upstream catchment. The constants used in the formula need to be adjusted for particular types of trade effluent, for small receiving waters or for sewer systems with large storage capacity.

Control of Pollution from Separate Sewers

Outfalls from separate (surface water) sewers have not been routinely consented in England and Wales, but consents can be imposed if considered necessary. Surface water sewers should only carry legitimate surface water, which depending on the flows in the receiving water, should not cause damage to the aquatic environment. Most surface water outfalls (SWOs) in England and Wales are not currently consented.

In Northern Ireland the Environment Protection Department of the DoE (NI) currently can only impose consent standards on discharges by the sewerage undertakers. This is because the sewerage agency is a Crown Service and as such may not be prosecuted. This is likely to change when the sewerage undertaker is privatized and a prosecution policy similar to that in England and Wales comes into force. Where an SWO discharge is considered unacceptable, an agreement is reached on the required future quality of the SWO.

In Scotland, since 1985, the River Purification Boards and now SEPA have had the power to consent discharges to controlled waters. Moreover, there is no provision to opt out for SWOs, but many SWOs built during the period 1950–1985 remain unconsented.

Offenses

Under section 85 of the Water Resources Act in England and Wales, and Schedule 23 of the 1989 Water Act in Scotland, it is an offense to:

"cause or knowingly permit any poisonous, noxious or polluting matter or any solid waste matter to enter any controlled waters".

A person shall not be guilty of such an offense if the discharge is made in accordance with a consent or if the discharge was made because of an emergency. In England and Wales, the EA may prosecute the polluter, providing that the correct procedure is followed. In Scotland, SEPA submit a report to the Procurator Fiscal who takes the case to court.

Responsibilities for offenses of polluting controlled waters caused by discharges from public sewers are set out in the Water Resources Act s87 (England and Wales) and COPA 1974 s31 (Scotland). The law states that where a sewerage undertaker did not cause, or knowingly commit the discharge, the undertaker will be deemed to have caused the discharge and thus be guilty of an offense unless the offense resulted because of a discharge:

1. caused or permitted into the sewer by another person or by another sewerage undertaker, which the undertaker had not agreed to receive or had agreed to receive it subject to conditions which were not met; and
2. which the undertaker could not reasonably have been expected to prevent.

Where these conditions are met, the person committing the discharge into the sewer, would be deemed the guilty party and would be liable to prosecution from the regulatory authority.

Storm Water Quality Regulations in Germany

Germany placed into practice significant standards of performance for wastewater facilities in 1977, through its ATV (Abwassertechnische Vereinigung) standards process. The regulatory approach used by the Germans, is technology based, assuming that if facilities are constructed to the specifications of the ATV Standard, the receiving waters will be adequately protected. Germany has been very proactive in enforcing the ATV Standards and, as a result, has probably constructed more facilities for storm water treatment that any other country in the world. Within the more than 34,700 combined sewer detention and retention facilities were constructed with a combined capacity of 12.8 million cubic meters. Within separated systems, Germany has constructed more 8600 detention/retention facilities totaling 7.7 million M^3 during this same period.

Standards for Combined Sewer Systems

The relevant standard for combined sewer systems is the ATV Standard ATV-A 128 "Standards for the Dimensioning and Design of Storm Water Structures in Combined Sewers" published in April 1992. This working group, under the leadership of Prof. Gottle and other concerned members of German institutes and concerned bodies, started their development in 1987. From 1987 to 1989 the working group developed the first draft of the ATV standard. The draft was then published in April 1990 for public comments and considerations and was then finally published in April 1992. The time of development for this standard lasted 46 months and 18 meetings were needed to develop the standard within the German contracts. This 1992 ATV standard replaced the former ATV standard from 1977.

ATV Standard ATV-A128 applies for overflow structures within the overall combined wastewater sewer system tributary to a sewage treatment plant. Structures with overflows in combined systems are structures with an overflow into a lake or river such as storm water overflows (SO), storm water tanks with overflows (STO), and sewers with storage capacity and overflow (SSCO).

Method of Approach

Basically, there are two procedures available for the dimensioning and verification of the objective of the storm water treatment:

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- simplified dimensioning procedure using diagrams (Chap. 8.1)
- verification procedure using pollutant load calculations (Chap. 8.2)

The objective is considered as being met if the requirements of these standards, with regard to pollutant retention, arrangement, design, dimensioning and method of operation of structures with overflows, are observed.

Standards for Separated Sewer Systems

Storm water holding tanks (SHT) are dealt with in ATV Standard ATV-A 117. Storm water sedimentation tanks (SST) serve for the treatment of storm water with separate systems. They are also not dealt with here.

Storm Water Quality Regulations in Japan

Japan has historically taken the lead for water pollution control in Southeast Asia, enacting its first laws in 1958, via the Water Quality Conservation Law (1958 Law No. 181) and the Factory Effluents Control Law (1958 Law No. 182). But the serious regulation of surface water pollution started in 1967 with passage of the Basic Law for Environmental Pollution Control (1967 Law No. 132), which collectively and systematically promoted various measures for pollution control at the national level. In the following years, two subsequent laws were passed, which in aggregate form the basis of regulation of storm water pollution in Japan. These laws are:

- The Sewerage Law (1985 Law No. 79), and
- The Water Pollution Control Law (1970 Law No. 138)

In addition to the national laws, local ordinances may also be enacted which supersede the national laws if they are more stringent.

The application of these laws to urban runoff pollution depends upon the origin of the discharge. Storm water in Japan is considered to be discharged to public water bodies (e.g. rivers, lakes, bays, seas, oceans and groundwater) via three principal routes. These are: 1) areas with *no storm sewer system* (e.g. gutters, trenches, channels, watercourses, small streams, and sometimes by pumping stations), 2) areas with a *separate system* (e.g. storm sewers), and 3) areas served by *combined sewers* (i.e. through overflow weirs, pumping stations, sewage treatment plants etc.) The applicability of regulations to storm water discharges depends upon the principal route of the discharge.

The Sewerage Law

The objective of this law, according to Article 1, is "to develop sewerage systems in order to contribute to sound development of cities and improvement of public hygiene…(and) to contribute to the preservation of water quality of public water bodies (Akagawa, 1990). The law contains receiving water quality standards that are used as guidelines for planning, and effluent water quality standards that must be met under various discharge conditions.

The applicability of the Sewerage Law is as follows:

- Where there is no sewer system, the Sewerage Law does not apply.
- In combined sewer systems, the effluent from the wastewater treatment plant must meet a prescribed set of water quality standards that vary depending upon the treatment process. Overflows from the system are subject to a different set of water quality standards that are less stringent than those for wastewater treatment plant effluents. The standards applied to both types of discharge are indicator bacteria, BOD5, Suspended Solids, and pH.
- The water quality of the storm water discharged from separate sewer pipes should also comply with the standards of the Law. These standards are less stringent than those for CSOs.

The Water Pollution Control Law (sometimes called Water Pollution Control Act)

Effluent standards are defined by the ordinance of the Prime Minister's Office. Industrial, commercial, and municipal wastewater dischargers must obey these standards. The standards include three kinds of categories: 1) substances harmful to human health (Cyanides, heavy metals, pesticides, etc.); 2) conventional pollutants (BOD, SS, and so on); and, 3) newly established standards for chlorinated hydrocarbons, and several other chemicals that adversely affect the ecologic environment.

Applicability of this law is as follows:

- Even if where there is no sewer system, storm water discharges to the public water bodies – which include open canals and ditches must obey this standard. Generally, there is no problem with this case.
- In areas of combined sewer systems, all the discharged water (storm water, treated water, mixture of wastewater and storm water) from the sewerage system (water from weirs, pumping stations, treatment plants) must meet the effluent standards of the Law.
- Storm water within a separate sewer system is considered as part of "public water body" in this law. Therefore, the water quality of the storm water from separate sewer pipes have no obligation, or duty to meet the standards of the Law. The implication is that the storm water is "clean". Waters discharged into the separate storm water pipes, however, must meet the value of the standards, as in the case of stormwater discharges to open canals and ditches.

Local Standards of Municipalities and Prefectures

The Water Pollution Control Law allows the municipalities and prefectures to establish local standards which are more strict than National Standards of the Law. The power of the local standards are stronger than that of the National Standards in the district. Tokyo has elected this alternative for control of factory effluents (Mizorogi, 1989).

Storm Water Quality Regulations in Australia

An evaluation of Australian catchments indicates that formal designation of environmental values and associated sustainable loadings and flows, necessary to undertake systematic design and performance assessment of storm water management practices is often unavailable. Under the *ARMCANZ/ANZECC National Water Quality Management Strategy 1991*, State governments are required to put in place catchment management plans which designate the environmental values and associated water quality guidelines, as the basis for systematic planning and management of activities within the catchments.

Identification of Sustainable Flow and Pollutant Loads/Reduction Requirements

Two approaches to determining storm water flow and loading reduction requirements are identified by the ARMCANZ/ANZECC Draft Storm water Management Guidelines 1996:

- catchment-wide based systematic assessment of sustainable loads and current exports;
- comparison of the current receiving water quality relative to the ambient water quality guidelines, with a requirement for a proportional reduction in total catchment exports where the ambient values are exceeded (State-Pressure-Response based approach).

Presently, there are only assessments of limited total catchment sustainable loads and current total catchment exports, which are necessary to determine the loading reduction requirement. A major program is in progress to redress this situation, through Total Catchment Management Committees, establishment of Catchment Management authorities, and salinity and algal management strategies of the Murray Darling Basin Commission.

Allocation of Sustainable Flow and Load Across Land Uses

Four possible approaches are utilized:

- allocation based on an assessment of the catchment land uses and management practices best responding to range of community environmental, social and economic objectives (Australian Capital Territory approach);
- allocation based on a flow proportional basis for each sub-catchment or land use (Murray Darling Basin Algal Management Strategy 1993);
- market based trading of nutrient and other pollutant export rights (limited use, in view of complexity in case of non-conservative pollutants:
- reliance on the application of BMPs across all sectors within a catchment (most widely based approach).

Discussion

It is very difficult to compare the rules and regulations of these countries, with the objective of determining which is the best. The rules are obviously aimed at solving the same technical problem, but the basis of and formulation of the laws and regulations reflect the cultures and politics of the individual countries; and, what works well in one country may not work at all in a country with a different culture and political system. Maybe this point is supported by the fact that the basic rules and regulations of Canada and the United States are very similar, reflecting geographic proximity, and cultures and political systems that are much alike.

The following statements can be made however, based on the authors' review of the rules and regulations presented here and their personal knowledge of the state-of-practice regarding implementation of these rules. With respect to CSO mitigation, Germany has by far the most prescriptive rules and regulations; and has been the most successful at mitigating discharges from these systems to

their receiving waters. The United States Canada, and Japan appear to run in second place significantly behind Germany; the rules of these two countries are less prescriptive, and therefore not as easy to enforce. The United Kingdom has, in the past, taken the most scientific approach to determining the degree of control that is required of individual dischargers, but this results in the weakest enforcement power, and hence a lack of implementation of mitigation programs. It will be interesting to see whether the prescriptive requirement (Formula A) enacted in 1994 will speed up the mitigation process in the UK. Where Australia falls with regard to the other countries, the authors do not feel qualified to assess.

Regarding regulations for pollution control of urban storm water, the United States is clearly the leader. However, except for a few progressive communities, meaningful implementation has been limited to the State of Florida, which has a strong prescriptive state law, followed by Maryland, Delaware, and Washington, which also have state laws. The Province of Ontario is making good progress in implementing storm water pollution control, but in the remainder of Canada the situation is similar to the U.S. In the other countries there is awareness of the problem, and a lot of discussion, but not much action outside of experimentation and pilot testing.

If the principal authors might venture a conclusion, it is that the best regulations are those that are prescriptive and leave little room for interpretation. While it is popular to argue against this approach as not being the most cost effective and not insuring that local receiving water quality objectives will be achieved, the effectiveness of these types of rules and regulations is demonstrated by the success of CSO programs in Germany, and storm water quality control programs in the State of Florida.

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Infiltration practice for control of urban stormwater

Pratique de l'infiltration comme moyen de contrôle des débits d'orages en milieu urbain

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ABSTRACT
Infiltrating stormwater locally into the ground instead of discharging to conventional pipe sewers is increasingly considered as a means of controlling urban stormwater runoff. This paper reviews the most recent developments within this field and points out some of the major problems remaining. Easy-to-use methods for designing stormwater infiltration structures are available but methodologies for determining the design parameters based on local conditions and technologies for clogging prevention are needed. No evidence so far points at a high risk of groundwater contamination but the quality of surface soils will decrease due to long-term infiltration of polluted stormwater runoff. Simplistic modelling approaches based on conceptual process descriptions are needed for assessing the impact on soil and groundwater in local areas. The perspectives in relation to control of stormwater runoff are clear: the runoff peaks and volumes are decreased, and the urban hydrological cycle is returned to a more natural state. In some aspects stormwater infiltration is more effective for runoff reduction and abatement of pollution discharges than detention basins. In the future, measures to promote urban stormwater infiltration need to be developed.

RÉSUMÉ
L'infiltration locale dans le sol de l'eau provenant des orages au lieu de la technique conventionnelle d'évacuation par des collecteurs est envisagée de plus en plus comme un moyen de contrôle des débits d'orages en milieu urbain. Cet article présente les développements les plus récents dans ce domaine et met en lumière les principaux points restants en question. Des méthodes d'utilisation simple existent pour dimensionner les structures assurant l'infiltration des eaux d'orage, mais il manque encore des méthodologies appliquées aux paramètres de dimensionnement qui soient basées sur les conditions locales et des technologies de prévention du colmatage. Il ne semble pas qu'il y ait de risque évident de pollution du sous-sol, mais la qualité du terrain en surface diminuera en raison des infiltrations répétées à long terme des eaux d'orages poluées. Des modélisations simples basées sur la description des processus en jeu sont nécessaires pour évaluer l'impact sur le sol et sur les eaux souterraines dans des zones locales. Les perspectives en vue du contrôle des débits d'orages sont claires; les pointes de débits et les volumes diminuent et le cycle hydrologique urbain se rapproche de l'état naturel. Par certains aspects, l'infiltration des eaux d'orages est plus efficace sur le plan de la réduction du débit de pointe et de la pollution que des bassins de rétention. Pour le futur, il est nécessaire de promouvoir les techniques d'infiltration des eaux d'orages en milieu urbain.

1 Introduction

Means of removing or decreasing problems related to urban storm drainage systems have received extensive attention during the past decades. Major sewer rehabilitation programmes have been initiated to prevent leakages and collapses, and strategies for controlling the runoff process are being developed. Treatment plants and detention basins in combination with real time control are intro-

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duced as compensating measures against pollution from combined sewer systems. However, a common aspect of these solutions is that tremendous costs are often involved and that measures are taken to reduce some adverse effects that inherently come with the structure of the highly artificial water discharge systems.

Source controls and *best management practices* relying on natural processes may be considered as supplemental or alternative solutions to conventional urban drainage systems. Among these *stormwater infiltration* has received increased attention during the past decade, but the existing knowledge does still not enable professionals to solve all problems faced in practical applications. Currently, no well-established *technology* and *design practice* exists and consensus lacks with respect to the risk for *contaminating soil and groundwater*. Furthermore, the perspectives in relation to *control of stormwater runoff* need to become visible, and measures to *promote stormwater infiltration* must be developed. The objectives of the present paper are to throw light on the recent developments within these issues and to point out some of the major problems still remaining.

2 Structural design and dimensioning

2.1 *Types of infiltration structures*

Infiltration of stormwater through green surfaces is the technique that comes closest to natural infiltration of rainwater, because it allows for a slow infiltration process where the microbial and chemical processes in the humic root zone have time to react and protect the groundwater from contamination. However, collecting stormwater from impermeable surfaces and spreading it out onto green areas puts restrictions on the design and use of urban space. Sub-surface infiltration structures, soakaways, are the most common types of infiltration systems. They are basically holes in the ground filled with rubble or stones. The stormwater is stored temporarily in the cavities between the stones while it slowly percolates into the surrounding soil. Unfortunately, the stormwater escapes the humic root zone by using this technique and so, there may be a much larger risk for groundwater contamination related to the use of sub-surface infiltration than surface infiltration.

A few types of infiltration structures are illustrated in Fig. 1. Direct discharge of roof runoff to grass lawns by using an ejector connected to the down spout and a splash pad with a slope away from the building is a common solution in many weekend cottage areas (a). Road drainage through permeable asphalt and use of the sub-base for water storage has shown to be rather efficient in connection with roads for light traffic (b), as have roadside infiltration in ditches or swales, or into the road shoulder for highways. The most common sub-surface infiltration structures in areas with a thick zone of medium permeability deposits are infiltration trenches (c). They are typically long and narrow to minimize the surface area at the bottom that is supposed to clog with fines after some time, and to maximize the ratio between the effective infiltration area (the sides) and the volume. Infiltration shafts (d) are frequently used in areas with deep gravel deposits and a thin superposed stratum of weathered material with low to medium permeability. They provide only little effective infiltration area and storage but this may be of minor importance due to the high permeability of the gravel.

Many combinations of surface and sub-surface infiltration in combination with green surfaces and water storage exist. Fig. 1(e) sketches a system developed for pre-treatment and infiltration of polluted stormwater runoff in Switzerland (Fehr, 1995). The water enters a storage basin equipped with a bottom membrane to prevent water from infiltrating directly. A drainage pipe in the bottom is connected to an infiltration shaft with a built-in oil separator, and the pipe is covered by 0.8 m of gravel, that develops into a humic soil with abundant vegetation within a few years after construction. During heavy rain storms water can be stored in the basin and slowly infiltrate through the soil layer. Any pollutants that are not screened off by the soil will be removed by the oil separator before infiltrating into the deep gravel sub-surface.

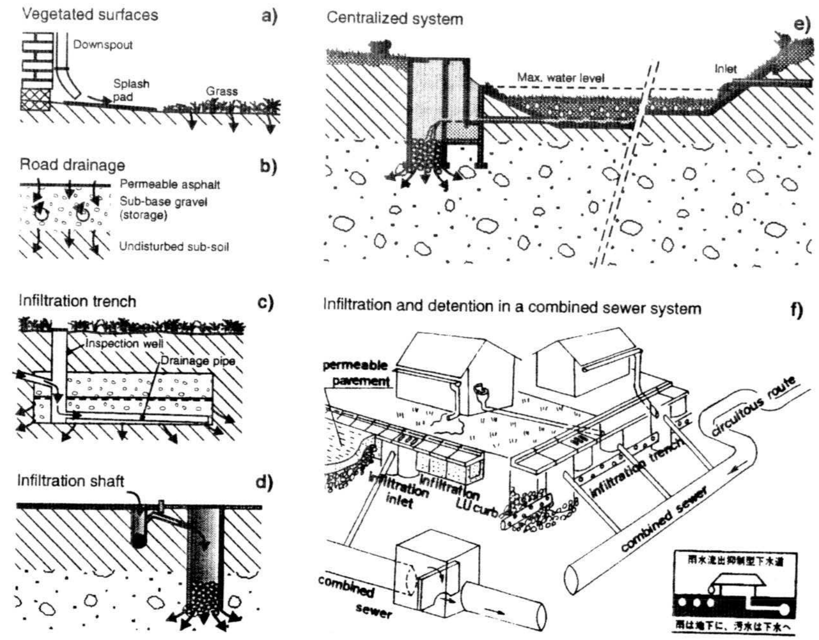

Fig. 1. Some different types of stormwater infiltration structures.

Fig. 1(f) shows the concept of the *experimental sewer system* (ESS) in Tokyo, Japan (Fujita and Koyama, 1990). All the elements are prefabricated concrete units equipped with screens and sand traps to prevent clogging. The Tokyo Metropolitan Government has implemented the ESS over an area of more than 1,423 ha with 33,450 infiltration pits, 286 km of infiltration trenches and 495,000 m^2 of permeable pavement during the past 15 years. The screens, sand traps and permeable pavements are cleaned between one and five times a year depending on the location, because the inflow of leaves and sediments depends highly on the proximity of vegetation and the use of the area. It has been confirmed in several cases that the infiltration function is still fully operational after 10 years of use, provided that proper clogging prevention measures are taken. Other combinations of infiltration systems and traditional drainage systems are possible. Solutions like the ones shown in Fig. 1e and 1f are only limited by the fantasy of the engineering profession and the availability of the technology required.

2.2 *Selected methodologies for calculating the dimensions of infiltration structures*

Formerly, infiltration systems were designed in a variety of ways, including *by guesswork* and *on experience*, and systematic design guidelines have only been published within the last few decades. Petersen et al. (1993) and Mikkelsen (1995) give recent reviews. Infiltration surfaces are typically

sized based on knowledge about their infiltration capacity, to absorb the runoff intensity of a predefined design storm. Considering the large variation of infiltration capacity over a surface it appears that this type of design is very approximate.
When designing sub-surface soakaways or other infiltration structures involving storage, the storage characteristics of rainfall need to be considered. Most current national design guidelines make use of the *rain envelope method* which is a well-known and simple method for design of detention basins. Both soakaways and detention basins may be described simplified by only two parameters; the specific storage volume ($v = V/A_r$), and the (time-invariant) specific flow restriction ($q_{FR} = Q_{FR}/A_r$), where V is the available storage volume, Q_{FR} is an average flow restriction at the outlet (the discharge capacity) and A_r is the drainage area that contributes effectively with runoff. The most significant difference is that for a detention basin the flow restriction is determined by an outlet pipe whereas for a soakaway it is determined but by the permeability of surrounding soil, the soakaway geometry and the water level in the soakaway.
Jonasson (1984) suggested using simplified groundwater flow theory to calculate Q_{FR} for a soakaway. It was argued that the bottom of a soakaway will eventually clog up with litter and particles. Thus, Q_{FR} was obtained from a simplified formulation of Darcy's equation for flow of water in saturated porous media as a unit-gradient flow through half the area of the side walls. The contribution of the bottom area and end walls to the flow was neglected, and the water level was supposed to be on average half-way between the bottom and the top. This implies that $Q_{FR} = K\ ^1/_2 A_{side}$ where K is the soil permeability and A_{side} is the area of the side walls.
The rain envelope method utilizes rainfall and infiltration envelope curves combined with simple mass balance considerations to find the critical storm duration and the necessary storage volume. The problem may be solved analytically by expressing IDF-curves with a mathematical equation (e.g. Mikkelsen and Jacobsen, 1993) or alternatively by automating the iterations with a computer program as suggested by Pratt and Powell (1993). However, none of these approaches cover up the general inadequacy of IDF-curves to describe storage characteristics of rainfall, including the effect of coupled rain storms.
Mikkelsen and Jacobsen (1996) presented a new methodology that has already been published as a national Danish design guideline. Since q_{FR} is time-invariant, the *emptying time* of a full detention structure may be written $t_e = v/q_{FR}$. Historical rain series are used as input to a simple conceptual model that simulates runoff and storage of water, and extreme statistics made from such computations are then depicted as shown in Fig. 2(right). Based on the geometry of an infiltration structure and two-dimensional flow assumptions its emptying time (t_e) can be calculated as illustrated on Fig. 2(left) for a long and narrow infiltration trench. Then, the necessary storage volume (v) for a predefined design return period (T) may be read directly from one of the curves in Fig. 2(right) and transformed into the dimensions of the infiltration structure. The graph in Fig. 2(right) can be used to design any type of soakaway by reformulating the equations specifying v, q_{FR} and t_e based on the actual soakaway geometry.
Some guidelines mention that soakaways should not be used, or that they should only be used when supplied with a discharge pipe, if the soil permeability is lower than a threshold value. This value is fixed at $2 \cdot 10^{-5}$ m s^{-1} in Sweden (VAV, 1983). However, it appears from Fig. 2 (right) that there is no abrupt transition where stormwater infiltration becomes impossible, but that the required volume may become unrealistically high when the emptying time is very large. The difinition of the term *unrealistic* depends on the local rainfall pattern (including the chosen design return period), on the permeability of the soil, and on the costs of construction works. Thus, a lower threshold of soil permeability is an economic restriction and not a technical one. Design guidelines should therefore not

preclude the use of stormwater infiltration in low permeability soils, but merely supply the necessary tools that allow the user to come to this conclusion under specific circumstances.
In most realistic design situations the errors introduced by resorting to this simple and easy-to-use design method are overruled by the uncertainty of the involved parameters (Mikkelsen, 1995). The largest amount of uncertainty is related with determining the soil permeability (K) on a spatial scale corresponding to the size of an actual infiltration structure. Thus, practical and inexpensive field-methods that facilitate measurements of soil permeability several metres below the ground need to be developed. Furthermore, the design return period (T) is mostly chosen rather fortuitously, and methodologies for relating T to possible detrimental effects would be beneficial (Petersen et al., 1994).

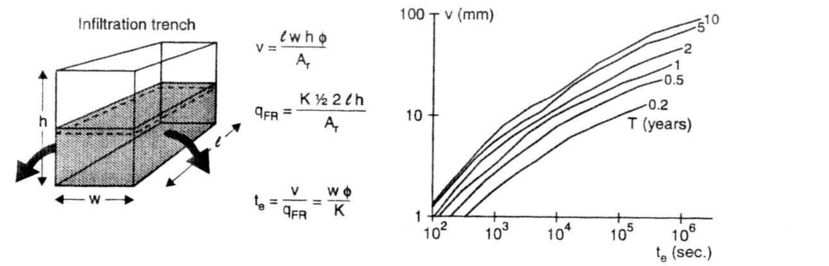

Fig. 2. Basics of the new Danish method for sizing soakaways, exemplified for a long and narrow infiltration trench. K and ϕ are the soil permeability and porosity, and w, l and h are the width, length and depth.

3 Risk of contaminating soil and groundwater

3.1 *Priority pollutants in relation to urban stormwater infiltration*

Direct comparison of typical concentration levels in stormwater runoff with drinking water quality criteria readily reveals that nitrogen (N) and phosphorus (P) is of little concern (Mikkelsen et al., 1994). If the typically large degree of attachment to particles is considered for heavy metals, it also appears that these substances do not represent a severe threat to potable groundwater resources. However, drinking water quality is not the only relevant issue to consider. Most metals can be considered critical if comparison is made with ecotoxic values, river water quality criteria (when the infiltrating water readily exfiltrates into a nearby stream) or target values for groundwater quality (Mikkelsen, 1995). Furthermore, their tendency to accumulate in the soil phase will eventually lead to soil concentrations exceeding established quality criteria.
Generally, organic micro pollutants have not been addresses in the same detail as heavy metals, partly because the necessary analytical methods have not been available for long, and partly because their inherent environmental problems have not been faced until recently. Furthermore, bio-accumulating compounds have received the most attention (e.g. polyaromatic hydrocarbons) because they are available in high concentrations in parts of the environment directly exposed to man (e.g. surface soils). The substances of largest environmental risk in relation to groundwater contamination (e.g. highly soluble compounds) are those that have been studied the least. Pitt et al. (1994) add pathogens (resulting mainly from animal droppings) and road salts to the already mentioned types of contaminants that may constitute a threat to the quality of ground waters. Grotehusmann (1995) summarized available data from German measurements on runoff water and

concluded that heavy metals plus polyaromatic hydrocarbons (PAH), simple aromatic compounds (BTX), polychlorinated biphenyls (PCB), volatile chlorinated hydrocarbons and pesticides are the most critical types of contaminants.

3.2 *Experimental evidence from detailed field studies*

In principle, two different strategies have been followed in field investigations of existing stormwater infiltration systems. In the first strategy the groundwater quality below and downstream from an infiltration system is directly brought into focus. By sampling and analysing seepage water and groundwater, it is supposed that it can be directly assessed whether infiltration leads to changes in groundwater quality. This type of strategy has been applied in several studies, e.g. Malmqvist and Hård (1981), Golver and Schneider (1983), Nightingale (1987a) and (BMFT, 1993). Generally, no significantly increased levels of priority pollutants, including selected heavy metals and trace organics, were found in the groundwater. However, the conclusion *no visible effects* may be due to a limited time of operation, meaning that critical pollutants have not yet reached the groundwater table because the substances present in critically high concentrations are absorbed in the soil phase. The conclusion may also be wrong if the seepage water is significantly diluted with groundwater before sampling or if the plume of contaminated water is not found due to heterogeneities in the subsurface.

The second strategy focuses on the soil phase by sampling and analysing the soil in or beneath an infiltration system. Some studies, e.g. Hogland et al. (1990) and Legret et al. (1993), followed the fate of pollutants in pervious road constructions and showed that heavy metals are strongly retarded in the construction itself. Others, e.g. Nightingale (1987b,c) and BMFT (1993) investigated the soil beneath the bottom of larger infiltration ponds reaching the conclusion that for many substances, in particular heavy metals, the soil between the bottom of the infiltration system and the groundwater table apparently acts as an effective pollutant trap. However, conclusions from this type of investigation are still constrained to the investigated sites, e.g. to specific conditions governed by the pollutant load in the stormwater, the infiltration system design, the age of the system and the properties of the soil where the water is infiltrated. Furthermore, high concentrations of pollutants in the soil phase do not necessarily mean that the pollutants cannot be leached during the next decades or centuries.

Mikkelsen et al. (1996) investigated two small surface and sub-surface infiltration systems for road runoff in Switzerland by uncovering the pollution retention pattern in the soil phase and assessing the mobility of the contaminants through extraction techniques. Measured contaminants included selected heavy metals, a number of PAH's and AOX (adsorbed organically bound halogens). In both the surface and sub-surface infiltration system the concentrations decreased rapidly to background levels within depths less than 1.5 m. This is shown for an infiltration shaft (sub-surface infiltration) in Fig. 3. The potential for groundwater contamination appeared to be limited, but the soil and runoff sludge found in the infiltration systems were heavily contaminated. The runoff sludge consists mainly of fines and organic matter and plays an important role, both as pollutant source and pollutant sorbent. Noteworthy, an obvious difference was not found between the ability of the surface and the sub-surface infiltration systems to retain pollution, due to the influence of the runoff sludge. The runoff sludge found in such systems may be an important parameter to consider for design of pollution retardation, even in sub-surface infiltration structures. However, an apparent antagonism is present between the requests for a high soil permeability and for some degree of clogging for retardation of contaminants.

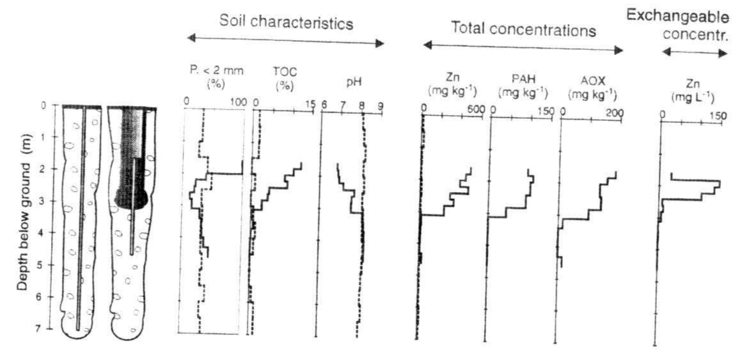

Fig. 3. Vertical profiles showing the depth distribution of selected soil characteristics and contaminant parameters in a profile through an infiltration shaft and the underlying gravel (full lines) and in a control profile uninfluenced by runoff infiltration (dotted line).

3.3 *Predicting the risk of soil and groundwater contamination*

Xanthopoulos and Hahn (1994) used simple mass balances to calculate the accumulation of well absorbable contaminants (heavy metals and PAH's) in the top soil layer of infiltration systems. Using average concentrations of contaminants in stormwater runoff they showed that soil concentrations exceeding established soil quality criteria may be reached within a few years or decades. Mikkelsen (1995) showed by accounting for the possible variation in runoff pollution that it may take anywhere between 10 years and several hundred years to reach critical soil concentrations. Such calculations are naturally very approximate and only apply for substances that strongly accumulate in the surface layers. However, they clearly document the uncertainty related with assessing the risk for contamination in planning situations.

A numerical unsaturated zone model was applied in Germany to simulate scenarios of contaminant transport from infiltration of stormwater (Weyer et al., 1993; Grotehusmann, 1995). The model was calibrated with data from lysimeter experiments and used to simulate the fate of selected heavy metals, PAH's and PCB's in a range of soil profiles. Compared with the simple mass balance approach described above, this model facilitates a more detailed description of the contaminants' depth distribution. It was possible to evaluate effects of varying soil compositions (mainly pH) on the mobility of heavy metals, and accumulation in the top soil of PAH to concentrations exceeding established soil quality criteria was found strongly dependent on a proper assessment of the rate of degradation (Grotehusmann, 1995). These modelling studies serve as an important step towards future effect assessment tools.

Obviously, simplistic modelling approaches based on conceptual process understanding are needed. Possible applications for such models would be assessments of minimum residence times for hydrophilic and degradable contaminants in the biologically active zone.

3.4 *Sustainable control of stormwater contaminants?*

In Switzerland, a site evaluation procedure has been prepared for use where potable groundwater resources are at risk (Hartmann et al., 1991; Krejci et al., 1993; Fehr, 1995). Decision diagrams have been made to help planners choosing between several types of infiltration structures based on approximate knowledge on the origin and type of stormwater and on the hydrogeological conditions at individual sites. The basic idea is that *polluted* stormwater should pass through a humic layer at the soil surface that effectively screens off any present well absorbable or degradable pollutants, whereas *clean* stormwater is allowed to infiltrate directly into the subsurface. What is *not* considered in this procedure is the ability of accumulated runoff sludge in sub-surface infiltration systems to retain contaminants. Furthermore, the possibility for contaminating surface soils seems to be totally forgotten. Wide scale use of stormwater infiltration through urban surfaces would have to take this into account, and proper remediation actions would have to be implemented in situations where public health is at risk due to human exposure to contaminated surface areas.

Boller and Häfliger (1996) showed that about 75% of the total mass load of the heavy metal copper (Cu) in a Swiss city would end up in either farmland (due to sludge application), river sediments or urban soils depending on the layout of the urban stormwater drainage system (combined sewers, separated sewers, or separated wastewater pipes in combination with stormwater infiltration). Contamination of farmland and river sediments is very difficult to remediate due to its diffuse nature. Thus, provided that the accumulated copper can be effectively retained in the infiltration systems without causing harm to human activity, infiltration may be seen as an effective means of *pollution* source control, which may again be seen as a step towards sustainable stormwater management. Such assessments should, of course, also be made for other types of stormwater contaminants. Geldof et al. (1994) and Mikkelsen (1995) discuss these issues in more

4 Control of stormwater runoff

4.1 *Multipurpose source control of urban stormwater*

Infiltration is often introduced with specific objectives such as *flood control, combined sewer overflow abatement, groundwater restoration, prevention of ground freezing and subsidence* or *drought prevention.* Also *decreased costs* are sometimes mentioned. Although most literature on these issues is very general some case- and simulation studies give indications with respect to compliance with objectives.

Carleton (1990) concluded from detailed simulation studies that a 41% reduction of the annual volume of runoff was possible in an Australian catchment, if a combination of infiltration and storage was used. Surface infiltration alone would still lead to considerable amounts of surface runoff and consequently to sewer flow during heavy storms. The simulated effect of various types of infiltration structures on peak flows with different return periods is shown in Fig. 4(left). Compared with the status situation (no infiltration) the efficiency of infiltration increased with an increased use of storage.

Geldof et al. (1994) summarized conclusions from Japan, Denmark and the Netherlands making it clear that stormwater infiltration may be efficient for abatement of floodings, reducing pollution discharges into receiving waters and counteracting drying-out of shallow groundwater resources in urban areas. The Japanese ESS illustrated in Fig. 1(f) is probably the best real-world example of the positive effects of stormwater infiltration. The ESS was methodologically introduced in the suburbs of Tokyo about 15 years ago, and compared with a catchment served by a traditional sewer system the number of inundations per year of an urban river has gradually decreased, cf. Fig. 4(right). Measurements furthermore show that the ESS reduces the annual volume of stormwater runoff with approximately 50% (Fujita, 1993).

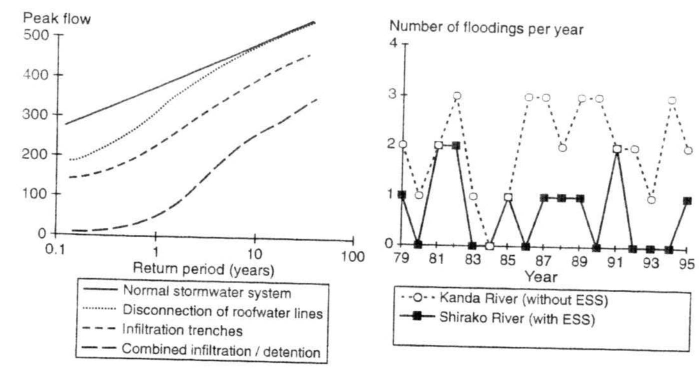

Fig. 4. Left: Effectiveness of different types of infiltration systems to reduce simulated peak flows (redrawn from Carleton, 1990). Right: The number of floodings per year due to runoff water from sewer systems in two urban rivers in Japan. The Kanda River basin is served by a traditional sewer system, but the ESS has gradually been adopted in the Shirako River basin since 1981, and now covers more than 1,400 ha.

Grotehusmann et al. (1994) simulated the possible benefits of retrofitting a traditional combined sewer system in Germany. The investigated scenario was based on redirecting the stormwater runoff from roof and courtyard areas to a system of interconnected infiltration ponds and trenches. This system relies partly on infiltration and partly on discharge into a local stream. By disconnecting 41% of the impervious area from the traditional sewer system the annual CSO volume and number of overflow events decreased by 50% and 14%, and the volume of stormwater flowing to the treatment plant decreased by 13%. Larger reductions of annual CSO volumes and numbers (90% and 98% in the specific example) were found possible by installing detention basins, but this would *increase* the volume of stormwater flowing to the treatment plant by approximately 300%. Clearly, stormwater infiltration and detention influences the treatment plant differently.

4.2 *Comparing the effectiveness of stormwater infiltration and detention*

Jacobsen and Mikkelsen (1993) compared stormwater infiltration and detention basins in four simulation studies using data from existing combined sewer catchments differing in both size and storage capacity. Annual CSO volumes decreased rapidly with an increased surface area connected to infiltration trenches, but similar reductions could obviously be obtained by constructing detention basins. However, as shown in Fig. 5(left), for all four catchments stormwater infiltration was found to decrease the nutrient emissions from the total system (CSO structures and treatment plant) whereas detention basins proved to be relatively neutral to the emissions from the total system. The reason is simple; detention basins increase the nutrient emissions from treatment plants due to extended periods with elevated flow (Harremoës and Sieker, 1993) and additionally, before overflowing upstream nutrient concentrations in wastewater are diluted with stormwater to concentrations equally low as the concentration in discharge water from treatment plants during rain (Henze, 1987; Durchschlag, 1992).

Each pollution discharge source (CSO structures and treatment plant) has distinct characteristics in terms of water volumes and pollutant concentrations. Additionally, the impact and the importance of the discharges depends on the type of receiving water (e.g. rivers, lakes or coastal waters). Jacobsen and Mikkelsen (1996) presented a theoretical study on the effect of stormwater infiltration and detention basins on four emission parameters that affect the quality of surface waters differently. All four parameters are commonly used for evaluating the effects of different intervention scenarios and can be calculated with readily available simulation models. The results are shown in Table 1. Generally, stormwater infiltration may be used to reduce annual volumes from CSO structures, extreme volumes from CSO structures and annual discharges of nutrients from the total system. However, the effect on the annual number of overflows from CSO structures is only marginal. On the other hand, detention basins may be used to reduce annual volumes and annual number of overflows from CSO structures, but they only affect extreme volumes from CSO structures marginally and they increase the annual nutrient discharges from the total system.

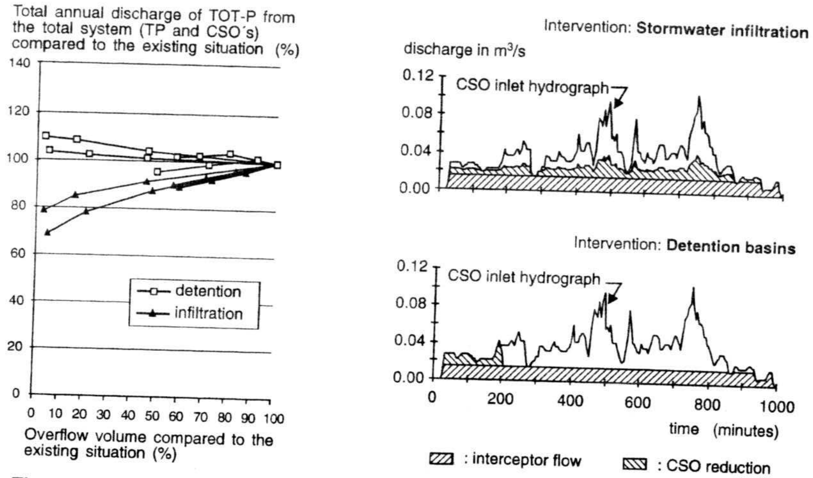

Fig. 5. The net effect of stormwater infiltration or detention in the upstream system. Left: Simulated total annual emission of phosphorus from four catchments as a function of the annual load from CSO structures (from Jacobsen and Mikkelsen, 1993). Right: Simulated effects on the CSO hydrograph for an extreme CSO event (from Jacobsen and Mikkelsen, 1996).

Table 1. The effectiveness of stormwater infiltration and detention for controlling emissions to surface waters from combined sewer systems. Positive effect (+), marginal effect (0), and negative effect (-).

	Annual CSO volumes	Annual number of overflow events	Extreme CSO volumes	Total annual nutrient discharges
Infiltration	+	0	+	+
Detention	+	+	0	-

The reason for this difference in behaviour is illustrated in Fig. 5(right) for an extreme CSO event corresponding to a return period of 1 year. For a theoretical catchment with a concentration time of 30 minutes and a specific interceptor capacity of 0.2 μm s^{-1}, two cases both leading to a 35% reduction of the *annual CSO volumes* were considered; infiltrating stormwater runoff from 25% of the impervious area, and introducing 1.5 mm of storage volume. For this specific *extreme event* infiltration reduces the overflow with an amount approximately proportional to the incoming flow throughout the event, corresponding to an 41% reduction of the overflow volume, whereas the initial abstraction caused by detention is relatively small (9%). Noteworthy, none of the interventions eliminate the overflow event entirely. For a more frequent CSO event introduction of storage might eliminate the event entirely whereas the effect of infiltration would still be approximately proportional to the incoming flow and hence not eliminate the event.

5 Promoting urban stormwater infiltration

5.1 *Economic reflections*

Estimating the costs of stormwater infiltration and comparing with conventional techniques is very uncertain since the technology is site-specific and not yet developed to a high standard (except in Japan). Furthermore, the implementation phase is usually seen in a long-term perspective where the cost of labour may change and it is unclear whether the involved expenditures and construction work should be seen as a public or a private duty.

Fujita and Koyama (1990) state that the ESS in Tokyo was estimated to cost 20% more than a conventional sewer system, but in return it has worked according to the purpose by eliminating severe floodings of an urban river during rain. The same effect would be possible by means of open detention ponds or underground detention facilities, but this would cost 3 and 10 times more respectively. Thus, in this case infiltration turns out to be much cheaper than conventional techniques if the same goals are to be met.

It is important to stress that future applications of stormwater infiltration in industrialized countries will be mainly in relation with environmental rehabilitation, and maintenance and renovation of existing sewer systems. Thus, the costs associated with implementing stormwater infiltration should preferably be included in the running planning budgets. Stormwater infiltration should furthermore be promoted in developing countries both for ecological and economical reasons, but also because the technique is better implemented if already considered in the planning phase of urban environments.

5.2 *Social and administrative reflections*

A well-developed technical standard and industry exists in the urban drainage profession, and administrative practice as well as professional skills are usually directed towards conventional technologies based on pipe systems and end-of-the-pipe treatment. Switzerland is one of the only countries that legally impose infiltration of urban stormwater runoff. Krejci et al. (1993) describe the administrative procedures necessitated by this new legislation. In most other countries the choice of drainage technology is more or less optional and based on tradition. To shift into more use of stormwater infiltration in the future education and economical incentives are necessary. Also, to maintain large numbers of infiltration units public awareness and involvement of local people is much more necessary than in traditional drainage systems.

Fujita (1996) gives an overview of the promotion measures currently used and planned in Japan. They include both standardization of design procedures, technologies and administrative procedures, administrative guidance when obtaining planning permissions, and public relations activities aimed at persuading the public to cooperate and install infiltration structures more or less free willingly. Also subsidy systems distributing money from planning budgets through various authority levels and down to the institution (or citizen) who is responsible for the actual work are established. However, fiscal and subsidiary systems are impeded by lack of transparency between different public budgets. Probably the best way of promoting infiltration practices in urban areas is by establishing demonstration sites where people in position to boost or implement infiltration practices can see the actual facilities at work. These people include politicians, bureaucrats of both central and local authorities, business people (manufacturers, consultants and contractors), residents, children and researchers.

6 Conclusions

Experience shows that infiltration structures will work if designed and maintained properly. Easy-to-use design methods accounting for rainfall storage characteristics, soil permeability and geometry of infiltration structures are available, but practical and inexpensive methods for measuring in-situ soil permeability are needed. Furthermore, technologies for clogging prevention and methodologies for relating the design return method to possible detrimental effects of stormwater runoff need to be developed.

No evidence has so far pointed at a considerable risk for groundwater contamination, but stormwater infiltration will eventually lead to contamination of surface soils. More research is clearly needed to identify which categories of contaminants that are critical and which processes are dominantly taking place in the subsurface under different conditions. Stormwater infiltration systems may act as effective traps for well absorbable contaminants, thus pointing at sustainable solutions for control of stormwater contaminants.

The perspectives in relation to control of stormwater runoff are clear; the runoff peaks and volumes are reduced, and the hydrological cycle is returned to a more natural state. Generally, stormwater infiltration may be used to reduce annual and extreme volumes from CSO structures, and annual discharges of nutrients from the total system consisting of sewer system and treatment plant, but the effect on the CSO frequency is marginal. For comparison, conventional detention basins may be used to reduce annual volumes from CSO structures and the CSO frequency, but they hardly affect extreme overflow volumes and increase the nutrient discharges from the total system.

Wide-scale application of stormwater infiltration in the future is impeded by a number of factors such as economic uncertainty and lack of standardized technology, and society is challenged through the request for increased public awareness about technical installations and the demand to administrative bodies to cope with problems across institutional boundaries.

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