Towards integrated stormwater–meltwater management in the coastal part of Norway

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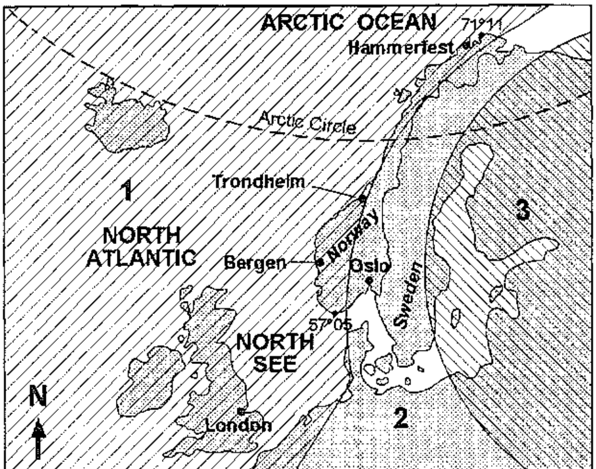
Abstract New directions in urban runoff and water environmental management in the coastal part of Norway are being introduced. The goal is to manage the total urban runoff (wastewater and stormwater) so that environmental damage is avoided and the goals for the receiving water are achieved at reasonable costs. It is mostly based on the results from the research programme carried out in the Birkeland basin and the subcatchment Sandsli, in Bergen, since 1981, where use of the blue-green concept and the Sandsli-system has been successful. The green trend in urban stormwater management utilizes the capabilities of nature to store huge stormwater-meltwater volumes and to reduce the pollution content in the water. In the planning process, blue areas like lakes, rivers and brooks are to be kept in their natural condition.

INTRODUCTION

In Norway, urban planning and urban runoff practice has been based on the effects of summer rainfalls, assuming that only the impervious paved areas contribute to the runoff (Thorolfsson, 1993). Furthermore traditional urban runoff management has been to lead the wastewater to treatment plants and to lead the stormwater-meltwater out of the source areas as quickly as possible (Thorolfsson, 1998).

The Project Group for Urban-hydrological Research in Bergen (PUB) initiated a project "Urban runoff in the coastal areas in Norway" (Thorolfsson & Sekse, 1989; Thorolfsson 1990a,b) with the objective of finding a solution to the urban runoff problems in the coastal regions of Norway. The special climatic and geological conditions call for revised practice in urban runoff management.

Norway is located in the northwestern corner of Europe, between latitudes 57°05'N and 71°11'N, a length of more than 1700 km. Half of this distance is north of the Arctic Circle. The topography is characterized by a coastal mountain range of moderate height (1000–2000 m) running the whole length of the country, dissected by valleys and fjords. Settlement is spread out along the coast and valleys, with towns in the range of 5000–225 000 inhabitants as active centres. Bergen at 60°18'N is the second largest city in Norway with 225 000 inhabitants and Hammerfest at 70°40'N with 7000 inhabitants is the world's northernmost town of this size (Fig. 1). Most towns are partly built on hillsides sloping down to the fjords and lakes, and partly on



1. NORTH-WEST EUROPE. Mild winters, cool summers, highest precipitation in the autumn (maritime climate).
2. CENTRAL EUROPE. Cold winters, warm summers, highest precipitation in the summer (continental climate).
3. EAST EUROPE. Very cold winters and very warm summers.

Fig. 1 Location of Norway and a rough delineation of climate zones.

flat areas adjacent to the fjords and lakeshores. Some towns are located on peninsulas bounded by fjords. The coastal towns would seem to have a large receiving water capacity but large variations in discharge and a complex network of fjords, lakes and rivers result in poor water exchange conditions in many areas. The climate is determined by the northerly location and proximity to the Atlantic Ocean with the warm waters of the Gulf Stream. Norway lies across the most frequent paths of Atlantic cyclones on the border between temperate and arctic air masses, bringing moist air. Most of the precipitation is generated by these cyclones. Therefore the precipitation follows the frequency of cyclone passages with the mountain range "wringing-out" most precipitation on the western side. Typical annual averages at the coast are from 2500 mm in the south to 1000 mm in the north, but in mountain areas, 3000 mm is often exceeded while areas further inland may have less than 500 mm. The winters are mild and the summers cool, and the highest precipitation is in the autumn and early winter often with more than 200 days with rainfall, sleet and snowfall. Urban and suburban areas experience maximum volume flow from autumn and winter frontal rains, often concurrent with a snowmelt on a saturated or frozen ground. The snowmelt may occur several times during the period October–April.

Early in the eighties the North Sea Oil industry started to move northwards along the shore of Norway, requiring huge land areas near the bigger cities. In the municipality of Bergen, this expansion was planned to take place in Bergen South Parks, south of Bergen City centre, including the Birkeland basin and later the Ådlands basin. This area is typical of other areas to be developed later along the coast of Norway. Therefore it was decided to implement a research programme into the development to find better solutions for stormwater management that may be used throughout the coastal part of Norway.

BACKGROUND

The research program has been carried out under the management of the Project Group for Urban-hydrological Research in Bergen (PUB). PUB is an organization which includes the Department of Hydraulics and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Norwegian Water Resources Administration (NVE), the Municipality of Bergen and the Bergen Housing and Developing Company Ltd. PUB was founded in October 1981 to identify and formulate the urban-hydrological needs for surveys, investigations and research, especially in the Bergen Region, and more generally along the west coast of Norway (Thorolfsson, 1998a). The reason for the establishment of PUB was the search for a solution to the stormwater runoff problems in connection with the development of the Birkeland basin in Bergen. Figure 2 shows the conditions in the Bergen region with the waterfronts, topography and coastal location.

Prior to urbanization there were only rural areas having agricultural and natural landscapes. Agricultural areas along the Skage Stream suffered from flooding during the wet periods, October–December (Thorolfsson *et al.*, 1982). There was interest in improving these conditions during the development of the basin. Therefore, the maximal flow out of the basin at the Skage Bridge should not exceed 3.0 $m^3 s^{-1}$ (Sekse, 1982). The agricultural interests wanted the Håvardstun Lake to be drained and the reclaimed area to be used for agricultural purposes. The urbanization covers the residential, commercial and industrial areas, Kokstad and Sandsli, 110 ha in total, with 5000 inhabitants and 4000 working places. The remaining area will be kept natural.

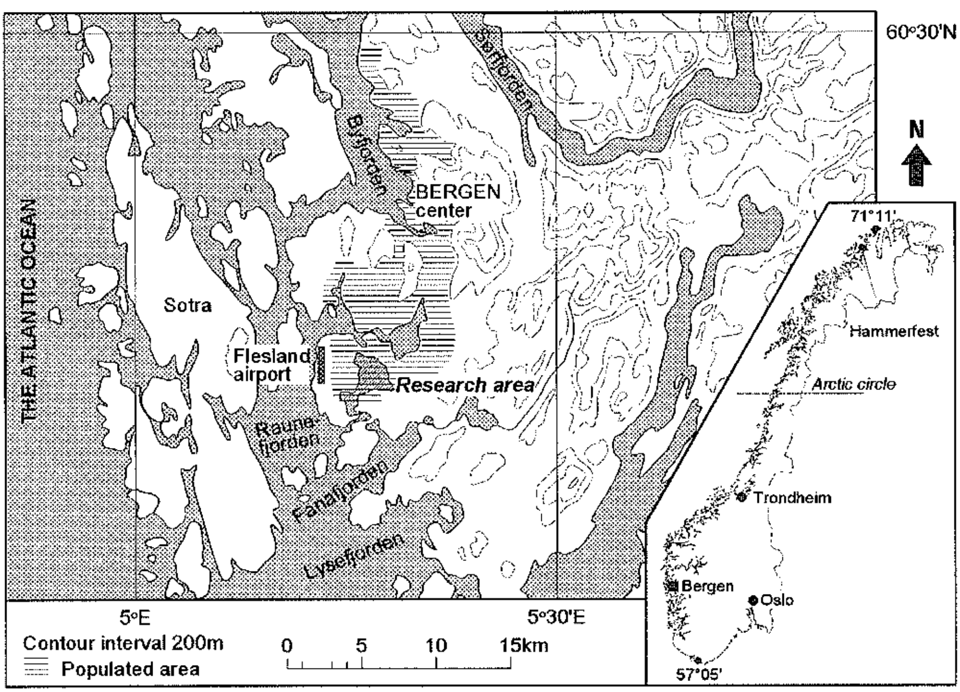


Fig. 2 The location of the City of Bergen and the Birkeland research basin.

The development of the Birkeland basin started in 1980. The basin is 460 ha and is located 15 km south of the Bergen centre and 3 km east of the Bergen airport, Flesland.

Lakes and streams form a significant part of the landscape. The Sandsli Stream runs from Skrane Lake to Håvardstun Lake with the Håvardstun Stream running from Birkeland Lake to Håvardstun Lake. The Skage Stream runs from Håvardstun Lake out of the basin through the Skage Bridge. The Håvardstun Stream is flat and the banks are flooded in wet periods; the banks then operate like dry ponds. Data for the lakes are shown in Table 1.

Table 1 Details of the three lakes.

	Runoff area (km^2)	Regulated elevation (m)	Area (m^2)	Detention volume (m^3)
Skrane lake	1.11	0.50	8.84×10^4	4.5×10^4
Birkeland lake	2.04	0.67	7.70×10^4	5.2×10^4
Håvardstun lake	1.45	0.96	3.32×10^4	3.2×10^4

Lakes and streams are kept in their natural condition, the idea being to use these as wet ponds for stormwater detention and water quality improvement. The surrounding wetlands could be flooded in wet periods. This would improve the water quality and smooth out peak flows; the Håvardstun stream was planned to allow overbank flooding. Local stormwater disposal (LSD) would be used wherever possible. Planners and decision-makers were sceptical about such solutions. They argued that there were no experience or design values available nationally or internationally for conditions similar to those found in the coastal part of Norway.

SOLUTIONS TO THE SURFACE WATER RUNOFF PROBLEM

The search for solutions to the surface water runoff problems identified the following alternatives:

- Alternative 1: construction of a stormwater diversion tunnel from Håvardstun Lake to downstream of the Skage bridge, resulting in small flows in the Skage brook and use of conventional stormwater systems in urban areas.
- Alternative 2: use the three lakes, the Skrane lake, the Birkeland lake and the Håvardstun lake, as controlling wet detention ponds, plus use surrounding wetlands as additional dry detention ponds, keeping the brooks natural and introducing local infiltration of stormwater for wash-out volume reduction.
- Alternative 3: replace all natural brooks with new smooth channels.

Alternative 1 would lead the stormwater quickly out of the area and in dry periods there would be low flows in the brooks. Planners and decision-makers were positive about this solution. Alternative 2 would improve the downstream conditions, preserve the groundwater table and secure low flow in dry periods. Detention in the lakes would provide some pollution control through sedimentation. This was the cheapest solution with costs being half of that for Alternative 1. Planners and decision-makers were sceptical about this solution. Alternative 3 was the most expensive solution (twice as expensive as Alternative 1) and was not considered further.

A combination of Alternative 1 and 2 was selected in spite of the fact that the latter was the cheapest and most appropriate to the environment. The main reason for this selection was that there was little or no experience in use of Alternative 2 solutions but there were strong interests in testing the function of these kind of systems. This hybrid solution was named the "blue-green concept".

NEW PRINCIPLES AND CONCEPTS

The runoff conditions in the Birkeland basin initiated the development of new principles and concepts for stormwater management that could be used in future development of new areas and upgrading existing areas.

The subcatchment Sandsli was served by systems for local stormwater disposal (LSD). The Sandsli LSD-systems used are subsurface percolation trenches, some subsurface percolation basins and a number of infiltration inlets for the stormwater from roofs and yards and other so-called clean areas, i.e. some parking lots. The idea was to prevent mixing of the non-polluted stormwater (roofwater) and the polluted stormwater (stormwater from roads). Stormwater from parking lots was considered to be in a grey zone. The concentrated polluted stormwater could then be collected and transported to an appropriate site for direct discharge or treatment.

The Sandsli system is compared with a conventional drainage system in Fig. 3 (Thorolfsson, 1998a). The system is based on the premise that the wastewater has to be conveyed which requires trenches below the frost-free depth all over the area. In Sandsli, the ground conditions consist of top layers of sandy soil or layers of boggy ground over a rocky subsurface with many cracks possessing good percolation capacity. During excavation for house foundations, road foundations and trenches for pipes, the boggy ground is removed down to the bedrock and replaced with stones from other areas where it is necessary to blast shallow rock. The broken stones fill

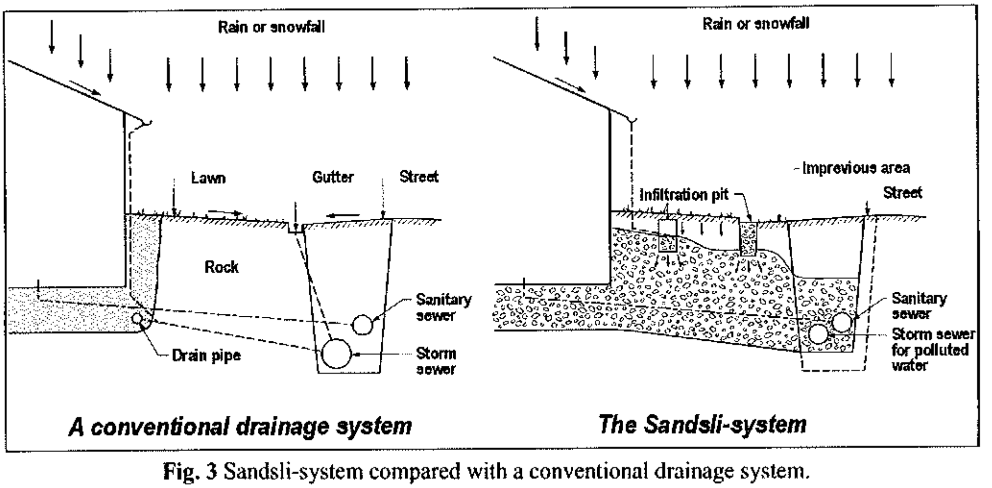


Fig. 3 Sandsli-system compared with a conventional drainage system.

deep holes where the boggy ground has been removed. In trenches, crushed stone of 8–22 mm diameter, is used around pipes and up to 200 mm above the top of the pipes and above this it is filled with broken stones. The effective porosity in these materials reaches about 30%, giving a huge volume for water storage and excellent conditions for percolation or water transportation to the rock fissures. All roof water and water defined as non-polluted from other areas is led to percolation. Infill insulation stops frost penetration and increases the storage volume. The Sandsli-system has reduced the total runoff volume by 50–70% and is directing the non-polluted stormwater to recharge groundwater. It has been functioning well during the winter in periods with rain and snow (Thorolfsson, 1997a). The Sandsli-system is calculated as being 20–40% cheaper than a conventional system.

The later development of the Ådland basin within the Lønningen area (73 ha) showed more difficult runoff conditions than in the Birkeland basin. The lake-stream-lake system (L-S-L system) was overloaded and a decrease in the peak flows was required. Detention of huge water volumes in the area during wet periods was required and it was decided to use the experience and results from the Birkeland basin as the conditions were broadly similar. Therefore the blue-green concept and a modification of the Sandsli-system were implemented.

The solution is based on using the Vestre Lake and surrounding wetlands as a detention pond where the water level is allowed to rise from +28.6 to +29.6 m a.s.l. The road across the basin is built like a dam with two controlling outlets to the Vestre Lake. Most of the boggy ground above the road was removed and replaced with crushed stone with 30% porosity below roads and buildings. This has given huge detention volumes under the ground in addition to possible percolation. The new groundwater level varies between +30.35 and +31.70 m a.s.l and the terrain level varies between +33.3 to +35.5 m a.s.l. The detention volume was calculated as being 28 000 m^3 and the discharge to Vestre Lake is controlled by adjustable equipment. Polluted water is collected and conveyed to the Flesland wastewater tunnel. Figure 4 shows the stormwater–meltwater detention basins in the Ådland basin.

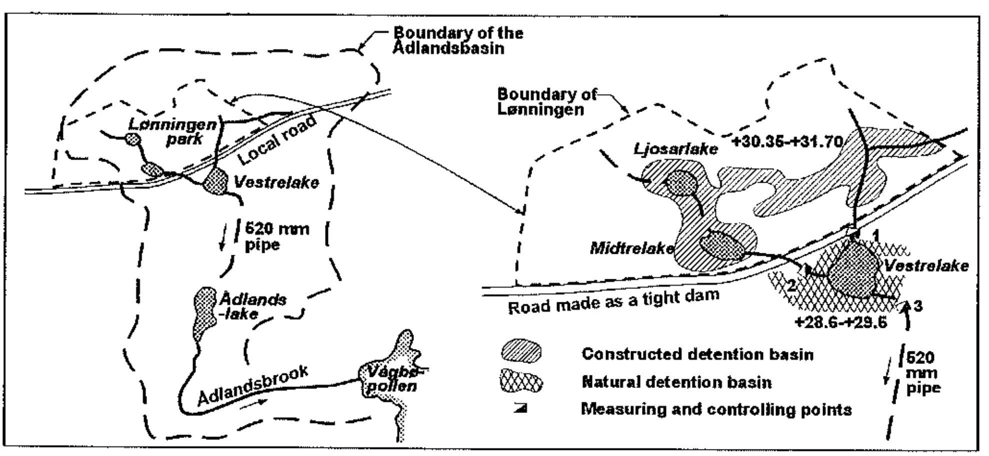


Fig. 4 The Ådland basin with natural and constructed detention basins.

RESULTS

The research programme has produced the following results:

- It is possible to handle a large part of the huge stormwater volumes within the drainage basin by use of the blue-green concept.
- The blue-green concept is accepted and enjoyed by the public and is also now accepted by previously sceptical technicians and officials.
- It is possible to separate the polluted and the non-polluted stormwater by use of the Sandsli-system and to recharge groundwater with non-polluted stormwater. The groundwater level is kept at a reasonable level.
- The new concepts have shown more cost-effectiveness than conventional drainage solutions.
- Development of preliminary guidelines for stormwater–meltwater management in urban areas within the Bergen region.

PRELIMINARY GUIDELINES

(a) Polluted and non-polluted stormwater-meltwater must not be mixed.
(b) Polluted stormwater–meltwater is to be collected and led to a discharge point where environmental damage is avoided or where treatment can take place.
(c) Non-polluted stormwater–meltwater is to be handled near to the runoff source using on-site stormwater management techniques or best management practice (BMP) in each basin.
(d) Increase in runoff during development is not allowed.
(e) Runoff improvements can be required through the development.
(f) A special permit is required if it is necessary to convey storm or meltwater out of its natural basin using artificial measures.
(g) Stormwater–meltwater should not damage the groundwater quantity or quality or create undesirable drainage problems.
(h) Plans for re-opening old creeks as "lead-in" pipes/channels should be prepared.
(i) In old built-up areas, roofwater should be separated from polluted stormwater and drained to groundwater.
(j) The potential for stormwater–meltwater management within green areas should be investigated.

CONCLUSIONS

The findings in the Birkeland basin and the Sandsli catchment have resulted in new strategies in urban runoff and stormwater management for the municipality of Bergen. This concept is now spreading along the coastal part of Norway where there are similar climatic and topographic conditions. Planners and decision makers have accepted solutions based on green trends in urban water management using nature to take up stormwater and to reduce the peak and volume of runoff and the associated pollution.

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