URBAN HYDROLOGICAL DATA COLLECTION IN COLD CLIMATE EXPERIENCES AT RISVOLLAN, TRONDHEIM, NORWAY

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ABSTRACT

In cold climate a special attention has to be given to the urban runoff conditions during the winter because of freezing, snowfall, snowmelt and urban hydrological data are rare and modelling on urban winter runoff is shortcoming. It is a great challenge to collect reliable urban hydrological data. At Risvollan in Trondheim, Norway year around high resolution data for; 1) short-term precipitation (minutes), 2) storm water flow, 3) air temperature and 4) rainfall-snowmelt rate have been collected since September 1986, using two separate measuring systems e.g. the NVE-system and the IVM-system. The IVM-system collects also data for wastewater flow, solar radiation, humidity, wind speed, wind direction and ground temperature. Data on snow water equivalent (SWE) have been collected in the catchment since winter 1993 in three snow courses (30 points).

A database is established both at NVE and IVM giving opportunity for:
1. Development of urban drainage models to simulate the year around runoff in cold climate.
2. Development of short-time step snow-routine for models.
3. Calibrate year around urban runoff models.
4. Carry out long-term simulations with urban runoff models.
5. Studies on the hydrological processes in urban areas during winter time.

The effort on data collection in winter time is higher than in summer time. The measuring station has to be visited more often in periods with heavy snowfalls and when temperatures are lower than -15^{o}C. The most adverse runoff situations occurs when heavy rainfalls fall on snow covered and frozen ground or wet snow falls on instruments with temperatures below zero. Very low temperatures, below -15C^{o}, are causing severe problems in operating the instruments. Heating and insulation of instruments is strongly recommended.

Keywords: Cold climate (CC), Data Collection, Risvollan, Snow Water Equivalent (SWE), Urbanhydrology

1. INTRODUCTION

1.1 Location and climate

Trondheim is located in Mid-Norway at 63^{o} 24'N, 30^{o} 25'E, about 70 km inside the coastline and about 700 km south of the Arctic Circle at 66° 33′N. Trondheim is a centre of education, technical and medical research, with 30.000 students. It is Norway's 3rd largest city, with 161,000 inhabitants.

Trondheim has a predominantly maritime temperate climate (Cfb) according to Køppen's classification, Køppen (1918/1936), but it is sheltered from the more windy conditions on the coast. The warmest temperature ever recorded is 35°C on July 22, 1901, and the coldest is -26.1°C in February 1899, amplitude of 61.1°C. The annual average precipitation is 850 mm, with winter being somewhat drier than summer. At summer solstice the sun rises at 03:00 and sets at 23:40. There is no darkness from May 20 to July 20. At winter solstice, the sun rises at 10:00, stays low above the horizon, and sets at 14:30.

Figure 1 shows 24 - hr temperatures and precipitation in Trondheim, compared to Oslo, the capital in Norway, at 59.90°N 10.70°E (humid continental climate) and Bergen at 60.38°N 5.30°E (maritime temperate climate) in the period 1961 - 1990.

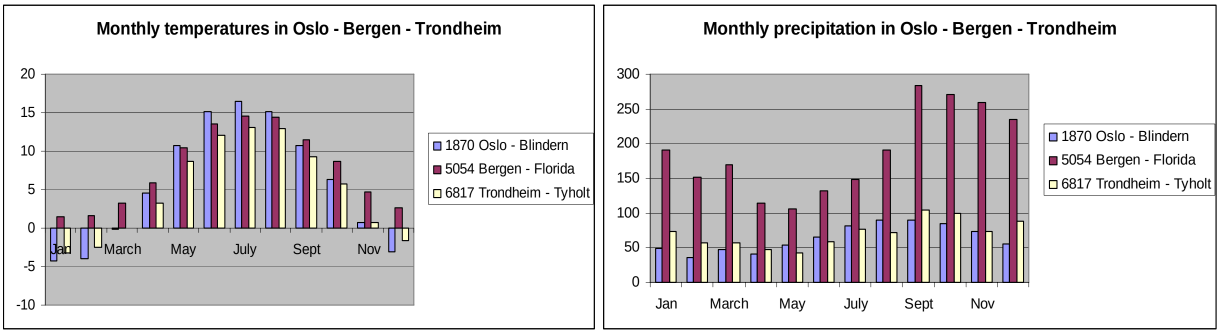

Figure 1 Average 24-hr temperatures and precipitation in Oslo, Bergen and Trondheim, Norway in the normal period 1961 – 1990.

The annual precipitation in Oslo is 654mm/yr, in Bergen 2250mm/yr and in Trondheim center 845mm/yr. Trondheim is having 4 months with temperatures below zero, i.e. January, February, March and December. During winter, temperatures are often shifting from plus to minus, due to the low pressure activities in the North Atlantic. It may result in heavy rainfall on snow and severe flooding, like at 31st March 1997 and 5. February 1999, Thorolfsson et. al. (2005) and (2003).

In Risvollan, at elevation 85 masl 4 km south east of the City Center, the annual average precipitation is 1003,5 mm of which 30 - 40% is falling as snow. Table 1 shows monthly average precipitation and temperatures at Risvollan in the period July 1st 1988 to June 30th 2002 (14 years).

Table 1 The average monthly precipitation (rainfall and snowfall) and temperatures for Risvollan measuring station in the period; July 1st 1988 to June 30th 2002.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Precip. (mm)	79,0	101,3	94,5	48,6	62,6	80,6	83,3	90,3	86,2	90,8	80,0	88,0	1003,5
Temp. (C^o)	-1,3	-1,8	0,3	4,0	8,2	11,8	13,9	13,2	9,5	4,8	0,7	-1,6	4,9

1.3 The challenge

In cold climate a special attention has to be given to the runoff conditions during the winter, Marsalek (1990), Maksimovic (2000). One of the challenges is to collect reliable urban hydrological data, because of low temperatures, snowfall, snow accumulation, snowmelt, snow removal, rain on snow etc. There is also a challenge in teaching and training students in data collection under winter conditions, Thorolfsson et. al. (2005).

The 1st UNESCO Workshop on Integrated Urban Water Management (IUWM) in Cold Climate at NTNU in Trondheim, Norway, 3-4. November 2005, focused on these issues and identified gaps and suggested solutions, Thorolfsson et. al (2006).

Following issues are of interest:

1. There are additional challenges in IUWM in CC regions compared to IUWM in CC-regions, because of the freezing and the snowfall - snow cover in CC-regions.
2. The urban water management systems must be able to handle these additional challenges. The focus has to be on research and development of methods and technologies that are appropriate for CC regions.
3. In CC-regions urban hydrological data are rare and modelling on urban winter runoff is shortcoming. Urban hydrological data collection has to be promoted.

High resolution data on rainfall-runoff are important, when studying urban drainage system. Such data are available in temperate climates and often for the summer period in CC-regions. But in CC-regions such data for the winter situation are rare, Maksimovic (2000).

In CC-regions, urban runoff calculations need also data fort air temperatures, snow accumulation, and snowmelt. Many measuring stations in cold climates measure rainfall – runoff relationship during summer time e.g. the NVE's urban network in Norway, but very few are measuring the precipitation (rainfall and snowfall) – runoff relationship during the winter. Lack of data for the winter conditions has resulted in failure in the simulations, when sizing and analysing the urban drainage systems and many flooding events and CSO discharges are caused by that reason, Thorolfsson (2000).

There is a need for models that can design urban drainage systems and the systems components and simulate the runoff situations year around, also in periods when temperatures are fluctuating around zero and there is a snow pack on the ground, Matheussen (2004), Muthanna (2007).

2. OBJECTIVE

The objective of the project on data collection at Risvollan is to:

1. Gather experience on year around data collection in CC-regions
2. Ddevelop a year around urban hydrological database with high resolution e.g. minutes
3. Give teaching and raining and education in data collection in CC-regions.

The database gives opportunities to:
1. Develop year around design events for urban drainage system in cold climate.
2. Develop and verify urban drainage models to simulate the year around runoff in cold climate
3. Calibrate year around urban runoff models
4. Conduct long-term simulations with urban runoff models (over years).
5. Study the hydrological processes in winter time.

To achieve these goals Risvollan Urban Hydrological Field Laboratory (RUHFL) and Risvollan measuring station (RMS) were established and put in operation in September 1986. Risvollan is run in co-operation between, 1) the Department of Hydraulics and Environmental Engineering (IVM), the Norwegian University of Science and Technology (NTNU), 2) the municipality of Trondheim and 3) Norwegian Water and Energy Administration (NVE).

3. RISVOLLAN URBAN HYDOLOGICAL FIELD LABORATORY (RUHFL)

3.1 Description of the catchment and the measuring station

Figure 2 shows Risvollan measuring station in winter and summer condition, see also

In winter time, 5th February 1993. Photo, Thorolfsson

In summer time, July 2003. Photo, K. Mjøen

Figure 2 Risvollan measuring station in winter and summer time.

Risvollan is a residential catchment with 1500 inhabitants, size 20 hectares. It is well defined regarding boundary, topography, geology and land use. It consists of 29.4 % impermeable surfaces;

roofs (10.9%) and other paved areas (18.5%), the remainder as grass lawn. The soil is clay with low infiltration. It is served by a separate sewer system. Diameters are ranging from 200 – 500 mm.

Risvollan was designed to investigate urban hydrological parameters year around. Data for rainfall and snowfall, stormwater runoff, wastewater flow, air- and ground temperature, humidity, lysimeter, wind speed and radiation are recorded on minute basis. Figure 3 shows, that the PLUMATIC tipping-bucket (2) is covered with a black plastic bag in winter time. The Lambrecht tipping-bucket (1) and the Fuess tilting gauge are heated and operate year around. All recording devices are placed in the insulated and heated cabin. The cabin has installed electricity power, telephone etc.

3.2 Instruments and data acquisition

Referring to figure 3 the following sensors were in operation March 1 2007:

Parameter	Instrument type
1) Precipitation	Lambrecht (tipping-bucket), for year around operation
2) Precipitation	PLUMATIC (tipping-bucket), only for summer operation
3) Precipitation	Fuess (Tilting / weighting), for year around operation
4) Snowmelt rate	Snow melt tray (1.5 x 1.5 m^2)
5) Air temperature	Aanderaa air temperature sensor 3145
6) Ground temperature	Aanderaa temperature sensor 2812
7) Solar radiation	Aanderaa radiation sensor no 2770
8) Wind velocity	Aanderaa wind velocity sensor no 2740
9) Relative air humidity	Aanderaa relative humidity sensor 2820
Cabin with: 1) Devices for measuring: - Storm water flow. - Wastewater flow. - The snowmelt rate 2) Data loggers and PC-based telemetric data transmission	 A100° V-note in the storm water channel, with float A P-B flume in the wastewater pipe-channel, with float. A vessel with float and a pump.

The recording system at Risvollan consists of two independent systems, 1) the NVE-data system and 2) the IVM-data system, so the raw data are collected on two separate loggers, NVE's Sutron 8210 and IVM's Aanderaa Data Reading Storage (DRS). Other recording media are also used, such as magnetic tape and strip chart recorders. Hand written records are used for control purposes. The recording equipments are located I an insulated cabin with a PC and a telephone. The telephone is used to control the data and to empty NVE's Sutron 8210 solid stage. The operator is visiting the station in summer time once a week and somewhat more often in winter time. .

The precipitation is measured by heated Lambrecht, type H1815. It is a tipping-bucket with a 200 cm^2 orifice and a resolution on 0.1 mm/tip and the Norwegian standard short-term rainfall LUMATIC, a tipping-bucket with a resolution 0.2 mm/tip and a funnel a 750 cm^2 in operation during the period, 15th May – 15th October). There is also a Fuess weighting precipitation gauge

The storm water flow is measured in a 100° V-note overflow, placed in a concrete channel in the basement of the cabin, using two independent 200 mm stilling well with floats. The wastewater flow is measured by use of P-B flume, type II, installed in the 250 mm concrete pipe, connected to a 200mm stilling well with a float.

The snowmelt rate is measured by use of a lysimeter. It is a collecting tray of aluminium, size 1.5 x 1.5 m^2 placed on the ground collecting the seepage water. A drain from the tray leads to a vessel in the frost-free basement in the cabin. The area of the tray is 1/10 of the area of lysimeter, so one mm water drained from the lysimeter lifts the float up one centimetre. The temperature- and humidity sensors are placed in a white, louvered, wooden instrument shelter, 2 meter above ground. Solar radiation is measured by a pyranometer, 2 meters above ground.

Snow surveys and snow water equivalent (SWE) measurements are conducted weekly. The snow courses comprise three paths with 30 measuring points, where measurements of snow depth and water equivalent are made, Thorolfsson et al. (1996) and Matheussen et al. (2002). Data on SWE in urban environments are rare. They give a good idea of how much water is stored in the catchment. Matheussen et al (2001) presented results from the observations of SWE in Risvollan catchment.

4. AN EXAMPLE ON SPESIFIC MEASUREMENTS IN COLD CLIMATE

The snow water equivalent (SWE) and the snow cover area (SCA) are key parameters. To achieve data on SWE, snow courses have been established. Figure 6 shows the snow courses in RUHFL. The snow courses no 1. 2 and 3 are the basic courses that were established in 1993, (Thorolfsson and Brandt 1996). The courses no 4 to 9 were established i winter 2001 in a PhD-research project. The measurements fit well with the Gridded Urban Hydrological Model (GUHM), developed in a PhD-research project, Matheussen (2004).

In the basic courses no. 1, 2 and 3 measurements are taken once a week. A snow tube made of 100mm PVC plastic pipe is used to take out samples from the top of the snow pack to the bottom of the snow pack. In each point the following is done:

1. Clean the tube
2. Penetrate snow tube into snow. Make sure it is hitting the soil below.
3. Dig out the snow tube and make sure no snow is lost from the core.
4. Weight the snow tube with snow in it and note the reading.
5. If there is ice slush or ice at the bottom, measures depth of ice and/or slouch layer and note it. If ice is hard use screwdriver to dig down to soil layer.
6. Measure snow depth and note it.
7. Note the exact position of the measurement point on the detailed map.
8. Make sure the readings seem reasonable and check weight for snow.

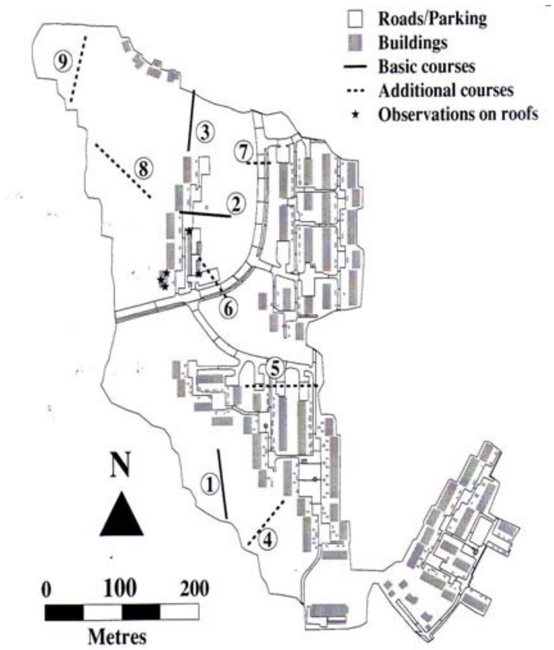

Figure 6. The snow courses and land cover type (LCT) in RUHFL, Matheussen (2004)

When all results are noted and the diameter (D) of the tube is known, the snow water equivalent (SWE) in each point can be calculated using the equations: Density = Snow/ ((pi*(D/2)^2)*SD) and SWE = Density * SD

A typical value for the snow density is 0.1 to 0.5 i.e. for new and old snow. If the snow depth is 35cm and the density is 0.2, then the SWE is 70mm in that point. If the snow cover is equally distributed in Risvollan on 20ha, the total amount of water stored in snow is, 200.000m^2 x 0.070m = 14000m^2, which may be potential for runoff when melting. It is additional runoff from rainfall. Such runoff condition has shown to cause serious floods in some situations, Thorolfsson, (2004).

Snow covered area (SCA) is found by field survey observations and by use of maps, air photos, web-camera photos, etc. By combining SWE and SCA we can estimate how much water is stored in the catchment. This water may later be released and runoff occurs. The hydro- meteorological conditions such as, air temperature, radiation, humidity etc, determine when runoff happens. These values can be put into a runoff model and the total volume from snow melt eventually in combination with rain can be calculated. The field teaching starts with an introduction to the students on the measurement procedure near RUHS. Figure 3 shows the students in field near RUHS in April 2002 doing exercises in hydrology basic course, to be instructed to do snow measurements.

Figure 7 In the field class in hydrology basic course in April 2002. Photo K. Alfredsen

5. EXPERIENCES ON DATA COLLECTION SINCE 1986

The period September 1986 to June 1st 1988 was a period of trial and testing, while winter time realized to be difficult and the data collected of a little value. Gradually we learned how to manage the instruments and the recording system to operate properly e.g. adding insulation here and heating there. It is mentioned, that use of ordinary lamps (40 to 100Watt) to heat instrument often solves the freezing problem. After this period the experiences with the data collection may be characterized as good. The operational efforts in the winter time are somewhat greater than in summer time, doing some additional work, but not that much as expected. The most serious out-of-operation situations and losses of data are due to flooding in the measuring station. Some of the floods occurred during rain-on snow-events, others during summer. The most serious flood occurred March 31 – April 2 1997. The second most serious data loss occurred on June 13th 2001, Nilsen et al (2001). Eleven floods occurred in the whole measuring period. Five events occurred during the winter period. They resulted in large damages and loss of data. The flood on March 31st1997, caused damages for millions of NOK, Nilsen et al (2001). All instruments in the measuring station had to be repaired.

Operational problems may also occur under large snowfall (more than 20 mm). Also under extreme low temperatures e.g. lower than -20C^o for many days, such as often realized in December and January, even February. Such climatic situations may stop the instruments operating. Operational actions are than required immediately, also in weekends and nights. Otherwise data may be lost.

6. RESULTS AND DISCUSSION

A web site is constructed, see: http://www.ivt.ntnu.no/ivm/risvollan/. Click “Real time Data” to look at the data collected last week. The unique data collected at RUHS and in RUHFL have been used in several PhD-research and MSc projects, Matheussen (2004), Muthanna (2007), Risholt (2002), Sand (1990), Sætern (2002) and many, many others. They are also included in many Master- and PhD-courses in hydrology and stormwater technology at NTNU.

At RUHFL all the four parameters, 1) precipitation (rainfall and snowfall), 2) storm water runoff, 3) air temperature and 4) snow melt rate, have successfully been recorded with high time resolution at Risvollan since 1st June 1988. In addition data for wastewater flow, solar radiation, humidity, wind speed, wind direction and ground temperature are collected on the IVM-system recording system. Data on SWE have been collected since winter 1993 in three snow courses (30 points) in the catchment and on the snowmelt tray since 1989. The ddatabase is giving opportunity for:

1. Development of urban drainage models to simulate the year around runoff in cold climate.
2. Development of short-time step snow-routine for models.
3. Calibrate year around urban runoff models.
4. Carry out long-term simulations with urban total models.
5. Studies on the hydrological processes in urban areas during winter time.

The data collection has resulted in several academic and practical outcomes. The most important is the creation two independent data bases, one located at NVE (the NVE-data base) and one at NTNU (the IVM database), containing urban hydrological data since June 1st 1988.

It is realised that the efforts on data collection have to be increased in winter time. The station have to be visited more than once a week in periods with heavy snowfalls and low temperatures, lower than -15^{o}C. The most adverse situation occurs when heavy rains fall on snow-covered and frozen ground or wet snow falls on instruments with temperatures below zero. Heating and insulation of instruments is strongly recommended. Action is needed when there are snowfalls at temperatures just below 0^{o}C.
The operator visits the station once a week year around but in winter time somewhat more. The annual costs for operating the measuring station are US 5.000,-. Maintenance is additional.

The data have been used in PhD-thesis, Muthanna (2007), Matheussen (2004), Nie (2004), Risholt (2000) and Sand (1990), as a basis for research project and papers, Thorolfsson and Sand (1991), Thorolfsson and Brandt (1996) and others, and supplied to students working, such AS MSc-thesis, Sætern (2002) and many, many others, see; http://www.ivt.ntnu.no/ivm/risvollan/

7. CONCLUSION

It is realised that the year around data collection at RMS on; 1) short-term precipitation, 2) storm water flow, 3) air temperature and 4) rainfall-snowmelt rate have been operating satisfactorily since 1st June 1988. Two separate measuring systems e.g. the NVE-system and the IVM-system are used, supplementing each other. Before 1st June 1988 was a trial and testing period. The IVM-system collects also data for; wastewater flow, solar radiation, humidity, wind speed, wind direction and ground temperature. Snow water equivalent (SWE) data have been collected since winter 1993.

Some breaks in the data collection have occurred, resulting in loss of data, mostly in periods with some extremes. These breaks are due to floods and low temperatures. Floods occur about equally often in summer and winter time.

The operator visits the station once a week year-around, but in winter time somewhat more. The annual costs for operating the measuring station are NOK 35.000, - (US5.000,-) by ratio summer/winter = 15./20.000 NOK. Maintenance is additional.

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