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Accounting for the urban water balance as a chance for urban planning

La prise en compte du cycle urbain de l'eau comme opportunité pour la planification urbaine

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RÉSUMÉ

Les terrains urbains équipés de systèmes de drainage conventionnels montrent des changements importants dans le cycle urbain de l'eau avec un écoulement accru, la diminution de la recharge des eaux souterraines et l'évapotranspiration. Durant les deux dernières décennies, un changement progressif a eu lieu vers un nouveau système de gestion pour l'infiltration et la rétention des eaux pluviales. Cependant, en se focalisant surtout sur des installations d'infiltration, la recharge des eaux souterraines pourrait accroître les problèmes structurels au niveau local. Le urbain de l'eau local dans les régions rurales est une référence importante pour les techniques alternatives (WSUD). C'est pour cela que le modèle WABILA est utilisé pour développer une solution quant à la conversion d'anciennes casernes de 26 hectares à Münster. Des toitures végétalisées, rigoles, trottoirs poreux et la récupération des eaux de pluie ont été choisis en tant que mesures de contrôle pour les eaux pluviales avec l'objectif d'avoir des déviations minimales entre le bilan hydrique des terrains urbains et ruraux. L'étude de cas montre qu'il est moins compliqué d'assurer la recharge des eaux souterraines et de réduire son écoulement, mais qu'il est toujours difficile d'atteindre les taux d'évaporation des régions rurales.

ABSTRACT

Developed areas with conventional drainage systems show severe changes in the urban water cycle with increased runoff, decreased groundwater recharge and evapotranspiration. During the last two decades a step by step shift towards infiltration, retention and detention of stormwater established new management systems. However, focusing mostly on infiltration facilities, groundwater recharge may increase locally causing structural problems. The local water cycle of the predeveloped area is an important benchmark for WSUD. Therefore, the WABILA model is used to generate a planning solution for the conversion of the 26 ha former Oxford barracks in Münster. Green roofs, swales, porous pavements and rainwater harvesting are selected as stormwater control measures to achieve minimal deviations between the water balance of the predeveloped and the developed area. The case study points out that it is less complicated to ensure the groundwater recharge and decrease runoff, but it is still difficult to meet the evaporation rates of the predeveloped state.

KEYWORDS

Urban planning, urban water balance, WABILA, water sensitive urban design

1 INTRODUCTION

Developed areas with conventional drainage of all storm water runoff show severe changes in the urban water cycle with increased runoff, decreased groundwater recharge and evapotranspiration. During the last two decades a step by step shift towards infiltration, retention and detention of stormwater established new management systems. However, focussing mostly on infiltration facilities, groundwater recharge may increase locally causing structural problems.

The ongoing paradigm shift towards water sensitive urban design (WSUD) offers a chance to integrate the local water cycle as an important benchmark for planning solutions for new developments. The new technical German guideline DWA-A 102 (2015) requires to keep the local water balance of new developments close to the one of the undeveloped area. For that purpose, the guideline includes a water balance tool which had been developed by the authors (Henrichs et al., accepted) in the joint research project SAMUWA (www.samuwa.de). The authors had the chance to advise an urban planner team (ARGE OXF, 2015) to develop WSUD solutions for a new development on the area of the former Oxford barracks in Muenster and to optimize their contributions to a natural local water balance.

2 WATER BALANCE MODEL AND CASE STUDY

2.1 WABILA Model

The fundamental WABILA concept is to support the selection of stormwater control measures (SCMs) to meet the requirements of the local water cycle in the early planning phase with a water balance model which only needs a few, general available input parameters (Henrichs et al., accepted). Therefore, WABILA describes site-specifically the mean annual values of surface runoff, groundwater recharge and evapotranspiration as portions of the rainfall. These partitioning factors are described by system functions for different impervious areas (roofs, porous pavements, etc.) and stormwater measures (infiltration areas, green roofs, stormwater harvesting, etc.). The system functions calculate the partitioning factors as mean annual values. The tool is based on regression functions for each measure and area, estimated by 40,000 simulations (Henrichs et al., accepted). WABILA is valid for small urban catchments (less than 25 ha).

As climate input data only mean annual values of precipitation and potential evaporation are needed, which can be taken from local water balances or if not available from the "Hydrologischer Atlas Deutschland" (HAD, <http://geoportal.bafg.de/mapapps/resources/apps/HAD/index.html>). For the calculation of the partitioning factors for infiltration measure the hydraulic conductivity and the soil characteristics are required.

$$P = ET_a + GWN + RD \quad \text{Eq. 1}$$

$$P = v \cdot P + g \cdot P + a \cdot P \quad \text{Eq. 2}$$

$$1 = v + g + a \quad \text{Eq. 3}$$

with P precipitation (mm/a), ET_a actual evapotranspiration (mm/a), GWN groundwater recharge (mm/a), RD surface runoff (mm/a), v (-) partitioning factor for evapotranspiration, g (-) partitioning factor for groundwater recharge, a (-) partitioning factor for surface runoff.

2.2 Oxford Barracks

From 2018 on the former British Oxford Barracks in Muenster will be developed as a residential area with several nearby home office options. Ecological, sustainable and social aspects are important for the new settlement of 26 ha size and 1.113 flats. One third of the floor area will be multifamily residences in reconstructed barracks buildings. Two third of the floor area will be in new built multi-storey houses and some terraced houses. Most of the existing buildings have steep roofs. All new buildings will have flat roofs. Existing workshop sheds with steep roofs will be reconstructed for residential purposes or as local workspaces. The former 2.5 ha drill ground in the centre will be reduced to a new urban space of 1.7 ha area. The traffic system consists of a network of side roads

leading to a main road in the central axis of the area, following and completing the historic infrastructure system. Some of the existing side streets with basalt paving will be conserved because of architectural reasons in listed ensembles. The technical infrastructure has to be completely new. Existing infrastructure can be used for a limited time during the development time. Buildings will cover an area of 5,3 ha, the paved area 9,2 ha and 12 ha will be permeable.

The area has three different types of soil (Figure 1). The north, with sandy loam, is less pervious, with a permeability of 14 mm/h and a very limited infiltration. The central area, consisting of loamy sand, has a higher permeability (54 mm/h) so that stormwater infiltration is possible as well as in the south with a permeability of around 200 mm/h. The mean annual water balance of the whole area has a surface runoff of $a=22\%$, groundwater recharge of $g=27\%$ and evapotranspiration of $v=51\%$ (cp. Figure 1). The water balance of the natural local conditions was calculated using the tool GWNeu (Messer 2013) which is included in the WABILA software.

The call for the urbanistic contest demanded a water concept meeting requirements of Water Sensitive Urban Design (WSUD). The new storm water system has to support a step-by-step development of the area. The low impact concept demands to keep the water balance of new developments close to the undeveloped state of the areas (DWA-A 102, 2015). The needs of common drainage requirements, priority flow and detention during big storm events must be met.

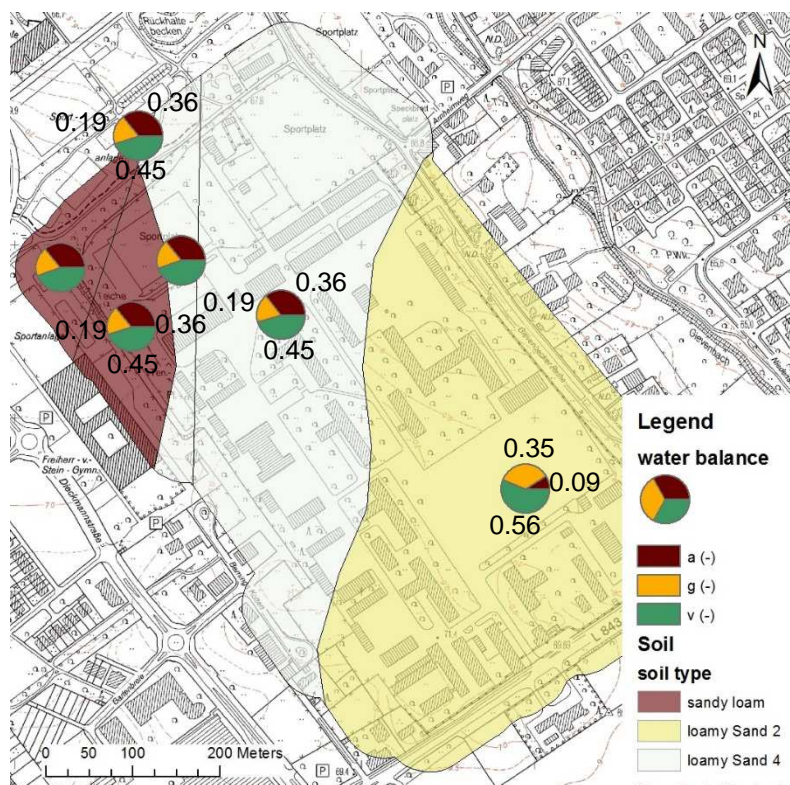


Figure 1: water balance and soil characteristics of the undeveloped area

3 RESULTS

3.1 WSUD concept

The main objectives for the storm water infrastructure are to approximate the natural water balance, to serve with a common drainage comfort, to support a reliable flood risk management during urban flash floods and to contribute to a liveable city climate and pleasant living environment.

The heterogeneous hydraulic conductivity and groundwater levels in the area as well as the step-by-step development of the area were important boundary conditions for the basic concept of stormwater management. It combines decentral and semi-central modules for retention and infiltration of stormwater runoff with a central runoff and detention system to take up surplus stormwater and to

serve as a priority runoff and detention path during flash floods.

Basic decentral measures on private grounds are flat extensive green roofs, stormwater harvesting for buildings with steep roofs and permeable paving as site specific options (cp. Figure 2). Underground parking will get intensive green roofs, whereas private ground level parking will be covered by permeable paving, depending of the local soil conditions. Decentral facilities may generate runoff during wet weather periods or during heavy rainfall. This runoff will be stored in semi-central components and will be either infiltrated into the ground or after detention routed to the central infrastructure depending on the local soil conditions. The semi-central measures belong to the shared components of a group of nearby private properties. They can be simple infiltration swales, rain gardens or other landscape designed spaces with the same function. The semi-central components will be allowed to generate a runoff of 3 L/(s·ha) at a return period of 5 years to the public central runoff and detention system.

Public roads will be asphalt streets with paved sidewalks. Public parking will be permeably paved where possible or are otherwise impermeable. The main road in the central axis will get four decentral treatment elements. Some old basalt paved streets of the barracks will be conserved as minor roads. Infiltration tests showed infiltration rates of around 20 L/(s·ha). All roads are connected to the central system.

The central runoff and detention system consists of a landscape designed western system and an eastern system with urban design. The western part of the area is served by five ditches being connected to a cascade of detention and infiltration basins in the central axis (central boulevard) of the area. Their attractive landscaping design will emphasize the important role of water in this residential district. The eastern part will be served by four open street channels showing water flowing in densely urban quarter during rainfall.

The former drill ground of the barracks will be replaced by a modern urban public open space integrating open detention corners, stimulating evaporation and putting water on stage as a liveable and refreshing element.

220 existing trees will be preserved and complemented by 132 new trees in the streets and open spaces. This supports evapotranspiration as well as the lush green open spaces.

The receiving water is a small creek and therefore a detention basin is optional if needed to reduce the hydraulic stress for immission control purposes according to the EG Water Framework Directive (EC-WFD, 2000).



Figure 2 : Illustration of the basic WSUD concept (Source: ARGE OXF, 2015)

3.2 Urban water balance

Figure 3 and Table 1 show the urban water balance components for the new development as mean annual values (mm/a) and the portioning factors as well as their deviations from the scenario “undeveloped area” (see chapter 2.2).

The scenario “runoff” consists of a conventional storm sewer network routing all storm runoff via a detention basin into the next receiving water. Compared to an undeveloped area the runoff is increased by the factor 2.2. The groundwater recharge is decreased by the factor 1.8 and the evapotranspiration by factor 1.4.

The scenario “WSUD” (see chapter 3.2) keeps the runoff of the undeveloped area. The groundwater recharge is increased by factor 1.3 and the evapotranspiration by factor 0.8 compared to an undeveloped area. All measures, like infiltration swales, green roofs, permeable pavements and rainwater harvesting are able to reduce the runoff in the area to a natural level. The groundwater factor g is 0.36 and hence 0.09 higher compared to the undeveloped area due to porous pavements, infiltration swales and raingardens, increasing the infiltration. In this example, it is necessary to increase the groundwater recharge to a higher level in order to counterbalance the deviation for the evapotranspiration.

The partitioning factor for evapotranspiration v is 0.42 and therefore the deviation is -0.09 to an undeveloped area.

Both, the deviations of the groundwater recharge and the evapotranspiration are within the tolerance

values of 0.05 to 0.1 given in the respective guideline DWA-A 102 (2015). However, evapotranspiration remains to be a weak component of the urban water cycle which cannot be met without additional measures to the conventional tools of WSUD. The main reason is that the lack of evapotranspiration of paved areas and even green roofs during summer cannot be compensated by evapotranspiration from infiltration areas or swales having a size of only 5 % to 20 % maximum of the connected paved areas.

Table 1: Water balance components and partitioning factors for the stormwater management solution

	water balance			partitioning factors			deviation factors		
	RD	GWN	ETa	a	g	v	a	g	v
	(mm/a)			(-)			(-)		
undeveloped	186	225	425	0.22	0.27	0.51			
runoff	408	127	301	0.49	0.15	0.36	+2.2	-1.8	-1.4
WSUD	173	298	347	0.21	0.36	0.42	1.07	1.3	-1.4

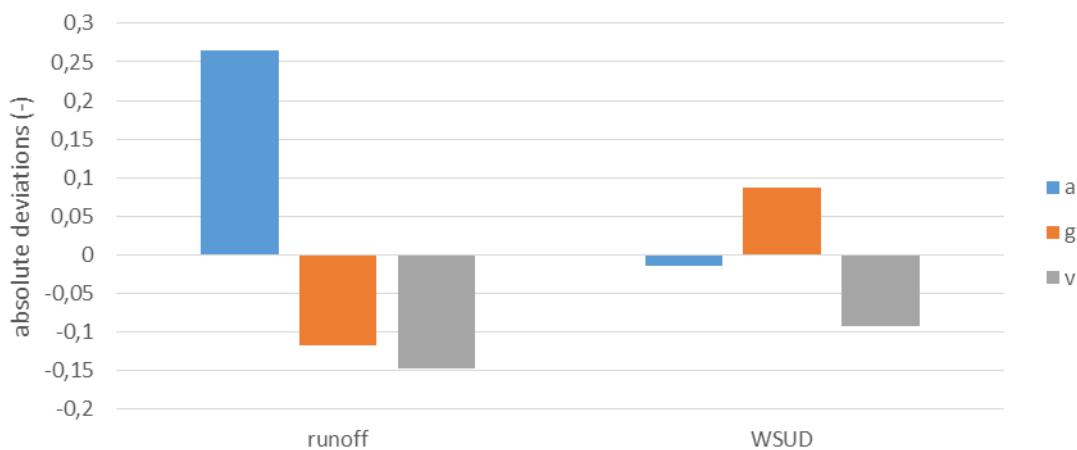


Figure 3: Deviations of partitioning factors for different rainwater management solutions compared to undeveloped area.

4 CONCLUSIONS

The case study confirmed that WSUD offers useful facilities to keep the local water balance of new developments close to the one of the undeveloped area. Runoff, often generating the biggest problems in receiving waters, can be kept very close to the undeveloped area, due to infiltration measures. Equally, the infiltration components lead to an increased ground water recharge.

Nevertheless, evaporation is still decreased when using simple WSUD facilities, compared to undeveloped areas. Hence the improvement compared to conventional conveyance systems is not as significant as required. Key factors for that are the conventionally sealed areas such as streets and steep roofs with only limited initial losses and therefore evaporation. But even green roofs show lacks of evapotranspiration during hot summer periods. Infiltration and detention facilities are not able to compensate these lacks as their areas are very limited compared to their runoff generating areas.

Thus it appears that evaporation remains an important component of the water cycle to be looked upon especially in view of longer heat periods due to climate change. A high density of trees and other evapotranspiration generating green or technical structures may be solutions to increase evaporation in urban developments.

The water balance was a very useful benchmark during the design process. "No goes" and misleading options could quickly be identified for the other partners. The developed solutions can be justified by their needs for the urban water cycle and can be reasonable integrated into the municipal development plan and private contracts with developers.

The water balance tool simplified and accelerated the cooperative design process of urban planners,

landscape architects and water engineers.

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