Storm water in the Netherlands

Climate change and urbanization will increase the frequency and magnitude of urban flooding and water quality problems in many regions of the world. In coastal and delta areas like The Netherlands, where urbanization is often high, there has been an increase in the adoption of sustainable urban drainage systems (SUDS). These have been installed with the expectation to reduce urban flooding and reduce the pollution impact of urban stormwater discharges on receiving waters. However, the performance of SUDS in delta areas such as the Netherlands (with high groundwater tables and low permeability soils) is often questioned and monitoring results on their long term efficiency are limited. Therefore, research results on the hydraulic performance and removal efficiencies of Dutch SUDS will improve the local design, implementation, maintenance and performance of these facilities.

Numerous research studies in the past have used laboratory-based experiments to model and predict the performance of SUDS field installations. However, the results of these studies were generally not calibrated or verified against reliable field performance data. Many factors can affect the performance of SUDS and some of these are extremely difficult to simulate in a laboratory. These factors can include: clogging, climate and seasonal effects, water table variations, maintenance and numerous site environmental conditions. For example, measured infiltration parameters such as hydraulic conductivity can have a spatial variation of up to two orders of magnitude which can result in laboratory and model outcomes with great uncertainty. There is a significant knowledge gap in the research information available pertaining to the performance of frequently applied SUDS devices such as sedimentation facilities, swales and permeable pavement systems. The research presented in this thesis has therefore focused on an in-depth investigation into the operational performance of 'old' SUDS installed in lowlying areas in The Netherlands.

In order to address this knowledge gap new standardized test procedures for full-scale testing are set up and tested to study the behaviour of these SUDS in the Netherlands. In the hydraulics laboratory of the TU Delft the removal efficiency of several sedimentation devices was tested in a standardized way.

This research into the performance of SUDS in the Netherlands included, see http://repository.tudelft.nl/view/ir/uuid:d4cd80a8-41e2-49a5-8f41-f1efc1a0ef5d/:

- Characteristics of stormwater (chapter 2)
- Laboratory testing of sedimentation devices (chapter 3)
- Field tests of:
  - Permeable pavements (chapter 4)
  - Bioretention swales (chapter 5)

For testing each of these facilities new monitoring methods have been developed, tested and evaluated.

Characteristics of stormwater

Detailed information on stormwater quality characteristics is essential to rate the efficiency of sustainable urban drainage systems (SUDS). Stormwater, flowing into storm sewers, is known to contribute to pollutant loads entering urban receiving waters; this can result in significant degradation of the receiving water quality. Knowledge of the characteristics of stormwater pollution would enable urban planners and drainage engineers to incorporate the most appropriate stormwater management strategies in their plans and to mitigate the effects of stormwater pollution on downstream receiving waters.

This requires detailed information on stormwater quality and treatability of the storm water. This study gathered stormwater pollution data at over 150 locations throughout the Netherlands. In 15 years a total of 7,652 individual storm events have been monitored. This

makes the database the largest stormwater quality database in Europe. The study compared the Dutch data to those presented in contemporary international stormwater quality research literature. The study found that the pollution levels at many of the Dutch sites did not meet the requirements of the European Water Framework Directive (WFD) nor Dutch Water Quality Standards. To meet these standards additional sedimentation, filtration or adsorption capacity is needed to capture small particles with attached pollutants. Detailed information on suspended sediment characteristics in stormwater is essential to be able to rate the efficiency of sustainable urban drainage systems (SUDS).

Efficiency of sedimentation devices

In the hydraulic laboratory of the TU Delft four sedimentation devices were tested on removal efficiency of suspended solids in stormwater by sedimentation. The treatment performance of these sedimentation facilities is investigated in a standardized way in order to compare their hydraulic performance and removal efficiency. In the tests, Dutch stormwater is simulated with a standardized mixture of water and sediment with a wellknown particle size distribution and fall velocity of these particles. The new test method proved to be a good method to compare the removal efficiency of small particles in the range of 5-60 µm of several sedimentation devices.

The observed removal rates for sediments up to 60 µm of the facilities with a storage volume in the order of 1,5 m3 and settling surface around 1 m2 drop to levels below 50 % at a flow rate of 10 l/s and higher. Given a flow rate of 10 l/s, small particle sizes up till 20 µm will not be removed by more than 10%. Particles over 60 µm are trapped with higher removal efficiency but these particles contain less adsorbed pollutants.

Since most of the tested facilities have no protection from hydraulic overloading, flush-out of earlier collected sediment at moments of higher discharges was observed. In order to comply with the Dutch maximum acceptable concentration (MAC) and or WFD standards, SUDS that contain a treatment step with filtration or adsorption can be advised. Two SUDS that are widely implemented in the Netherlands are: permeable pavements and swales. However, the effectiveness of these SUDS is sometimes questioned, especially in the low lying parts of the Netherlands with the soil consisting mainly of clay and peat and its high groundwater tables. Research on the hydraulic performance of these SUDS in the Netherlands is scarce, in particular on their resistance to progressive clogging in the years after implementation.

Permeable pavements

Permeable pavements are specifically designed to promote infiltration of stormwater through paved surfaces in order to reduce runoff volumes and to improve water quality by filtering sediment and other pollutants. This research evaluates the performance of permeable pavements using a new experimental test method developed to more accurately determine the surface infiltration rate. The method is a full-scale falling head method which involves inundating a large area of the pavement in order to determine the infiltration rate through the pavement surface. The method has been tested on 8 locations in 5 Dutch municipalities to achieve measurements on the infiltration capacity of permeable pavement over seven years after construction and without maintenance.

Infiltration rates of newly installed permeable pavement systems are generally very high, but rates can decrease significantly over time due to clogging. Newly installed permeable pavements in the Netherlands should demonstrate a minimum infiltration capacity of 194 mm/h (270 l/s/ha). In field tests on older pavement infiltration rates ranging between 29 and 342 mm/h were determined. Permeable pavement guidelines in the Netherlands recommend that maintenance should be undertaken on permeable pavements when the surface infiltration falls below 20.8 mm/h. According to this guideline, none of the 8 pavements tested in this study would require immediate maintenance. Clogging of permeable pavements over time is

inevitable due to its filter function. However; over 80 % of the pavements evaluated in this study were found to have an infiltration capacity of more than 70 mm/h after over seven years of continuous service without maintenance.

Swales

Bioretention swales (in Dutch called "wadi's") have been introduced in the Netherlands around 1998. Swales are one type of SUDS device that has been used globally for well over two decades now to provide stormwater retention and conveyance and improve stormwater quality. The main design objectives of swales, and the purpose of their installation, can however vary considerably. Even under conditions of high groundwater tables (up to 0.5m under the swale) and low permeable soil such as clay the emptying time of the swales should be less than 48 hours.

This research demonstrated that 75% of the swales tested in the study meet the required hydraulic performance levels even after years in operation and without maintenance. The individual swales show a variation of the infiltration capacity of 0.08 to 2.16 m/d.

SUDS in the Netherlands and around the world

The results obtained in this study are encouraging and important for the implementation of permeable pavement and swales in The Netherlands, since the performance of SUDS in delta areas and in areas in the world with comparable hydraulic circumstances has been viewed with skepticism. The research undertaken on Dutch SUDS field installations has demonstrated with new, full scale monitoring methods that most of the bioretention swales and permeable pavements tested in this study meet the required hydraulic performance levels even after years in operation and without maintenance. Standardized tests of sedimentation devices however demonstrated that these facilities have a limited effectiveness for particles smaller than 60 µm while receiving a normal hydraulic loading.

The applied methods of full scale testing of SUDS can easily be applied to observe the hydraulic performance of swales and permeable pavement after years of operation. Innovative monitoring methods and visualization of these experiments using video footage allows real-time observation of the entire infiltration process. Recording these observations in a logbook can provide insight in their demand of maintenance and can also help to improve their design.