Modélisation du bilan hydrologique urbain à l'échelle de la ville avec SWMM UrbanEVA : Étude de cas d'Innsbruck

City-wide urban water balance modelling with SWMM UrbanEVA: A Case Study of Innsbruck

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RÉSUMÉ

Le développement urbain et l'imperméabilisation généralisée des sols ont considérablement modifié le bilan hydrologique naturel, exacerbant des problèmes tels que l'épuisement des nappes phréatiques, la surchauffe urbaine et les inondations. Pour y remédier, de nouvelles directives privilégient la restauration du cycle naturel de l'eau via la réduction du ruissellement et l'augmentation de l'évapotranspiration. Cette étude présente un modèle de bilan hydrologique à grande échelle pour la ville d'Innsbruck utilisant SWMM-UrbanEVA, intégrant des données détaillées sur les infrastructures bleues et vertes. Le modèle utilise une imagerie aérienne haute résolution et des données climatiques pour classifier l'occupation du sol et simuler le bilan hydrique à long terme de 173 quartiers. Les résultats initiaux indiquent que, bien que l'évapotranspiration domine le bilan (73-74 %), le modèle sous-estime actuellement le ruissellement par rapport aux modèles d'assainissement validés. Une validation croisée avec un modèle de quartier détaillé attribue cet écart à une surestimation des surfaces déconnectées dans les données d'enquête. Les travaux futurs se concentreront sur l'intégration des facteurs d'ombrage et le calage du modèle par rapport aux modèles conceptuels de réseaux d'assainissement établis.

ABSTRACT

Urban development and widespread impervious surfaces have significantly altered natural water balances, exacerbating challenges such as groundwater depletion, urban overheating, and flooding. To address this, new guidelines prioritize restoring natural water cycles through reduced runoff and increased evapotranspiration. This study presents a large-scale water balance model for the city of Innsbruck using SWMM-UrbanEVA, incorporating detailed Blue-Green Infrastructure (BGI) data. The model utilizes high-resolution aerial imagery and climate data to classify land use and simulate the long-term water balance across 173 districts. Initial results indicate that while evapotranspiration dominates the water balance (73-74%), the model currently underestimates runoff compared to validated sewer models. Cross-validation with a detailed district model attributes this discrepancy to an overestimation of disconnected areas in the underlying survey data. Future work will focus on integrating shading factors and calibrating the model against established conceptual sewer models.

KEYWORDS

Blue-Green Infrastructure, SWMM-UrbanEVA, Urban Water Balance, Validation, Water Management

1 INTRODUCTION

Urban development, characterized by widespread impervious surfaces, has fundamentally altered the natural water balance. This alteration leads to significant environmental challenges, including groundwater depletion, urban overheating, and increased flooding. With the ongoing impacts of climate change, these challenges are expected to become more severe. Consequently, new guidelines, such as those from the (DWA, 2022), have set goals for new developments to approach a natural water balance. Achieving this often requires a reduction in surface runoff and a simultaneous increase in groundwater recharge and, specifically, evapotranspiration.

However, effectively implementing these measures requires a comprehensive understanding of the urban system. A full city-scale water balance model is essential to spatially identify areas with the greatest deviation from the natural water balance, allowing planners to prioritize interventions where they are most needed (Zeisl et al., 2018). While commonly used Blue-Green Infrastructures (BGI)—such as bioretention systems and soakaways—often increase groundwater recharge considerably, they are frequently limited in their ability to increase evapotranspiration. Standard water balance tools, such as WABILA (Henrichs et al., 2016), generally estimate water balances using simplified statistical relationships or regression-based partitioning. Furthermore, creating a sophisticated urban water balance model requires precise information on the areas connected to BGI; however, this data is often incomplete or unavailable. Models based solely on aerial images can be flawed, as the specific hydraulic connections of impervious surfaces to BGI are not visible from above.

The goal of this research is to establish a validated, physically-based water balance model for the urban area of Innsbruck using SWMM-UrbanEVA. By integrating detailed connectivity surveys with a city-wide simulation, this approach accurately quantifies the annual water balance components at the district level. This allows for the spatial identification of hotspots with the highest need for action, providing a transferable methodology for prioritizing climate adaptation measures in other cities.

2 METHOD

2.1 Case study

The case study for this research is the alpine city of Innsbruck, located at 574 meters above sea level. The study area covers approximately 50 km² and supports around 130,000 inhabitants. Innsbruck experiences a humid continental climate, with a mean annual temperature of 9.4°C and 911 mm of rainfall based on the 1981-2010 period. The city is divided into 173 districts, which are utilized for demographic, administrative, and planning purposes. The local soil composition is primarily characterized as very permeable loamy sand, which makes the case study suitable for infiltration based BGI.

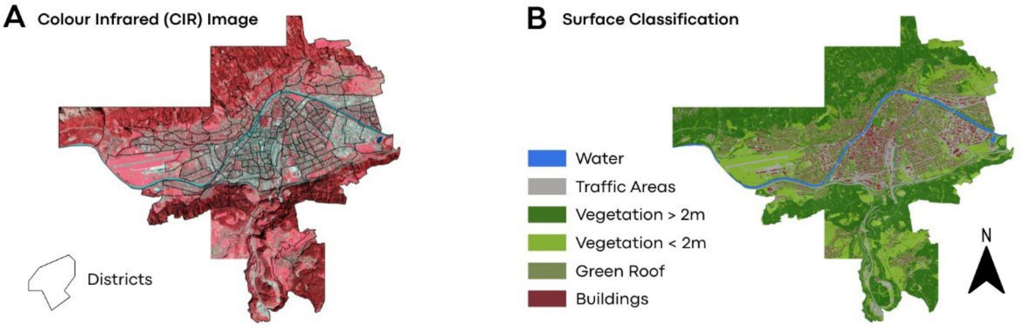

Figure 1: Overview of the Innsbruck case study area. (A) High-resolution (0.2 m) Colour Infrared (CIR) imagery used as the basis for surface identification. (B) Resulting surface classification categorizing the urban fabric into six distinct classes.

2.2 Data Availability

The study utilizes a robust dataset, including:

- Aerial Colour Infrared (CIR) images with a resolution of 0.2 meters (Figure 1A).
- A Digital Elevation Model (DEM) and Digital Surface Model (DSM) with a resolution of 0.5 meters.
- Climate data from a convection-permitting model covering three 30-year periods (past 1971-2000, near future 2031-2060, and far future 2071-2100), including rainfall and potential evapotranspiration (PET)

(Hauser et al., 2026).

- Sewer network data from the digital sewage network registry and a calibrated 1D hydrodynamic model.
- A database of disconnected areas in Innsbruck for each building and street.
- The KAREN conceptual sewer model, validated by in-sewer and overflow measurements (Hauser et al., 2026).

2.3 Model approach

Model inputs relied on land use surface classification derived from high-resolution (0.2 m) Colour Infrared (CIR) images and a Digital Surface Model (DSM). This classification categorizes the urban surface into six distinct classes, as illustrated in Figure 1B. The SWMM-UrbanEVA rainfall-runoff model (Hörnschemeyer et al., 2021) was implemented at the district level, treating each district as a single subcatchment. Within this framework, vegetated areas (comprising vegetation < 2m and > 2m) were integrated as Low Impact Development (LID) controls based on their specific surface areas. Based on a survey of disconnected areas, (BGI)—specifically soakaways and swales—was incorporated into the model. These elements were dimensioned according to Austrian design guidelines relative to the connected impervious areas they manage. A typical sizing ratio of approximately 1:10 was assumed (1 m² of BGI per 10 m² of impervious area). Consequently, the respective portions of impervious surfaces were hydraulically connected to these LID modules in the simulation.

To cross-validate this simplified lumped approach, a detailed model was created for a specific district (Campus area) using SWMM-UrbanEVA. In this detailed iteration, individual buildings, streets, BGI, and pervious areas were represented as distinct subcatchments. Unlike the city-wide model, this detailed validation relied on specific plans and field visits rather than the general survey of disconnected areas. Comparing the detailed and simplified models allows for an assessment of the validity of the lumped approach and its results. Additionally, the KAREN conceptual sewer model (Hauser et al., 2026), available for the entire Innsbruck case study and validated by in-sewer measurements, serves as a benchmark for calibrating and validating the runoff component of the water balance model.

Future work will involve: (i) filtering for districts characterized by low slopes and high percentages of impervious areas, as the model is not valid for the alpine forest regions north and south of the city; and (ii) applying shading factors to each subcatchment to account for local microclimates. These factors will be derived from a GIS analysis of short-wave radiation using the DSM and DEM (Weiler et al., 2019).

3 RESULTS

3.1 Water balance of the city of Innsbruck

The unvalidated water balance results for the three simulated periods (Table 1) indicate that the city-wide system is driven primarily by evapotranspiration, which accounts for 73-74% of the balance. This high percentage is due to large forest and meadow areas located in the north and south of the city (Figure 1 & Figure 2A). Groundwater recharge is the second largest component at approximately 19%, with the highest values observed in the Inn valley east and west of the city center (Figure 2B). These locations correspond to urban areas with a high proportion of disconnected surfaces and high BGI implementation. Surface runoff is comparably low at 7%, originating mainly from the highly impervious city center (Figure 2C). However, there are significant spatial disparities; the city center exhibits 60% runoff, 5% groundwater recharge, and 35% evapotranspiration, whereas forest areas show <1% runoff, 7% groundwater recharge, and 93% evapotranspiration.

Table 1: Water balance results for the Innsbruck case study, showing the percentage distribution of Evapotranspiration, Groundwater Recharge, and Surface Runoff for past (1971–2000), near-future (2031–2060), and far-future (2071–2100) climate scenarios.

Period	Evaporation (%)	Groundwater recharge (%)	Runoff (%)
1971-2000	73	19.3	7.1
2031-2060	74	18.7	7.3
2071-2100	73	19.4	7.5

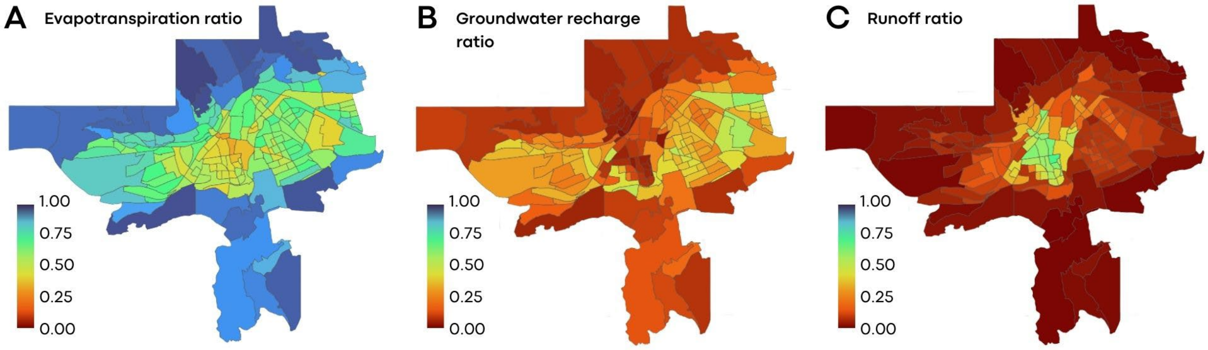

Figure 2: Spatial distribution of the simulated mean annual water balance across 173 districts. The maps illustrate the ratio of (A) Evapotranspiration, (B) Groundwater recharge, and (C) Surface runoff relative to total precipitation.

3.2 Cross validation and Comparison

Cross-validation was performed on a single district where all BGI and impervious connections are known, using a detailed SWMM UrbanEVA rainfall-runoff model. The results revealed pronounced differences: the simplified city-wide model underestimates runoff and overestimates groundwater recharge. This error stems from data inconsistences in the city-wide database of disconnected areas, which identified more areas as "disconnected" and managed by BGI than exist in reality. This suggests that the survey data has weaknesses and must be handled with caution.

Furthermore, the runoff results from the city-wide water balance model were compared to the validated KAREN model. The water balance model significantly underestimates runoff (2.9 million m³/year) compared to the KAREN model (4.9 million m³/year). This discrepancy is primarily driven by the difference in connected impervious area. The water balance model accounts for 452 ha, while the KAREN model accounts for 685 ha. This aligns with the single-district cross-validation, confirming that the discrepancy lies in the definition of connected areas.

4 NEXT STEPS

Future research will focus on refining the model by integrating shading factors and calibrating runoff against the KAREN model and the standard WABILA approach. This technical validation will unlock the model's potential as a strategic planning instrument. By correlating simulated water balance components with urban heat island data, the model will help identify synergies between stormwater management and climate adaptation. Furthermore, the spatially distributed results will allow planners to compare district performance and prioritize interventions in areas with the greatest deviation from the natural water balance. This targeted approach is essential for developing city-wide strategies

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