# Green Roof performance in sub-arctic climates: water quality and vegetation survival on a green roof in northern Sweden

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## Performance des toitures végétalisées dans un climat subarctique : qualité de l'eau et survie de la végétation sur un toit végétalisé dans le nord de la Suède

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## RÉSUMÉ

Un grand nombre d'études dans le monde entier se sont penchées sur le ruissellement et la qualité des eaux pluviales avec des toitures végétalisées. Il manque cependant des études sur l'évaluation de ces sujets dans les climats froids. Par conséquent, dans une étude menée à Luleå, dans le climat subarctique du nord de la Suède, nous avons étudié les pollutogrammes de la qualité de l'eau de ruissellement sur un toit végétalisé extensif de Sedum. Une étude comparative a été réalisée sur un toit en acier galvanisé situé à proximité. Les données ont été recueillies sur un cycle d'un an. Les prélèvements pour l'analyse de la qualité de l'eau du toit végétalisé ont été effectués avant et après la fertilisation du toit végétalisé. En outre, une évaluation visuelle du développement et de la survie des plantes a été réalisée. Les eaux de ruissellement du toit végétalisé contenaient des concentrations relativement élevées de nutriments N et P, tandis que les concentrations en métaux, à l'exception du Cu, étaient en général plus faibles que dans les eaux de ruissellement du toit en métal. Lors de la comparaison des différents volumes d'eau, les masses accumulées des métaux sélectionnés Cd, Cu, Pb et Zn étaient moins importantes dans les eaux de ruissellement du toit végétalisé. Les études visuelles sur la survie des plantes ont révélé qu'un petit nombre seulement des 10 espèces initiales de Sedum avaient survécu. La couverture végétale du toit était faible. Le Sedum acre a eu le taux de survie le plus élevé. Il s'agit d'une espèce originaire des régions froides.

## ABSTRACT

Many studies worldwide have investigated runoff and the quality of stormwater from green roofs. However, there is a lack of research evaluating these issues in cold climates. Thus, in a study conducted in Luleå in northern Sweden's sub-arctic climate, we investigated runoff quality pollutographs from an extensive green roof of Sedum. A comparative study was conducted on a nearby galvanised steel roof. The data were collected over one annual cycle. The water quality sampling from the green roof was carried out both before and after the green roof had been fertilized. In addition, a visual evaluation of the development and survival of the plants was undertaken. The runoff from the green roof contained relatively high concentrations of nutrients N and P, while the metal concentrations, with the exception of Cu, were commonly lower than in runoff from the metal roof. When comparing the different water volumes, the accumulated masses of the selected metals, Cd, Cu, Pb and Zn were lower in the run-off from the green roof. The visual studies of plants' survival revealed that only a few of the original 10 Sedum species survived. The vegetation cover on the roof was low. Sedum acre had the highest survival rate; this is a species native to cold climates.

## KEYWORDS

Extensive green roof, cold climate, vegetation survival, heavy metals

## INTRODUCTION

Green roofs are becoming more and more popular in urban environments due to their aesthetic and environmental benefits. (Bengtsson, Grahn, & Olsson, 2005). Today, they are often used as a component of stormwater management systems, being part of concepts like SUDS, LID or WSUD (Bengtsson, 2005). A green roof with a growing medium and vegetation has (compared to a conventional roof) a greater ability to retain water within the substrate as well as the potential for evapotranspiration to occur, depending on the ambient conditions. Runoff from a green roof occurs only when field capacity has been reached (Bengtsson et al., 2005). Thus, a green roof buffers the peak runoff. The lag time to peak runoff is longer for a green roof than a conventional roof for the same rain event. The factors that affect the water retention capacity and runoff dynamics depend on:

- the characteristics of the green roof: the number of layers, type and thickness of substrate, vegetation, roof geometry (slope/length of slope), roof position (shaded or not, orientation), roof age and
- the weather conditions: length of preceding dry period, season/climate (air temperature, wind conditions, humidity), rain characteristics (intensity and duration) (Czemiel Berndtsson, 2010).

There are two main types of green roof: intensive and extensive. Intensive roofs, often called roof gardens, have a thicker layer of soil, which commonly exceeds 30 cm, so that taller vegetation can grow on the roof. In contrast, the soil layer on an extensive roof is usually only a few centimetres thick, and the plants are often a mixture of *Sedum* and other succulents (Bengtsson et al., 2005). The majority of green roofs installed in Sweden are extensive. Many of the extensive roofs currently established in Sweden were constructed according to recommendations based on experiences from Germany (Emilsson, 2008).

Most studies evaluating green roof functionality have been conducted on roofs that are located in warmer climates (Lee, Lee, & Han, 2015; Vijayaraghavan & Raja, 2014). There are only a few studies of green roofs in cold climates. Some research has investigated the thermal effect of the snow layer and one of the conclusions is that green roofs reduce heat flow through the roof, thereby reducing demand for heating energy in winter (Lundholm, Weddle, & Macivor, 2014; Zhao & Srebric, 2012). No study has so far evaluated green roof performance in sub-arctic climates (e.g. northern Sweden) where the climatic and hydrological conditions differ greatly from temperate climates. Despite this, similar solutions are delivered by the industry in Northern Sweden's sub-arctic climate as in central Europe's temperate climate. Thus, this paper presents preliminary data on vegetation survival and runoff quality (metals and nutrients) from a green roof in Luleå, Northern Sweden, located at 65.5°N, approximately 100 km south of the Arctic Circle.

## MATERIALS AND METHODS

The green roof that we investigated is an extensive *Sedum* roof constructed in autumn 2012 with an area of 220 $m^2$ and a slope of 1:8. During 2013 and 2014, composite runoff samples from both the green roof and a metal roof were collected manually from five rainfall events. The flow from the green roof was measured using a Teledyne ISCO 2150 Area Velocity Module. To enable a comparison, a nearby galvanised steel roof of approximately the same size was examined as part of the study. Since no flow meter could be installed in association with the metal roof, the flow from it was calculated based on precipitation data in the software SWWMM. The precipitation data were collected using a rain gauge (Geonor T200-B) located at Luleå University of Technology about 3 km north of both roofs***. The data has also been calibrated against rainfall data from the Swedish Meteorological and Hydrological Institute (SMHI) whose rainfall gauges are located at Luleå Airport about 4 km south of the roof.

Sampling was carried out during five rainfall events and the snow melt period in 2014. The samples were analysed on ICP-SFMS for total and dissolved heavy metals and phosphorus applying EPA standard method 200.8.

Vegetation growth and survival was monitored by visual inspection**. Inspections took place in June 2014, September 2014 and September 2015. In both winters, the roof was snow covered between about November and April.

## RESULTS

### *Vegetation*

The green roof was constructed using mats consisting of *Sedum*-vegetated substrate on a geotextile. At the time of construction (2012) the following 12 species/varieties were present on the roof:

- ***Sedum acre*** (Golden Carpet Stonecrop)
- ***Sedum ewersii*** (Pink Mongolian Stonecrop)
- ***Sedum album*** (White Stonecrop)
- ***Sedum album*** “Lime” (Coral carpet)
- ***Sedum album*** “Murale” (Murale White Stonecrop)
- ***Sedum album*** (Coral carpet)
- ***Sedum hybridum*** (Czar’s Gold)
- ***Sedum kamtschaticum*** (Russian stonecrop)
- ***Sedum floriferum*** (Weihenstephaner Gold)
- ***Sedum spurium*** (Caucasian stonecrop)
- ***Sedum pulchellum*** (Widow's cross)
- ***Sedum sexangulare*** (Tasteless stonecrop)

The visual inspections in both 2014 and 2015 revealed that only a few of these species (mainly *Sedum acre* and occasional plants of *Sedum album*) had survived on the roof in Lulea (Figures 1 and 2). *Sedum acre* is native to** northern Sweden, (inter alia) in the Luleå archipelago. When laid, the turf had almost complete vegetation cover, but by August 2014 there was only about 20-30% cover, with an increase to 35-40% cover in August 2015, based on the images, (figure 1-3).

The spring and summer of 2014 were relatively dry and after snowmelt from early May to the end of June, approximately 6 weeks, no rain event occurred. The total precipitation in May, June and July, 2014, was 35, 9 and 50 mm, respectively (sum 94 mm) This probably adversely affected the vegetation. In contrast, in May to July 2014 there was relatively high, regular precipitation (in total 285 mm during these three months, only 10 days without precipitation in this period) which obviously supported vegetation growth. This may be the main reason for the observed differences in vegetation cover between 2014 and 2015. However, only the two species *Sedum acre* and (less frequently) *Sedum album* were present on the roof.

These data, despite being preliminary, emphasise clearly the need to develop green roofs which are better adapted to the climate of their location.

Figure 1: View of the same roof section. Left: end of May 2014, middle: early September 2014, right: early September 2015.

Figure 2: Detail of vegetation **at the** end of May 2014.

Figure 3: Detail of vegetation **in** September 2015.

***Runoff and water quality***

The water quality data from the green roof show that Cu concentrations varied between the samples. According to the Swedish freshwater quality criteria guidelines (Swedish EPA, 2000), they are classified as class III or IV (moderately high and high, respectively). However, these concentrations may be problematic since the majority of Cu was in its dissolved form (Table 2). Zn and Pb concentrations, however, were low and moderately low.

In contrast, the water quality results from the reference metal roof show very high concentrations of Zn (class V). According to the Swedish EPA (2000) water in class V may cause severe environmental impacts. In addition, the majority of the Zn was in its dissolved form.

Phosphorus was only analysed for two rainfall events in June 2013 and August 2014. During May 2014 the roof was fertilized. The P concentrations were very high. These results underline the importance of minimising fertilisation of green roofs when water quality aspects have to be considered. The event mean concentrations (EMC) are shown in Tables 1 to 4.

Table 1, Total EMCs for the Green roof.

| | Date | Cu µg/l | P µg/l | Pb µg/l | Zn µg/l | ADD |
|---|---|---|---|---|---|---|
| Rain | 2013/06/02 | 4.60 | | 0.60 | 32.18 | 20 |
| Rain | 2013/06/10 | 46.86 | | 0.90 | 35.57 | 2 |
| Rain | 2013/06/14 | 10.20 | 666.80 | 3.94 | 31.31 | 3 |
| Rain | 2013/09/18 | 20.52 | | 0.51 | 60.09 | 1 |
| Snowmelt | 2014/02/14 | 23.45 | 3661.23 | 0.67 | 77.55 | |
| Rain | 2014/08/18 | 12.40 | 1252.00 | 1.64 | 56.69 | 2 |

Table 2, Dissolved EMCs for the Green roof.

| | Date | Cu µg/l | P µg/l | Pb µg/l | Zn µg/l | ADD |
|---|---|---|---|---|---|---|
| Rain | 2013/06/02 | 3.55 | | 0.03 | 17.75 | 20 |
| Rain | 2013/06/10 | 42.17 | | 0.39 | 28.81 | 2 |
| Rain | 2013/06/14 | 5.94 | 491.70 | 0.04 | 24.69 | 3 |
| Rain | 2013/09/18 | | | | | |
| Snowmelt | 2014/02/14 | 19.53 | 2725.11 | 0.46 | 73.61 | |
| Rain | 2014/08/18 | 15.47 | 1771.45 | 0.12 | 29.58 | 2 |

Table 3, Total EMCs for the **metal** roof.

| | Date | Cu µg/l | P µg/l | Pb µg/l | Zn µg/l |
|---|---|---|---|---|---|
| Rain | 2013/06/02 | 22.99 | | 4.10 | 998.96 |
| Rain | 2013/06/10 | 2.58 | | 1.22 | 660.56 |
| Rain | 2013/06/14 | 1.73 | 17.91 | 0.53 | 1060.57 |
| Rain | 2013/09/18 | 3.57 | | 1.01 | 1596.21 |
| Rain | 2014/08/18 | 5.33 | 66.69 | 3.90 | 1047.65 |

Table 4, Dissolved EMC for the metal roof.

| | Date | Cu µg/l | P µg/l | Pb µg/l | Zn µg/l |
|---|---|---|---|---|---|
| Rain | 2013/06/02 | 16.56 | | 0.30 | 845.80 |
| Rain | 2013/06/10 | 2.05 | | 0.14 | 562.65 |
| Rain | 2013/06/14 | 1.60 | 6.90 | 0.14 | 977.07 |
| Rain | 2013/09/18 | 3.43 | | 0.64 | 1596.21 |
| Rain | 2014/08/18 | 1.48 | 2.86 | 16.57 | 0.15 |

## CONCLUSIONS

The visual assessment of the vegetation on the green roof showed that most of the commonly used *Sedum* species did not survive in the subarctic climate. Therefore more appropriate green roof plant communities that are better adapted to specific (e.g. cold) climates are needed.

The water quality data revealed that some metal concentrations and phosphorus concentrations from the green roof are above the guideline values, at levels that may risk biological effects. The results show that a large proportion of the metals is dissolved. The high phosphorus concentrations are probably to be fertiliser application.

## REFERENCES

Bengtsson, L. (2005). *Peak flows from thin sedum-moss roof.* Nordic Hydrology, 36(3), 269-280.

Bengtsson, L., Grahn, L., & Olsson, J. (2005). *Hydrological function of a thin extensive green roof in southern Sweden.* Nordic Hydrology, 36(3), 259-268.

Czemiel Berndtsson, J. (2010). *Green roof performance towards management of runoff water quantity and quality: A review.* Ecological Engineering, 36(4), 351-360.

Emilsson, T. (2008). *Vegetation development on extensive vegetated green roofs: Influence of substrate composition, establishment method and species mix.* Ecological Engineering, 33(3–4), 265-277.

Lee, J. Y., Lee, M. J., & Han, M. (2015). *A pilot study to evaluate runoff quantity from green roofs.* Journal of Environmental Management, 152, 171-176.

Lundholm, J. T., Weddle, B. M., & Macivor, J. S. (2014). *Snow depth and vegetation type affect green roof thermal performance in winter.* Energy and Buildings, 84, 299-307.

Swedish EPA (2000) *Environmental Quality Criteria - Lakes and Watercourses.* Report 5050. Swedish Environmental Protection Agency (Naturvårdsverket), Stockholm, Sweden.

Teemusk, A., & Mander, U. (2007). *Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events.* Ecological Engineering, 30(3), 271-277.

Vijayaraghavan, K., & Raja, F. D. (2014). *Design and development of green roof substrate to improve runoff water quality: Plant growth experiments and adsorption.* Water Research, 63, 94-101.

Zhao, M., & Srebric, J. (2012). *Assessment of green roof performance for sustainable buildings under winter weather conditions.* Journal of Central South University of Technology (English Edition), 19(3), 639-644.