# Integration of Urban Green and Blue Infrastructure by Means of an Interactive and Geo-spatial Webmap-Tool

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**Abstract:** As a contribution to the nationally funded project INTERESS-I, we developed a web-based tool that balances rain and grey water drainage on the one hand, and vegetation water demand on the other. The tool combines GIS-balances of rain and grey water harvest in a catchment area and a day-by-day calculation of water demand from different vegetation structures respective of local weather history, shading situation and soil water conditions. The tool shows the drought period length a specific water storage volume can bridge.

**Keywords:** Blue-green infrastructure, urban water harvest, irrigation, urban climate change adaption

## 1 Introduction

Global climate change accelerates conflicts in urban water use. Hot and dry summers increase water demand of vegetation and the need for irrigation of parks and other green infrastructures. Using drinking water for this purpose is unacceptable, and many conflicts between municipalities are now under consideration regarding the export of water from the periphery to urban centres for irrigation. This is particularly relevant when local water use must be restricted due to water scarcity. Storing rainwater runoff and locally treated domestic grey water for irrigation purposes can be an appropriate solution to this conflict. Here, the first challenge is to balance rain- and grey water harvest and irrigation demand on a daily basis. In addition, the second challenge is to determine the size of a storage facility, which efficiently – as a precautionary option – secures irrigation water during hot periods.

To link urban water harvest and urban irrigation demand, three main questions arise: (1) What quantities of water can a given area provide? (2) How much water is needed to maintain the vitality of vegetation in a given area under given meteorological conditions? (3) How much storage capacity should be installed to bridge the time lag between rainfall and irrigation periods?

Many studies have been conducted analysing irrigation demand and water harvesting potential as an inevitable adaptation to climate change. However, most studies focus on irrigation demand of agriculture on a large scale. Available studies regarding irrigation water requirements in urban areas do not adequately answer all three questions stated above. For example, LUPIA et al. (2017) and CHIU et al. (2020) only estimate irrigation water demand on a monthly basis, thereby ignoring short-term soil water conditions and soil characteristics in their analysis of the water saving potential of harvesting rainwater. CAUTERUCCIO & LANZA (2022) improve on this by recognizing the water storage capability of soil and performing their calculations on a daily basis. However, they only focus on a single (converted military) area. In contrast to this, we provide a comprehensive framework that includes all parts of the system – supply, demand, and storage – on a daily and local basis, which is also available at a citywide extent.

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As a contribution to the nationally funded project INTERESS-I (https://www.interess-i.net/), we developed a web-based tool that interactively supports urban planners and other local stakeholders in deriving strategies for the use of urban water resources for irrigation and its optimization e. g. via the sizing of storage facilities. The tool was developed and implemented for Stuttgart, Germany.

# 2 Material and Methods

## 2.1 Urban Water Harvesting

Urban water harvest for irrigation can be obtained from roofs and runoff-generating streets, as well as grey water from residential and other buildings. To get data for this we used data from Cadastre Information System ALKIS to identify corresponding urban surfaces. In addition, data from the German Meteorological Service for Stuttgart city center station were used to calculate the formula for an estimate of precipitation runoff water (PWR):

$$PWR = hN \times A \times C_m \text{ [mm]} \quad \text{(Eq. 1)}$$

where hN is precipitation height [mm], A is area under consideration and $C_m$ is average runoff coefficient accoding to Table 1.

To estimate private domestic grey water production, we used GIS readable data from Cadastre Information System ALKIS and district-related population statistics for the districts of Stuttgart. From these we achieved a rough estimate for the number of inhabitants of each building by disaggregating district data. There are different empirical rates of grey water production depending on building use. For residential buildings, a rough estimate is 45 liters of slightly polluted greywater per inhabitant per day (BDEW 2019). Production rates for office-, commercial-, and bank-buildings can be assumed as 9 liters per employee per day (DVGW 2008). According to DENA (2017) usable floor space per employee is 31 m² (office and banks) and 34.9 m² (commercial and mixed-use). Using these estimates,we were able to apply the equation for the estimate of grey water production per day (GWP) for a specified urban area:

$$GWP = TF / FPH \times GWPH \times 1000 \text{ [m}^3\text{]} \quad \text{(Eq. 2)}$$

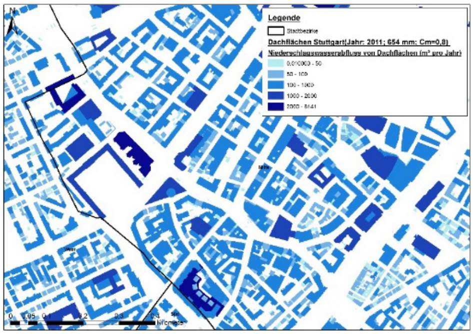
where TF is total floor, FPH is floor per inhabitant, GWPH is grey water production per Inhabitant [l per day]

Figure 1 shows an example for the accounts of water harvest on a yearly basis.

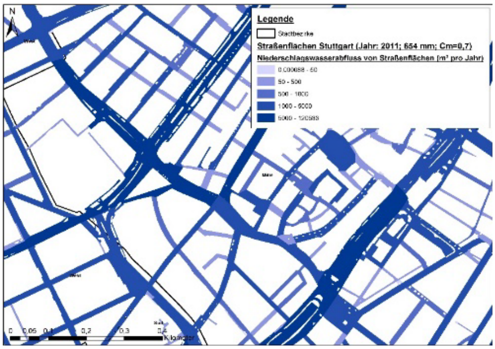
**Table 1:** Runoff coefficients used from DIN-NAW (2016)

| Surface type | Cm |
|---|---|
| Pitched roof | 0,9 |
| Flat roof | 0,8 |
| Green roof | 0,3 |
| Street | 0,9 |


a)




b)




c)

**Fig. 1:** Water harvest from grey water, roof drain and street drain summed up for the year 2011: a) grey water, b) roof runoff, c) street runoff

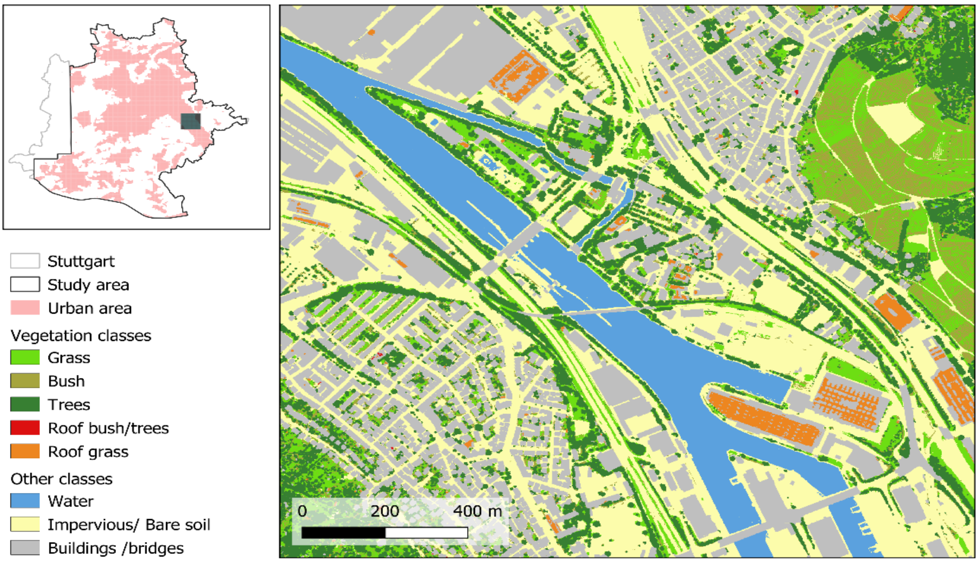



**Fig. 2:** Example for vegetation structures as detected by NARVAEZ-VALLEJO et al. (2023)

## 2.2 Vegetation Structures

Using methods of object-based satellite image classification, vegetation objects were detected from data of the Pléiades Earth Observation Mission (0.5 m resolution) for the urban areas of Stuttgart. In addition, highly accurate surface heights were detected using Lidar technology. Both information layers together result in a nearly citywide spatial distribution of the three vegetation types “grass/herbaceous”, “shrub” and “tree”. More details and corresponding results are published in NARVAEZ-VALLEJO & SCHWARZ-V.RAUMER (2023). Figure 2 shows a sample of these results.

## 2.3 Vegetation Water Supply

When to irrigate and how much? This question refers to the dynamic character of soil water storage, evapotranspiration and the necessary amount of water for irrigation. Irrigation for urban green spaces often follows experience-based irrigation rates and rules or, as we do here, rules that are compiled on a more scientific basis and communicated in handouts like FLL (2015) and ALB (2020). Plant available field capacity (PFC) plays the decisive role in FLL (2015) and ALB (2020). They assume that the aim of irrigation is to prevent water saturation of PFC below 30 % or above 80 % (see Tab. 2).

**Table 2:** Saturation of plant available field capacity (PFC) and plant development (according to FLL 2015, 39)

| Saturation of PFC [%] | Plant development |
|---|---|
| < 30 | Water stress |
| 30 – 50 | Still sufficient water supply |
| 50 – 80 | Optimal water supply |
| 80 – 100 | Development and formation of waterlogging, danger and occurrence of oxygen deficiency |

To map irrigation demand spatially and temporarily during a year, it is necessary to consider meteorological patterns. The annual variation in precipitation and evapotranspiration on a day-by-day basis determines the availability of soil water for plants and the necessity and amount of irrigation. For tree irrigation, however, species-specific interaction with groundwater and special irrigation techniques should be considered. Similar to FLL (2015) and ALB (2020), our approach does not consider this for the purpose of simplification.

We have implemented the interaction of vegetation structure, soil properties and meteorological patterns using a dynamic model as suggested by SWIM (KRYSANOVA et al. 2000). As a first approximation, our model follows the balance equation,

$$SW(t+1) = SW(t) + PRECIP_t - ET_t - PERC_t \qquad \text{(Eq. 3)}$$

where $SW(t)$ denotes soil water content start of day t, $PRECIP_t$ denotes precipitation [mm], $ET_t$ denotes evapotranspiration [mm], $PERC_t$ denotes percolation [mm] during day t

and thus, neglects surface runoff and subsurface flow. Again, simplifying soil water processes, we assume that SW is equal to the saturation of PFC and Percolation PERC is assumed to happen only if PFC is filled.

Calculation of ET follows FLL (2015) and ALB (2020) and multiplies potential evapotranspiration $ET_{pot}$ with site related factors as described in Table 3.

$$ET = ET_{pot} \times V \times M \times T \times S \qquad \text{(Eq. 4)}$$

**Table 3:** Components of ET calculation

| Name | Meaning | Factor values | Inputs used |
|---|---|---|---|
| V | Vegetation | 0,8 if grass<br>1,0 if bush<br>1,3 if tree | Vegetation as described in 2.3 |
| M | General site soil moisture type | 0,6 if dry<br>1,0 if fresh<br>1,6 if wet | estimated from urban soil map (HOLLAND 1995) |
| T | Soil texture type | 1,5 if sand<br>1,0 if sandy loam<br>0,8 if loam/silt/clay | estimated from urban soil map (HOLLAND 1995) |
| S | Site shadowing situation | 0,7 if shadow<br>1,0 if semi-shaded<br>1,3 if full sun | Based on 3D-LOD2 and for groups of 5 days during whole year at a 5m-raster level covering complete study area. |
| $ET_{pot}$ | Potential Evapotranspiration | Refer to page 46 in part 2 of SWIM manual (KRYSANOVA et al. 2000) | Method of PRIESTLEY-TAYLOR (1972), requires solar radiation, air temperature, and elevation as inputs taken from next available climate station |

From the two calculations above, it is possible to calculate the necessary water supply to satisfy the demand following the rule, "If PFK saturation is less than 30% irrigate as much as necessary to get PFC saturated by 80%" (FLL 2015, ALB 2020). The calculation is possible for every location in the study area that is covered by vegetation on a daily/5m-rastercell basis in the period 2001-2019.

## 2.4 The Water Storage Model

The storage model for the filling quantity S on day t of a storage facility (tank, reservoir etc.) with the maximum filling quantity $S_{max}$ is based on the simple water balance equation

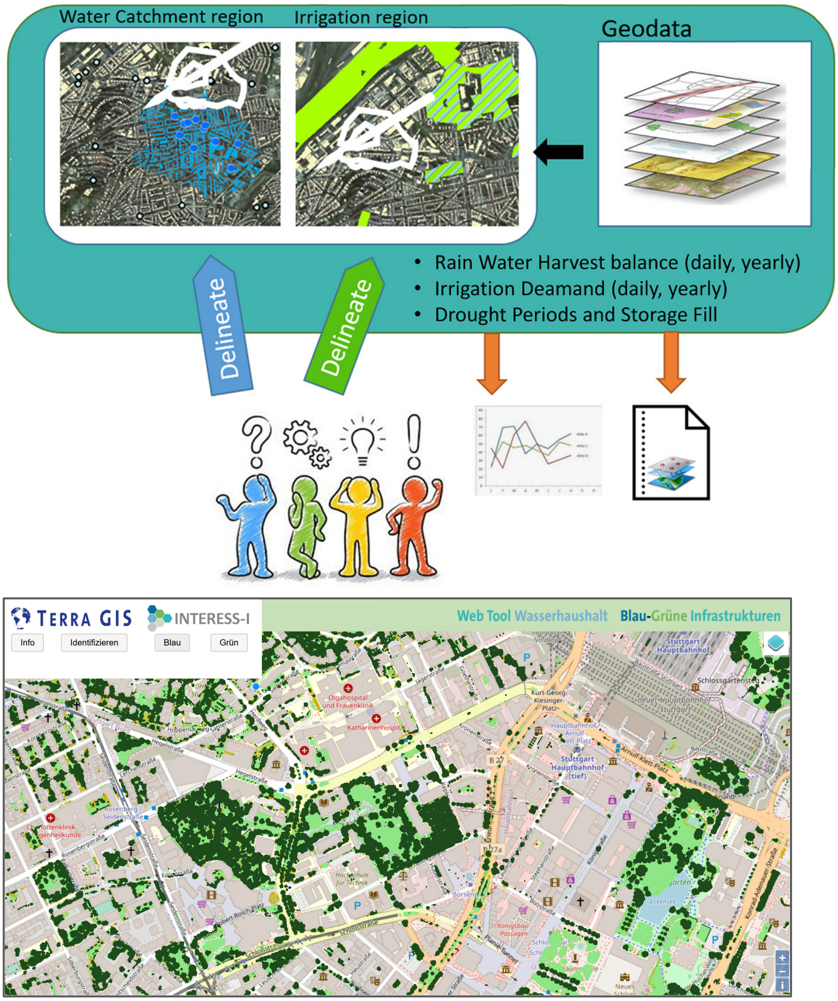
$$S(t) = S(t-1) + WH(t) - D(t) \qquad \text{(Eq. 5)}$$

where $t = 1,...,365$ , $S(0) = S_{max}$ , if $S(t) > S_{max}$ then $S(t) = S_{max}$ , WH(t) is water harvest, D is drain during day t.

Water harvest is available as a daily value composed of three components: (1) greywater (constant), (2) rainfall dependent roof runoff and rainfall dependent street runoff. The reservoir is partially drained on days when irrigation is required (as explained in 2.3). This is especially necessary when drought periods must be bridged. Therefore, the size of the reserveoir $S_{max}$ determines the length of a drought period, which can be bridged. The simulation of the reservoir filling keeps a record of that length. This enables the implementation of an optimization routine that adapts size of the reservoir $S_{max}$ according to a given acceptable length of a drought period.

## 3 Web-mapping and User Interaction

We developed a web-based planning tool[1] that allows the delineation of a catchment region for rain- and greywater harvest and specifies the green infrastructure that is to be irrigated (Fig. 3). The system can be used to compare less hot years with very hot years and considers local site conditions (soil, meteorology and shading). It supports the evaluation of site and irrigation management strategies.




(a)

(b)

**Fig. 3:** (a) Basic idea of the web map-tool and (b) user interface (http://bgtool.terragis.net/)

[1] We used OpenLayers, MapServer, GDAL, PHP, Python, R, PostGIS to implement the tool.

The tool offers two main functionalities for a given year in the period of 2001-2022:

(1) *Area based analysis.* Interactively select the area for water supply and the area to be irrigated. This leads to a) the selection of buildings and streets, which are analysed concerning their contribution to irrigation water and b) the highlighting of selected vegetation structures (Trees, shrub, grass). It is possible to combine grey water, roof and/or street run-off. The system's output describes how much irrigation water the selected "blue" area provides, irrigation water demand of the selected "green area" and the drought period length a specific storage facility is able to bridge.

(2) *Localized analysis.* Interactively select a location (5m raster cell). This leads to a display of a day-by-day history of water harvest and irrigation demand, as well as meteorological and soil water parameters.

Figure 4 shows an example of the tool usage. We used our University buildings, which are located around a small park, and the attached streets as an example harvest area to compare the roof and street water harvest with the irrigation demand of the central part of the park. For the year under consideration (year 2022), the selected harvest area generally provides more water than the yearly water demand for vegetation irrigation. The synchronisation between water availability and water demand is possible if a maximum drought period of 10 days is acceptable. Otherwise, such a period can be bridged by storing 218 m³ of harvested water. To bridge shorter drought periods, storage must be increased.

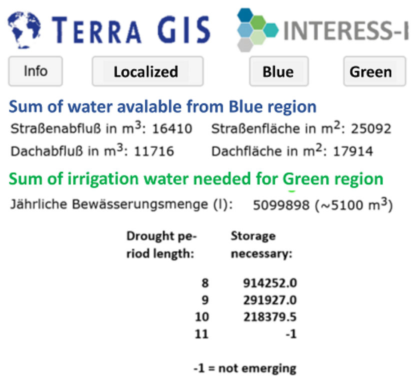
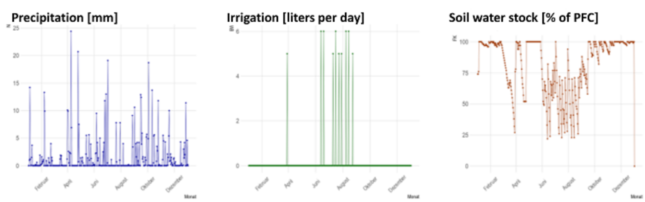
<table>
<tr><th>User Activity</th><th colspan="2">Tool response</th></tr>
<tr><td></td><td>Screen map section</td><td>Screen report section</td></tr>
<tr><td>1. Select roof water harvest area<br><br>2. Press "blue" button.</td><td></td><td rowspan="2">
</td></tr>
<tr><td>1. Select area to be irrigated<br><br>2. Press "green" button.</td><td></td></tr>
<tr><td rowspan="2">1. Select "Localize" button<br><br>2. Click into vegetation area</td><td colspan="2">Plot window</td></tr>
<tr><td colspan="2">
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**Fig. 4:** Example of user selection and system output for very dry year 2022 (partly translated from German)

# 4 Discussion and Outlook

The identification of irrigation water demand and supply for a total municipal area is an innovative challenge, which we solved with the intensive use of remote sensing and GIS data coupled with simplified, pre-established models. The implemented webmap-tool supports irrigation management and the calculation of necessary storage capacities for rain- and grey water retention. The model that our tool implements accepts many simplifications:

- Water harvest is based on a rough estimate of inhabitants per building, and it doesn't respect detailed surface runoff coefficients and rainwater sewage systems.
- Vegetation is classified in only three types (grass, bush, trees), and the types do not perfectly correspond to the FLL/ALB approach.
- The soil water balance model is simplified by neglecting different layers of soil depth and root systems, as well as surface runoff and percolation.
- The urban soil-map we used just gives a very inaccurate estimate of plant available field capacity and does not record urban area anthropogenic soils that occur as heterogeneous mixtures of undefined material in erratic patterns.
- We only use meteorological data from one logging station.

Because of these simplifications and the lack of calibration and validation for the FLL/ALB approach, the other sub-models, and the complete approach and implementation, the current example presented here only satisfies the requirements of a *demo version*. First analyses of the model results demonstrate a realistic outcome with a proper order of magnitude. In this way, our approach presents a prototype for the implementation of a useful and productive tool that helps manage and maintain the vitality of urban green infrastructure. The tool potentially supports scenario calculations, and thus has the potential to trigger decisions for interventions related to the urban water cycle. To achieve this, we are planning an extensive validation project. The optimized and calibrated tool will then be available to the public administration but also to private property owners.

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ALB = Arbeitsgemeinschaft Landtechnik und Landwirtschaftliches Bauwesen Bayern e. V.

BDEW = Bundesverband der Energie- und Wasserwirtschaft

DENA = Deutsche Energie-Agentur GmbH

DIN-NAW = DIN-Normenausschuss Wasserwesen (NAW)

DWD = Deutscher Wetterdienst

FLL= Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V.