



Impacts from future changes in climate and population on Stockholm main sewer system

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Introduction

A city's hydrological processes are directly related to climate and will thus be affected by climate change. For example, an overall increase in precipitation will increase both inflow to treatment plants and risk of spill of untreated combined sewage overflow to recipients. Increases in more intense short-term precipitation will increase the risk of high water levels locally and floods in the sewer system. For a wider discussion on urban hydrology and climate change, see e.g. Berggren et al. (2008).

Two key issues complicate hydrological climate change impact assessment in an urban environment as compared with rural areas. The first is that the relevant scales in urban hydrology are much smaller ($>1 \text{ km}^2$; $>10 \text{ min}$). The second is the highly dynamical nature of cities, i.e. their constant evolution by changes in e.g. population, infrastructure and land use. This evolution may exacerbate but also offset climate changes, which is difficult to account for. As a consequence of these complications, to date only few impact studies focusing on urban hydrology have been performed, but the number is growing (e.g., Semadeni-Davies et al., 2008a,b).

Stockholm main sewer system model

Within the Mistra-SWECIA Stockholm case study, the Swedish Meteorological and Hydrological Institute (SMHI) and Stockholm Vatten AB (SVAB; the Stockholm Water Company) have performed a joint study on the future loads on the main sewer system in central Stockholm. About half of this system is "combined", i.e. storm water and sewage are transported in the same pipe. During rainfall events, storm water dominates. To reduce risk for flooding of combined sewage water, a number of overflows exist. This system, which is designed according to former and today's regulations, is already today partly underdimensioned and thus sensitive to possible future climate changes, especially to an increased water level in the Baltic Sea and Lake Mälaren and also to increased precipitation locally.

SVAB has developed computer models of the main sewer system in Stockholm using the MIKE Urban software. Calculations are made in two steps. In the first, the contributing runoff from each sub-catchment is estimated by a hydrological model, using meteorological observations (precipitation, temperature, evaporations) as input. In the second calculation, transport through the sewer pipe network is simulated by hydraulic modelling. The model describes the main sewer system with a high level of detail and has been calibrated to reproduce measurements of water



discharge and levels. In our study, the parts of the total model that generates inflow to the Henriksdal treatment plant were used.

Before simulating the possible impacts of climate change, two types of baseline simulations were performed representing today's climate. One was a continuous simulation and the other an event-based one. The aim of the former simulation was to study the function of the sewer system during an extended period covering all seasons. The year 1984 was selected as the annual rainfall total was close to the climatological average and as it contained a few distinct and challenging rainfall events. The aim of the event-based simulation was to study the system's function at times with high runoff. For this purpose, around 200 major runoff events during the period with available observations (1983-2007), were identified and used. In the baseline simulations, the Henriksdal model was thus run with meteorological observations during 1984 and during the major runoff events over about two decades.

Climate projections and model input

Three different climate projections were considered. These built on the IPCC SRES emission scenarios A2, A1B and B2 and the global climate model ECHAM (Roeckner et al., 1996), with a further regionalization with the regional climate model RCA (Kjellström et al., 2005) for the 1961-2100 period. From the model simulations, time series of precipitation, temperature and evaporation from a 3x3 matrix of RCA gridboxes (50x50 km) centred over Stockholm were extracted and analyzed. From the total period, four 30-year sub-periods were defined. One was designated as a reference period (1981-2010; covering the period of available observations), the other three periods representing future scenarios (2011-2040, 2041-2070, 2071-2100). Table 1 shows the projected changes of precipitation, temperature and evaporation in Stockholm.

| | Temperature (°C) | | | Precipitation (mm/yr) | | | Potential evaporation (mm/d) | | |
|-----------|------------------|------|------|-----------------------|-----|-----|------------------------------|-------|-------|
| | B2 | A1B | A2 | B2 | A1B | A2 | B2 | A1B | A2 |
| 1981-2010 | 5.4 | | | 549 | | | 1.52 | | |
| 2011-2040 | +1.2 | +0.5 | +0.9 | +6 | -12 | +5 | +0.47 | +0.06 | +0.30 |
| 2041-2070 | +2.0 | +1.7 | +1.8 | +37 | +43 | +44 | +0.88 | +0.42 | +0.80 |
| 2071-2100 | +2.8 | +2.8 | +3.4 | +61 | +73 | +69 | +1.44 | +0.97 | +1.61 |

Table 1

The climate scenarios were used to modify the historical observations in line with the expected future changes by the Delta Change method (Hay et al., 2000). In this method, Delta Change Factors (DCF) are derived from climate model data, representing the relative change from the reference period to some future period. For rainfall, 30-min data were used to estimate DCFs that depend on both intensity level and calendar month (Olsson et al., 2009). For temperature, daily data were used to estimate DCFs that depend on both temperature value and calendar



month. For (potential) evaporation, DCFs were estimated on a monthly basis. DCFs for each of the three meteorological variables considered were calculated for each of the three future periods. These were then used to modify the historical observations to obtain climate scenario time series.

Besides the changes in climate, also future population change was taken into account. The population was expected to increase by 25% until 2030, and the corresponding increase in water use was included in the model. After 2030, the population was assumed constant.

Main model simulation results

In the analysis of model results, the focus was on three aspects: (1) inflow to Henriksdal treatment plant, (2) spill of untreated sewage and (3) high water levels at critical points.

The annual inflow to the Henriksdal plant was – based on these scenarios – found to increase by 15-20%, mainly during winter. Most of the increase takes place already over the period 2011-2041, much due to the population increase. In the latter half of the 21st century, the inflow remains relatively constant as increasing precipitation is offset by a simultaneously increased evaporation. Total as well as maximum inflow associated with rainfall events increases by some 10% because of changed precipitation patterns towards higher intensities.

The volume of water that has to be spilled untreated to recipient is estimated to increase substantially as an effect of climate change. On an annual basis, the average estimated increase is approximately 0-10% until period 2011-2040 and approximately 20-40% until period 2071-2100 (Figure 1a and 1b). In relative terms, most of the increase takes place in autumn and particularly in winter. In absolute terms the main increase is in summer, when ~90% of the spill occurs in today's climate. Spill associated with rainfall events increases similarly, although somewhat more in the former period and less in the latter.

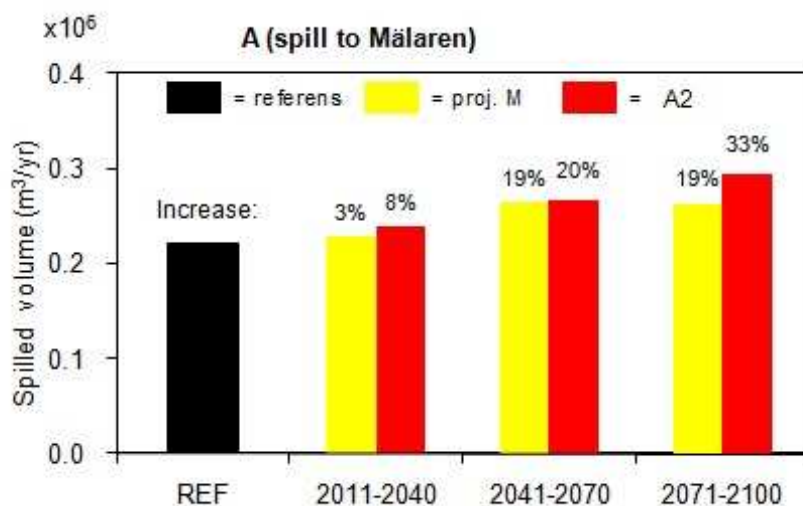


Figure 1a

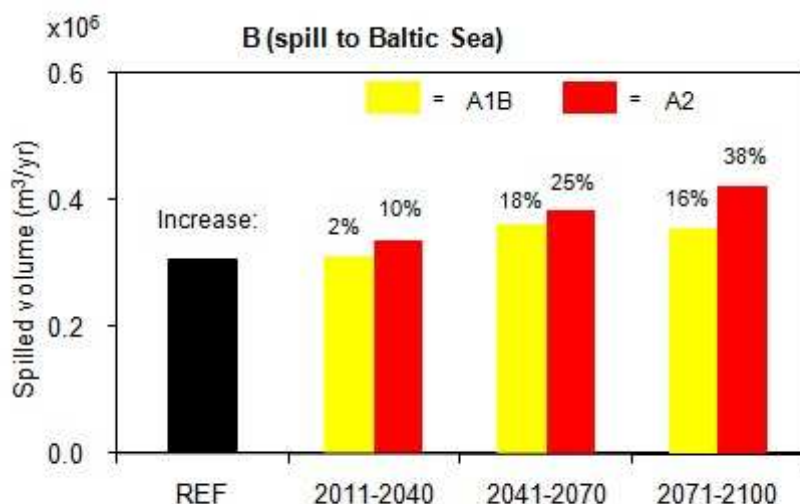


Figure 1b

The frequency of high water levels, conventionally defined as 0.5 m above top of pipe, in five critical points varies widely for the different projections and future periods. Overall, however, the frequency is estimated to increase by 10-20% by 2011-2040 and 30-40% by the period 2071-2100.

Concluding remarks

The most significant climate change impact in our study appears to be increased spill volumes to Mälaren and Saltsjön. This implies that measures may have to be taken as already today the spill volumes are close to the legal limits. An increased inflow to the Henriksdal treatment plant would imply an increased need for water treatment. In turn, increased frequency of high water levels indicates an increased flood risk in central Stockholm. The described situation would be further aggravated by a further population increase after 2030 and, not least, changing water levels in Lake Mälaren and the Baltic Sea.

It must be emphasized that the number of climate projections considered in this study is small and that the downscaling to central Stockholm by Delta Change is associated with large uncertainties. Even so, the results are consistent overall and in line with similar studies elsewhere. Further research would seem to be called for to investigate other aspects of sewer system impacts as well as developing adaptive measures, if and when required.

References

- Berggren, K., Svensson, G., Viklander, M. 2008. Urban drainage and climate change: a problematic approach? MISTRA-SWECIA Newsletter No. 1.
- Hay, L.E., Wilby, R.L., Leavesley, G.H. 2000. A comparison of delta change and downscaled GCM scenarios for three mountainous basins in the United States. *J. Am. Water Resour. Assoc.* 36(2): 387–397.
- Kjellström, E., Bärring, L., Gollvik, S., Hansson, U., Jones, C., Samuelsson, P., Rummukainen, M., Ullerstig, A., Willén, U., Wyser, K. 2005. A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). Reports Meteorology and Climatology, No. 108, SMHI, Norrköping, 54 pp.



- Olsson, J., Berggren, K., Olofsson, M., Viklander, M. 2009. Applying climate model precipitation scenarios for urban hydrological assessment: a case study in Kalmar City, Sweden. *Atmos. Res.* 92: 364-375.
- Roeckner, E., Arpe, K., Bengtsson, L., Christoph, M., Claussen, M., Dümenil, L., Esch, M., Giorgetta, M., Schlese, U., Schulzweida, U. 1996. The atmospheric general circulation model ECHAM4: model description and simulation of present-day climate. Report No. 218. Max-Planck-Institut für Meteorologie, Hamburg, 90 pp.
- Semadeni-Davies, A., Hernebring, C., Svensson, G., Gustafsson, L.-G. 2008a. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. *Journal of Hydrology* 350: 100-113.
- Semadeni-Davies, A., Hernebring, C., Svensson, G., Gustafsson, L.-G. 2008b. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. *Journal of Hydrology* 350: 114-125.