Stormwater management planning from a holistic hydrologic perspective

Mise en place d'un système de gestion des eaux pluviales à partir d'une étude hydrologique globale

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RÉSUMÉ

La démographie de la ville de Vänersborg, en Suède, augmente d'années en années, entrainant une demande croissante de logements. Nordkroken fait partie des zones urbaines en développement. Il s'agit d'une zone de faible altitude située sur les rives du lac Vänern et à l'extrémité d'un bassin versant relativement important. La localisation et les conditions hydrologiques de Nordkroken complexifient la mise en place d'un réseau de collecte des eaux pluviales. Afin de concevoir un système de drainage des eaux pluviales adapté et durable pour la zone, une méthodologie (basée sur un logiciel existant) a été développée. La méthodologie permet de modéliser les grands processus hydrologiques majeurs sur la zone et de quantifier le bilan hydrique selon trois scénarios (en termes d'urbanisation) : situation naturelle, situation actuelle et situation future. Sur la base de l'analyse des résultats pour les conditions naturelles et la situation actuelle, un système de drainage des eaux pluviales a été projeté et testé dans un scénario correspondant à la situation future. Les résultats ont montré que les niveaux d'eau de la nappe souterraine ont un impact très important sur le ruissellement et notamment sur l'efficacité du système de drainage des eaux pluviales. Suite à cette analyse, la modèle mis en place pourrait être tester avec un réseau de collecte qui permettrait de drainer les eaux pluviales mais également les eaux souterraines, afin de minimiser les risques d'inondation. La méthode pourrait également être utilisée pour tester le réseau de collecte pour un climat futur plus humide ou plus sec, comme par ex. pour évaluer les impacts de la montée des eaux ou l'augmentation de l'évapotranspiration sur le bilan hydrique de cette région (ou de toute autre).

ABSTRACT

The population in Vänersborg municipality, Sweden, is growing and the demand for attractive housing areas is therefore increasing. One of the planned development areas is Nordkroken which is a low-lying area located on the shore of lake Vänern and at the lower end of a relatively large catchment. The location and hydrological conditions of Nordkroken makes the planning of a stormwater system challenging.In order to design a robust and sustainable stormwater drainage system for the area, a methodology (based on existing commercial software) was developed where all the major hydrologic processes in the area were modelled and the water balance quantified for three scenarios – natural conditions, current situation and future situation. Based on an analysis of the results for natural conditions and current situation, a stormwater drainage system was designed and tested in the scenario for future situation. The results showed that groundwater levels had a major impact on the area, including on the effectiveness of the stormwater drainage system and with this knowledge a system could be designed that provides drainage of both stormwater and groundwater and minimizes flooding risk. The method could also be used to test the system in a future wetter or drier climate, e.g. evaluate impacts of rising lake levels or increased evapotranspiration on the water balance and water services of this (or any other) area.

MOTS CLÉS / KEYWORDS

flooding; geohydrology; integrated modeling; stormwater management; sustainable urban drainage; urban hydrology

INTRODUCTION

In Sweden, as well as in many other countries in the world, the increased urbanization and upcoming climate change, are imposing several challenges and new aspects on the water related services of our societies. (Chocat et al., 2007) For instance there is an increasing demand for green and open stormwater solutions, and there is also a growing need for securing societies for flooding or long dry periods due to upcoming climate change. In addition, many attractive sites for future developments are located in areas close to lakes and seas, which are particularly exposed to flooding and effects of climate change.

Flooding can occur from several directions – from above (rainfall), from below (groundwater/sewer surcharge) or from the side (rising sea water levels or surface water levels). A sustainable society needs to be able to cope with all these types of flooding events. Thus, stormwater systems can no longer be designed as separate pipe systems if they are to fulfil the above requirements. An approach that accounts for the entire urban hydrology needs to be designed in order to meet the demands of a sustainable society. Furthermore, a sustainable stormwater system needs to be able to manage future effects from both climate change and increased urbanization and development in an efficient manner.

The municipality of Vänersborg in Sweden is located just south of lake Vänern, the largest lake in the country (5 600 km2) . Approximately 5 km east of the city centre lies the development area Nordkroken, a 36 ha area which currently consists of approximately 100 detached houses and holiday cottages (see Figure 1).

Nordkroken is located at the lower end of a 13 km2 catchment and next to the shoreline of Vänern, with groundlevels only marginally higher than the lake water levels. Flooding occurs frequently due to high groundwater levels, and the only existing drainage system in the area is an irregular network of ditches constructed mainly by property owners to protect their own premises.

Recently the municipality of Vänersborg proposed a new local development plan for Nordkroken which would result in additional houses in the area. Due to this, the water utilities were imposed by regional authorities to provide water distribution and wastewater services, as well as a stormwater drainage system for the Nordkroken area. The stormwater system should ideally solve the existing flooding problems as well as minimize the risk of future flooding, which includes handling effects of climate change and increased urbanization in the area. (Vänersborg municipality, 2016)

The purpose of this study is therefore to develop a methodology that can be used to design a sustainable stormwater system in areas like Nordkroken, where the stormwater runoff is closely linked to the entire hydrologic cycle.

1 METHODS

The methodology consists mainly of analyses based on a hydrogeologic and hydrologic model of the watershed, built up using the modeling tool MIKE SHE and MIKE URBAN (DHI 2016). Model components include all main processes within hydrogeology, such as precipitation, evapotranspiration, runoff, infiltration and groundwater flow, as well as flows in piped and open stormwater systems, and the modelling concept has successfully been used in several previous studies (e.g. Gustafsson, 1997)..

By altering the model description of the area a variety of scenarios can be studied, ranging from completely natural conditions to densely populated and altered conditions. The model can thus be used to evaluate the consequences of different stormwater systems for both the current development situation as well as future scenarios including urbanization and climate change effects. The following section describes the modelled processes and model setup more in detail.

2 DEVELOPMENT SCENARIOS

Three development scenarios have been studied in order to be able to evaluate the hydrologic conditions of Nordkroken as well as the current and future stormwater management systems.

These are :

- A. Natural conditions, describing the pre-development situation without any housing or drainage.
- B. Current situation, describing existing housing and drainage systems.
- C. Future situation, including both existing housing and drainage systems as well as planned future developments, planned changes in ground levels and the designed future stormwater system

3 RESULTS AND DISCUSSION

3.1 Development scenario A - Natural conditions

The simulations for the natural conditions scenario show that the original site has poor drainage conditions, high ratio of runoff from pervious areas due to high groundwater levels, and that a major contribution to the water balance comes from the upstream catchment.

The computed surface water depths at the two dimensioning hydrologic scenarios (10 year event in the autumn and 30 year event in the summer) for natural conditions, shows that the autumn rain leads to much more extensive flooding than the summer rain, even though the rainfall volumes are similar and the 30 year event is more intense. This shows that the natural runoff conditions are largely affected by the levels of groundwater and soil saturation.

3.2 Development scenario B – current situation

The current situation scenario deviates from natural conditions in the following aspects:

- Impervious areas (houses and roads) are added
- The existing network of ditches is included

This development scenario has been run for hydrologic scenarios 2 and 3, and the purpose is to assess and quantify the need for additional stormwater management measures. The results will be used as a basis to design the future stormwater management system for Nordkroken.

The computed surface water depths at the two dimensioning hydrologic scenarios (10 year event in the autumn and 30 year event in the summer) for the current situation shows that the autumn event still creates more extensive flooding than the summer event, however the magnitude and extent of the flooding is substantially smaller than the corresponding results from natural conditions. This effect is due to the network of ditches that crosses the area at present, that creates runoff paths for surface water and has a draining function on groundwater levels.

3.3 Development scenario C – Future situation

Based on the results from development scenarios A and B, a future stormwater system has been designed and added to the model setup. The setup has also been modified to account for the planned housing developments.

The future stormwater management system is suggested to be based on a network of open ditches/swales, similar to the current system but extended and deepened where considered necessary. Open stormwater systems are generally more efficient at conveying stormwater than pipe systems below ground, particularly during situations with high runoff flows. Moreover, they have a draining function in situations where groundwater levels are at or above surface levels which is particularly beneficial for areas like Nordkroken where flooding is frequently caused by groundwater rather than stormwater. A comparison between the results for natural conditions and current situation shows that the existing ditches are efficient when it comes to reducing flooding during situations with combined high groundwater levels and intense rainfall.

In order to evaluate the impact of future housing developments and urbanization on the stormwater system, the flow to the ditches and swales for the two dimensioning hydrologic scenarios has been analyzed with regards to origin. During a 10 year event in autumn, the runoff from pervious areas constitutes almost half of the total discharge, whereas during a 30 year event in summer, runoff from impervious areas constitute a majority of the discharge and runoff from pervious areas is less than 10% of the total runoff. The total discharge is 65% higher for the 10 year event compared to the 30 year event. An urbanization process, where pervious areas are converted to impervious areas, will thus, at least initially, probably have a marginal effect on the runoff volumes for the autumn scenario since pervious areas already contribute a lot to the runoff volumes in the current situation.

4 CONCLUSIONS

The general conclusions of this study is that the method developed for Nordkroken provides a good overview of the overall urban hydrology with relatively simple means and has proven very useful in designing a robust stormwater system. Furthermore, the results clearly show the importance of including a full description of boundary conditions such as upstream surface inflows and groundwater, and include seasonal variations, for “wet” sites where soil water and groundwater can be expected to interfere with the runoff processes. If only the stormwater in the development area had been included in the analysis, the main causes of flooding (groundwater and upstream inflows) would not have been detected.

This methodology could thus very well be applied in many other areas and for an extended range of problems, including issues related to climate change, increasing sea water levels, effects of changes in land use on flooding and drying events, among others. Since the main part of the analysis is based on natural (undeveloped) conditions and the current situation, the methodology is particularly valuable and important in the early stages of urban planning and well suited to provide the basis for all further planning related to water and urban hydrology in the development area.

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