The overall paper is an important contribution to the science of decision-making with GIs across spatial scales. There are a few conceptual questions I had that I was not able to follow in the paper, but it appears the work is there. A bit further clarification would be helpful, and in that case, I would accept the manuscript for publication.

Please see below a few comments:

- The grammar and writing style is excellent. I do not have any major comments on the technical writing. However, while I understand the rationale for doing so, the many use of acronyms reads to me as confusing. Several of these acronyms mean essentially the same thing at the decision-making scale. Perhaps consider condensing the number of acronyms if feasible? Not necessary, it just was hard for me to follow. I see the graphic in Figure 1, which does help explain this concept a bit across the 3 spatial scales, but it is still hard to follow when reading the introduction. Perhaps re-state the acronyms in Fig. 1 caption and use all in the graphic? (e.g., UWB, SM are missing).

Response:

Thank you for your positive feedback on the grammar and writing style of our manuscript. We appreciate your insightful comments regarding the use of acronyms, which we understand can be confusing when overused.

To address your concerns, we will take the following actions:

1. We will add a comprehensive list of acronyms to the manuscript to help readers understand the terms used.
2. We will reduce the number of acronyms by eliminating those that are infrequently used.
3. We will redraw Figure 1 to replace unnecessary acronyms with their full names.
4. We will restate the remaining acronyms in the caption of Figure 1 to ensure clarity.

These revisions will be incorporated to enhance the readability of the introduction and provide a clearer understanding of the concepts across the three spatial scales.

- Very minor corrections noted here:
    - Line 116: "a agent-based framework" should be "an agent-based framework"
    - Line 159: "dynamic(s) of (the) watershed"?
    - Figure 1: Should the text near WM Agent state "Bi-level multiagent system"?

- Line 578: Period instead of ;?

Response:

Thank you for your careful review and for pointing out these minor corrections. We appreciate your attention to detail. We will make the following revisions:

- Line 116: Change "a agent-based framework" to "an agent-based framework".
- Line 159: Clarify the phrase to "dynamics of the watershed".
- Figure 1: Update the text near WM Agent to "Bi-level multiagent system".
- Line 578: Replace the semicolon with a period.

In addition to these corrections, we will thoroughly review the manuscript to avoid similar minor errors.

- The socio-hydrological application at various spatial scales applies to GIs in any urban community, not just alongside rivers. Perhaps consider re-phrasing the references to how GIs interact with hydrology near river networks.

Response:

Thank you for your insightful comment. You are correct that the socio-hydrological application at various spatial scales applies to green infrastructures (GIs) in any urban community, not just those alongside rivers. The distribution of green and blue water throughout a watershed can change with the development of GIs, which collect and use rainwater both directly and indirectly. For example, GIs can increase groundwater recharge (Zhang and Chui, 2019) and evapotranspiration (Ebrahimian et al., 2019), while also potentially altering urban water use patterns and subsequently urban and watershed hydrology (Pennino et al., 2016; Chen et al., 2019).

We will add explanations and relevant references to the introduction section to clarify how GIs interact with hydrology beyond river networks. Specifically, we will address the broader implications of GIs within urban communities.

The primary reasons for our initial focus on river connections are twofold: 1) River connections are a significant factor in the effect of GIs on urban and watershed hydrology concerning water resource allocation, and 2) Including other hydrological connections driven by GIs into the multi-spatial scale system introduces complexity that can be challenging to address comprehensively. We will include additional explanations regarding these considerations in the model assumptions section of the methodology and relevant appendix sections.

Moreover, the multiagent socio-hydrologic framework we proposed is designed to be flexible. It is feasible to incorporate additional hydrological connections driven by GIs within the framework to provide a more comprehensive description of the interaction between GIs and hydrology in the watershed. We will add corresponding explanations in the conclusion and future research sections.

References

Zhang, K. and Chui, T.F.M., 2019. A review on implementing infiltration-based green infrastructure in shallow groundwater environments: Challenges, approaches, and progress. *Journal of Hydrology*, *579*, p.124089.

Ebrahimian, A., Wadzuk, B. and Traver, R., 2019. Evapotranspiration in green stormwater infrastructure systems. *Science of the total environment*, *688*, pp.797-810.

Pennino, M.J., McDonald, R.I. and Jaffe, P.R., 2016. Watershed-scale impacts of stormwater green infrastructure on hydrology, nutrient fluxes, and combined sewer overflows in the mid-Atlantic region. *Science of the Total Environment*, *565*, pp.1044-1053.

Chen, J., Liu, Y., Gitau, M.W., Engel, B.A., Flanagan, D.C. and Harbor, J.M., 2019. Evaluation of the effectiveness of green infrastructure on hydrology and water quality in a combined sewer overflow community. *Science of the Total Environment*, *665*, pp.69-79.

- Most of the mentioning of the "socio" part of GIs being part of a socio-hydrological system in the introduction refer to housing types or anthropogenic activities in upstream portions of the drainage basin. While this is true, the socio component of GI systems extends far beyond these considerations and might be worth a mention. For example, how GIs become community recreational meeting spots, have been shown to reduce human health issues, improve mental well-being, provide urban sources of food, improve heat island effects, reduce noise, etc. Or, are you mostly referring to the "socio" component being the complex decision-making required? This was a bit confusing to me.

Response:

Thank you for your valuable comment. We appreciate your suggestion to expand on the "socio" component of green infrastructure (GI) systems beyond housing types and anthropogenic activities in upstream portions of the drainage basin.

In our decision-making framework, we primarily focus on the dynamics of socioeconomic relationships related to water use and conflict driven by the introduction of GIs in urban and watershed water resource allocation. This is an important social issue associated with balancing cost with the equity of water use rights among various water use agents (urban cities) within a watershed (Baumol, 1988; Fisher, 1981).

Specifically, on a city scale, the development of GIs can reduce the cost of accessing water resources. GIs can enrich urban water users' choices and gradually change their water use habits. In general, water demand might increase as the cost of water use decreases (water supply-demand cycle effect – Kallis, 2010).

However, on a watershed scale, due to geographic location effects (i.e., upstream and downstream conflicts) and GI introduction, although the overall cost of water use for each city decreases compared to the scenario without GIs, the degree of cost reduction varies between cities. Upstream cities experience a higher reduction in water use costs compared to downstream cities, leading to inequity in water use and potentially worsening water conflicts among urban areas.

Therefore, while the introduction of GIs like a types of new technology, does reduce the cost of water resources use at a local level, it can also exacerbate inequity in water use among different regions within the watershed without appropriate policy interventions (Kristal and Cohen, 2017). To address this conflict between cost and equity of water use driven by GIs, we propose the inclusion of a watershed manager agent in the IGWM framework. This agent would guide urban water managers' decisions by implementing a water management policy, such as a streamflow penalty strategy. This solution aims to ensure that each city can access water resources equitably and at a relatively low cost by developing GIs to use rainwater directly and indirectly, thereby promoting stable development within the watershed.

We acknowledge that the "socio" component in the socio-hydrologic framework we proposed primarily addresses complex decision-making related to water use and conflict driven by GIs. We will include more explanation about the issues in the introduction, results, discussion, conclusion, and future research sections to provide a more comprehensive view of the "socio" component.

References

Baumol, W.J., 1988. The theory of environmental policy. Cambridge University Press.
Fisher, A.C., 1981. Resource and environmental economics. Cambridge University Press.
Kallis, G., 2010. Coevolution in water resource development: The vicious cycle of water supply and demand in Athens, Greece. Ecological economics, 69(4), pp.796-809.
Kristal, T. and Cohen, Y., 2017. The causes of rising wage inequality: the race between institutions and technology. Socio-Economic Review, 15(1), pp.187-212.

- Conceptually, while I agree that the planning paradigm described at the city-level in Figure 1 is ideally how city-scale GIs should be constructed, in practice, I do not think this is happening. Instead, due to the long timeframe associated with stormwater funding and construction, GIs tend to be developed sporadically on a project-by-project basis, not in real-time, tightly coupled with the water use and demand, as depicted here. Although I understand that in order to model this as an ABM, you had to make such a coupling decision, perhaps consider a time delay in the model, or mention this limitation in reflecting real-world decision-making patterns. This also applies to the hydrologic connections in Fig 1B, between each urban area linked by real-time riverine flows between them. The city-scale decision-making of GI does not align temporally with the hydrologic flows of connecting river systems, even though the time steps appear to be monthly.

Response:

Thank you for your thoughtful comment. We agree that GIs tend to be developed sporadically on a project-by-project basis rather than in real-time, tightly coupled with water use and demand. To address this, we have considered different decision variables with different time periods in our agent-based model for urban water management at the city scale.

Specifically, for GI construction decisions, we have set the time step to annually, while for water supply portfolio selections, it is set to monthly (See Equation A10, page 36). The total construction area of the three types of GIs within an urban area over a year approximates the total construction area built by project-by-project efforts within the same period. In our model, the decision variables associated with GI construction represent the total construction area of the three types of GIs within an urban area from the previous year.

The model mechanism operates as follows: the decision variables associated with GI construction are first generated and input into the urban water balance model as parameters, which can change urban land features. Then, the decision variables associated with water supply are generated based on the specific urban water balance model. This approach addresses the issue of different time periods for GI construction and water supply.

Similarly, for simulating hydrologic connections between urban areas, we consider the average monthly flow dynamics between urban areas. This fits the time step for water supply portfolio selections by urban water managers.

In summary, we acknowledge that urban water supply, discharge, and river flow are real-time processes, whereas GI construction periods can vary from several months to several years. While our model assumes an annual time step for GI construction and a monthly time step for water supply and river flow, we believe this approach reasonably approximates real decision-making scenarios for urban and watershed water managers. This tradeoff balances model complexity and computational feasibility.

We will add more explanation to the corresponding part of the methodology section to help readers understand the model approximation assumptions. Additionally, we will discuss the limitations of this model assumption in the conclusion section.

- Another conceptual question I have - the overall model framework depends on GIs being used at-large for water storage and demand. Perhaps this is common in some parts of the world, but in the US, where the case study is conducted, most GIs are used for runoff abatement, which is then linked back into the greywater infrastructure system and sent offsite to reduce flooding issues. Some rainwater harvesting systems are used for on-site capture and use for irrigation, but these are very small-scale in nature (like someone's personal lawn) and not designed systematically to be a major contributor to widespread irrigation needs. At least I am not aware of this being common practice in the US.

Response:

Thank you for your insightful comment. We agree that the widespread use of green infrastructures (GIs) for rainwater utilization in the US is not yet common practice. However, there are several reasons we chose a watershed in the US for our case study.

First, while GIs are more commonly used for runoff abatement and linked to greywater infrastructure in the US, we believe there is a strong foundation and potential for their broader application. Some regions in the US face serious water scarcity issues (Schmidt et al., 2023), and various government levels are already encouraging the development of GIs for purposes such as sustainable stormwater management (Roy et al., 2008), reducing urban flood risk (Bhandari et al., 2018), and improving runoff quality (Guo et al., 2014). These initiatives provide a solid basis for the potential expansion of GIs to include rainwater harvesting and integration with grey infrastructure for comprehensive urban water cycle management.

Second, there are existing water conflict issues within US watersheds (Philpot et al., 2016), and few studies have examined the potential impact of GIs on these conflicts. Exploring the potential of GIs for rainwater utilization in US watersheds is therefore a valuable area of study.

Additionally, using the proposed model framework requires access to various types of data, such as hydrological, meteorological, urban land data, and GI-related data (e.g., construction and maintenance costs). US watersheds often have extensive and easily accessible data, which supports the feasibility and accuracy of our model. This was a practical consideration in selecting a US watershed for our case study.

While we acknowledge that the current widespread use of GIs for rainwater harvesting in the US is limited, we believe that investigating this potential is worthwhile. We will add more explanation to the corresponding part of the methodology section to clarify our rationale and discuss the limitations of our study in the conclusion section.

References

Khan, Z., Alim, M.A., Rahman, M.M. and Rahman, A., 2021. A continental scale evaluation of rainwater harvesting in Australia. Resources, Conservation and Recycling, 167, p.105378.
Ennenbach, M.W., Concha Larrauri, P. and Lall, U., 2018. County-scale rainwater harvesting feasibility in the United States: Climate, collection area, density, and reuse considerations. JAWRA Journal of the American Water Resources Association, 54(1), pp.255-274.
Schmidt, J.C., Yackulic, C.B. and Kuhn, E., 2023. The Colorado River water crisis: Its origin and the future. Wiley Interdisciplinary Reviews: Water, 10(6), p.e1672.
Roy, A.H., Wenger, S.J., Fletcher, T.D., Walsh, C.J., Ladson, A.R., Shuster, W.D., Thurston, H.W. and Brown, R.R., 2008. Impediments and solutions to sustainable, watershed-scale urban stormwater management: lessons from Australia and the United States. Environmental management, 42, pp.344-359.

Bhandari, S., Jobe, A., Thakur, B., Kalra, A. and Ahmad, S., 2018, May. Flood damage reduction in urban areas with use of low impact development designs. In World Environmental and Water Resources Congress 2018 (pp. 52-61). Reston, VA: American Society of Civil Engineers.
Guo, J.C., Urbonas, B. and MacKenzie, K., 2014. Water quality capture volume for storm water BMP and LID designs. Journal of Hydrologic engineering, 19(4), pp.682-686.
Philpot, S., Hipel, K. and Johnson, P., 2016. Strategic analysis of a water rights conflict in the south western United States. Journal of Environmental Management, 180, pp.247-256.

- It seems to me that the concept being simulated is actually systematic decision-making for detention-pond and reservoir storage at both the city watershed scales, and how inter-city feedbacks can impact the overall cycle. Which is not necessarily "Green Infrastructure" as I understand it to be used in the literature and community.

Response:

Thank you for your insightful comment. We understand your concern regarding the distinction between green infrastructure (GI) and grey infrastructure, such as detention ponds and reservoir storage, and how they impact urban water cycles and inter-city feedbacks.

We agree that large-scale centralized grey infrastructure, like reservoir storage, indeed plays a significant role in urban water cycles and interactions between urban areas. However, the dominance of grey infrastructure in socio-hydrologic dynamics also presents challenges in urban and watershed water resource management. These challenges include unsustainable development (Munoz, 2016) and the supply-demand cycle (Di Baldassarre et al., 2018). In watersheds with severe water scarcity issues, building large-scale centralized grey infrastructure can lead to over-extraction of water to support a population beyond the region's carrying capacity, potentially harming the watershed environment (Di Baldassarre et al., 2018). Additionally, in economically disadvantaged regions, the high cost of constructing and maintaining centralized grey infrastructure may be prohibitive.

These challenges have led to increased interest and advocacy from governments, the academic community, and practitioners for the development of decentralized green infrastructures (Sitzenfrei et al., 2020; Daigger and Crawford, 2007). GIs are generally considered more sustainable and affordable. Numerous studies have demonstrated the effectiveness of GIs in urban water systems, and several countries have begun to implement GI practices extensively. Examples include Low Impact Development (LID) in the US (Zahmatkesh et al., 2014), Water Sensitive Cities in Australia (Howe and Mitchell, 2011), Sustainable Urban Drainage Systems (SuDS) in the UK (Andoh and Iwugo, 2002), and Sponge Cities in China (Guan et al., 2021).

The increasing scale of GI development and its role in urban water systems have motivated us to explore the potential of GIs for direct and indirect rainwater reuse in urban water systems and their implications for water conflicts within watersheds. Additionally, we are interested in understanding how to make IGWM decisions, including GI construction and water supply portfolio selections, when GIs are widely used for rainwater reuse.

In our paper, we adopt a broad definition of GIs, encompassing three types: rainwater harvesting systems, stormwater harvesting systems, and infiltration-based GIs. This includes GI practices that convert impervious areas into pervious areas to increase groundwater recharge and indirectly use rainwater, such as urban green spaces and constructed wetlands. For example, a detention pond can be considered a GI in our model. If the water in the detention pond is used for infiltration, it is regarded as an infiltration-based GI. If the rainwater collected by the detention pond is reused, it is considered a stormwater harvesting system. By using this generalized definition of GIs, our model can include a wide range of GI practices within urban areas.

Although the impact of a single GI practice on the urban water cycle may be small, the cumulative effect of all GI practices within urban areas on the urban water cycle and hydrological interactions between urban areas cannot be ignored, especially with the continuous development of GIs.

We will add more explanation to the corresponding sections of our paper to clarify our rationale and discuss the implications of using GIs in urban and watershed water resource management.

References

Di Baldassarre, G., Wanders, N., AghaKouchak, A., Kuil, L., Rangecroft, S., Veldkamp, T.I., Garcia, M., van Oel, P.R., Breinl, K. and Van Loon, A.F., 2018. Water shortages worsened by reservoir effects. Nature Sustainability, 1(11), pp.617-622.

Sitzenfrei, R., Kleidorfer, M., Bach, P.M. and Bacchin, T.K., 2020. Green infrastructures for urban water system: Balance between cities and nature. Water, 12(5), p.1456.

Daigger, G.T. and Crawford, G.V., 2007. Enhancing water system security and sustainability by incorporating centralized and decentralized water reclamation and reuse into urban water management systems. Journal of Environmental Engineering and Management, 17(1), p.1.

Munoz, N.J., 2016. What Is The Economic Feasibility Of Implementing Grey Water Infrastructure At The Citywide Level?. Master's Projects and Capstones. 353. https://repository.usfca.edu/capstone/353

Howe, C. and Mitchell, C. eds., 2011. Water sensitive cities. IWa Publishing.

Zahmatkesh, Z., Karamouz, M., Burian, S.J., Tavakol-Davani, H. and Goharian, E., 2014. LID implementation to mitigate climate change impacts on urban runoff. In World Environmental and Water Resources Congress 2014 (pp. 952-965).

Andoh, R.Y. and Iwugo, K.O., 2002. Sustainable urban drainage systems: a UK perspective. In Global Solutions for Urban Drainage (pp. 1-16).

Guan, X., Wang, J. and Xiao, F., 2021. Sponge city strategy and application of pavement materials in sponge city. Journal of Cleaner Production, 303, p.127022.

- Perhaps this is me not understanding the Markov property, but it seems counter-intuitive to apply this property, essentially stating the decision-making process is stochastic and its future evolution is completely independent of its history, as the opposite paradigm is key to a system operating "socio-hydrologically".

Response:

Thank you for your insightful comment. We appreciate the opportunity to clarify our use of the Markov property in the context of our model.

The basic concept of the Markov property refers to the memoryless characteristic of a stochastic process, meaning that the future state of the process depends only on the present state and not on the sequence of events that preceded it (Frydenberg, 1990).

In our framework, we approximate the interaction between urban areas within a inter-city-scale IGWM framework as having Markov property. Specifically, consider a scenario where multiple urban areas are situated along a river, sharing water resources from the same river. The decision-making processes for water withdrawal and discharge in upstream urban areas affect those in downstream urban areas due to the flow of water along the river. To simulate these interactions, we begin with the decision-making process of the first urban area upstream. This initial decision influences the subsequent decision-making processes of the adjacent downstream urban areas, following the river's flow. Our multiagent framework arranges the decision-making processes in a sequence based on the urban areas' locations along the river. The decision-making of the upstream urban area serves as the initial state, and the decision-making of the next downstream urban area is the subsequent state. This process continues sequentially along the river.

Thus, the interaction process among urban areas in our model resembles the Markov property: the future state (decision-making of a downstream urban area) depends only on the present state (decision-making of the adjacent upstream area) and not on earlier states (decision-making of other upstream areas).

This is why we consider the interaction between urban water manager agents in watershed-scale IGWM as exhibiting Markov property. We will add more explanation to the corresponding parts of the introduction and methodology sections to help readers understand this basic assumption for the multiagent system.

References

Frydenberg, M., 1990. The chain graph Markov property. Scandinavian journal of statistics, pp.333-353.

Case Study:

- This is an extremely large watershed area for designing with GI. Was this selected at random, or is there a decision-making entity that manages this trans-state watershed systematically? I looked up the UMRBA association, and they don't seem to actively manage water supply and use in this basin.

Response:

Thank you for your insightful comment. We appreciate the opportunity to provide clarification regarding the selection of our study area and the role of decision-making entities.

Our bi-level multiagent framework is designed to capture the interactions among multiple stakeholders, including urban water managers and a watershed manager, at different authority levels within the watershed-scale IGWM.

For urban water managers, their responsibility is to make decisions regarding city-scale IGWM within their respective urban areas. This includes decisions on GI construction and water supply portfolios.

For the watershed manager, we refer to an entity like the Upper Mississippi River Basin Association (UMRBA). While the UMRBA does not actively manage water supply and use within urban areas, it plays a crucial role in managing water resources across the Upper Mississippi River Basin (see weblink 1). Our model framework involves the watershed manager enacting a streamflow penalty strategy to ensure equitable surface water allocation. This strategy involves setting low flow thresholds at various checkpoints along the river. Urban areas that withdraw surface water beyond these thresholds incur penalties. This approach is inspired by the water level management priorities established by the UMRBA, which aim to balance multiple objectives such as disaster preparedness, economic growth, and ecological health (see weblink 2).

We acknowledge that the UMRBA's actual water level management policy integrates these multiple purposes. However, in our model, we focus solely on the goal of equitable water resource allocation to explore the conflict between cost and equity of water use driven by GIs in the Upper Mississippi River Basin (Guo, 2023).

References

Guo, Q., 2023. Strategies for a resilient, sustainable, and equitable Mississippi River basin. River, 2(3), pp.336-349.

Links

1. https://www.encyclopediadubuque.org/index.php/UPPER_MISSISSIPPI_RIVER_BASIN_ASSOCIATION
2. https://umrba.org/document/umrba-2022-water-level-management-priority-actions

- I looked at the 1 citation mentioned for using GI in this geographical region (Askey-Merwin, 2020), and this publication addresses mitigating flooding, not storing rainwater via GIs and re-use in widespread irrigation projects. Moreover, the Mississippi River is one of the highest-flow rivers in the US and has a complex network of laws and regulations regarding water extraction for municipal or industrial use. I am not aware of water quantity being an issue here for irrigation purposes, so I am confused why there is a study suggesting GI is being actively proposed, managed, and constructed at the watershed scale and the city scales in real-time to ensure water availability here. If it is purely for a conceptual purpose of explaining complexities of GI planning in general, that is fine, but in that instance, I wouldn't necessarily limit the model to connecting urban communities along a main river stem, as this limits the application substantially. However, the model is already built under these assumptions, so I do not recommend re-designing. I am just pointing out it conceptually is difficult for me to see the application outside of this theoretical explorative study.

Response:

Thank you for your detailed comment and for highlighting important considerations regarding the application of our model framework to the Upper Mississippi River Basin.

We acknowledge that the Upper Mississippi River Basin is one of the water-rich regions in the US. However, this basin hosts a diverse range of stakeholders and water users. Over 70% of the area is dedicated to agriculture and animal husbandry, while only 5% is urbanized, yet it supports a population of approximately 24 million, particularly in high-density metropolitan areas. Additionally, the basin includes the national Wildlife and Fish Refuge and 12,000 miles of commercially navigable channels, which require maintenance of environmental flows for ecological health and navigation purposes (see weblink 1). Consequently, water competition among different users with varying objectives is significant, especially in the context of climate change. Under these conditions, the water quota for urban use might be limited, making water conflicts among urban areas a pertinent issue, even in this high-flow river basin.

Currently, the primary purpose of developing GIs in the basin is to manage stormwater, mitigate flooding (Askey-Merwin, 2020), filter pollutants, and enhance the quality of life. Our framework also incorporates the development of infiltration-based GIs to manage stormwater and increase groundwater recharge, which complements the integration of GIs with grey infrastructure in urban water systems.

We acknowledge that there is no existing government policy specifically advocating for rainwater harvesting and direct reuse via GIs in the basin. However, recent studies have begun to call for rainwater harvesting and reuse through GIs (Guo, 2023) and have demonstrated the potential for such practices in the basin (Ennenbach et al., 2018). Therefore, we believe it is both feasible and valuable to apply our proposed model framework to the Upper Mississippi River Basin to explore the potential and outcomes of widespread GI development for direct and indirect rainwater use at different scales.

We also agree that applying our model framework to a basin facing severe water scarcity, such as the Colorado River Lower Basin (Schmidt et al., 2023), or to regions with established policies for GI development for rainwater use, such as the Albemarle-Pamlico river basins (Ghimire and Johnston, 2013), may be more suitable and meaningful. We will add a discussion on case study selection in the relevant sections of the case study and limitations and future research sections of the conclusion.

References

Ennenbach, M.W., Concha Larrauri, P. and Lall, U., 2018. County-scale rainwater harvesting feasibility in the United States: Climate, collection area, density, and reuse considerations. JAWRA Journal of the American Water Resources Association, 54(1), pp.255-274.

Askew-Merwin, C., 2020. Natural Infrastructure's Role in Mitigating Flooding Along the Mississippi River, Northeast-Midwest Institute Report, 16 pp.

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Ghimire, S.R. and Johnston, J.M., 2013. Impacts of domestic and agricultural rainwater harvesting systems on watershed hydrology: A case study in the Albemarle-Pamlico river basins (USA). Ecohydrology & Hydrobiology, 13(2), pp.159-171.

Schmidt, J.C., Yackulic, C.B. and Kuhn, E., 2023. The Colorado River water crisis: Its origin and the future. Wiley Interdisciplinary Reviews: Water, 10(6), p.e1672.

Links

1. https://www.fws.gov/refuge/upper-mississippi-river

- Where are you getting water demand data for irrigation, and how does this change over time? What factors drive this in the model? I see that you simulated "urban" water demand via population and urban layouts, but as mentioned, this is a tiny percentage of the overall water resources in the basin, and is likely to be impacted significantly by urban-scale GI units. I see some mentioning of irrigation demand in Eq A10, but it is unclear to me what these equations mean or how the underlying data were gathered. Is the irrigation a basis of cropland type?

Response:

Thank you for your insightful comment and for giving us the opportunity to clarify our approach to water demand data and its drivers in the model.

In our model, we focus exclusively on water demand within urban areas, and agricultural water demand is not included. We consider three types of urban water demands: indoor potable, indoor non-potable, and outdoor non-potable water demand. These categories are inspired by the work of Last (2011) and are measured based on the associated urban populations and layouts using the method described in Last (2011).

Regarding irrigation demand within urban areas, it primarily refers to the water needed for maintaining vegetation in both large-scale and small-scale infiltration-based GIs. Large-scale GIs include street trees, urban green spaces, parks, and gardens (Fam et al., 2008; Caetano et al., 2014) etc., while small-scale GIs encompass green roofs, rain gardens, and bioretention systems (Mechelen et al., 2015) etc. These plants require irrigation to sustain their basic ecological functions.

As outlined in the 14 row of Eq. A10 (Page 36), the estimation of urban irrigation demand involves the ratio of soil moisture for plant demand to saturated soil moisture (fsm). This ratio is used to determine the minimum storage level of the shallow soil layer required to meet the basic water demands of plants. The equation is inspired by the Australian Water Resources Assessment-Landscape (AWRA-L) Model (Frost et al., 2016), and the relevant parameters are set according to the recommendations in this work.

In our IGWM optimization model, the constraint for urban irrigation demand in month t is formulated such that the storage level of the shallow soil layer in month t cannot be less than the specific minimum storage level required for plants' water needs. This ensures that the basic water requirements of urban vegetation are met.

We will add a detailed explanation of the IGWM optimization model to Appendix A3 to ensure readers can understand its technical details. Additionally, we will provide more detailed explanations and references to demonstrate how the underlying data for our model were gathered in the case study.

References

Last, E.W., 2011. City water balance: a new scoping tool for integrated urban water management options (Doctoral dissertation, University of Birmingham).

Caetano, F., Pitarma, R. and Reis, P., 2014, June. Intelligent management of urban garden irrigation. In 2014 9th Iberian Conference on Information Systems and Technologies (CISTI) (pp. 1-6). IEEE.

Fam, D., Mosley, E., Lopes, A., Mathieson, L., Morison, J. and Connellan, G., 2008. Irrigation of urban green spaces: A review of the environmental, social and economic benefits. CRC for Irrigation Futures Technical Report, 4(08).

Van Mechelen, C., Dutoit, T. and Hermy, M., 2015. Adapting green roof irrigation practices for a sustainable future: A review. Sustainable Cities and Society, 19, pp.74-90.

Frost, A.J., Ramchurn, A. and Smith, A., 2016. The bureau's operational AWRA landscape (AWRA-L) Model. Bureau of Meteorology technical report.

- I am not qualified to review the set-up of the ABM model, particle optimization schemes, or economic theory choices. Please ensure one of the other reviewers has this expertise and can comment on the methodology.

Response:

Thank you for your suggestion, and we greatly appreciate your academic integrity and professionalism in reviewing our manuscript. The majority of the technical details of our model, the associated solution approach, and the motivation for our economic theory choices are provided in the relevant sections of the introduction, methodology, and appendix. We also hope that other reviewers with expertise in these specific areas will comment on the model and the associated solution approach we propose. Their feedback will help strengthen our study and improve the quality of our paper.

- I do not see where the channel geometry is used for the Muskingum-Cunge routing method.

Response:

Thank you for your question regarding the use of channel geometry in the Muskingum-Cunge routing method.

In our study, we have chosen the Muskingum-Cunge routing method to simulate the hydrologic connections between urban areas. This method is a data-driven river channel model that uses a storage relation to link inflow and outflow in a channel reach (Garbrecht and Brunner, 1991). The storage relation is defined by the following equation:

$$S = k[x \cdot I + (1 - x) \cdot O],$$

where (k) is a storage coefficient, (x) is a weighting factor, (I) is the inflow rate to the reach, and (O) is the outflow rate from the reach. This equation allows us to model changes in streamflow within the river reach. The outflow of the river reach at time (t), ($Q(t)$), can be expressed as:

$$Q(t) = C_1 \cdot I(t) + C_2 \cdot I(t-1) + C_3 \cdot O(t-1),$$

where ($Q(t-1)$) is the outflow of the river reach at time ($t-1$), and ($I(t)$) and ($I(t-1)$) are the inflow rates at times (t) and ($t-1$), respectively. The Muskingum-Cunge routing method is flexible enough to simulate flow changes in river channels at any time step. The model parameters (C_1), (C_2), and (C_3) can be calibrated and verified using inflow and outflow time series data for specific time steps. Given the model parameters (C_1), (C_2), and (C_3), and the initial inflow time series data, we can simulate the outflow time series in the river reach using the model. Therefore, it does not require the use of channel geometry information.

We hope this clarifies our approach and the rationale behind using the Muskingum-Cunge routing method in our study.

References

Garbrecht, J. and Brunner, G., 1991. Hydrologic channel-flow routing for compound sections. Journal of Hydraulic Engineering, 117(5), pp.629-642.

- I am not following how USGS stations for the Mississippi river could be used to calibrate urban water use.

Response:

Thank you for your insightful comment regarding the use of USGS stations for calibrating urban water use.

In our model framework, we need to calibrate two types of models: the Urban Water Balance Simulation Model (UWB-SM) and the Muskingum-Cunge routing model. The calibration process is somewhat intricate due to the spatial differences between the inlet and outlet of urban areas and the locations of the adjacent USGS stations.

Firstly, we identify the inlet and outlet locations of an urban area based on its GIS map. We then estimate the monthly inflow and outflow time series data for the urban area using a map correlation method (Archfield and Vogel, 2010) with available monthly streamflow observations from the associated USGS stations in the study system.

These estimated monthly inflow and outflow time series data for each urban area are used to calibrate both models. The calibration process for the Muskingum-Cunge routing model is straightforward and involves using the outflow data from the upstream urban area and the inflow data of the adjacent downstream urban area.

The calibration process for the UWB-SM is more complex. For this calibration, the estimated monthly inflow time series data and the associated monthly rainfall time series data collected from NOAA databases are used as inputs for the UWB-SM. In this model, we assume that rainwater and stormwater supply are not considered, and urban water demands—both indoor and outdoor—are met solely through surface water and groundwater supply. The ratio of surface water to groundwater supply is set based on relevant reports or estimations. The monthly amounts of surface water and groundwater withdrawals are determined based on this setting.

Subsequently, the simulated monthly outflow time series data for the urban area, computed using the UWB-SM, are compared with the estimated monthly outflow data to calibrate and validate the UWB-SM. We will add more explanation about the model calibration in the relevant part of the case study section. We hope this clarifies our approach.

References

Archfield, S.A. and Vogel, R.M., 2010. Map correlation method: Selection of a reference streamgage to estimate daily streamflow at ungaged catchments. Water resources research, 46(10).

- The discussion of results is very convoluted. Perhaps consider a concluding paragraph with bullet-points of the main take-aways that can be widely applied. For example, key insights about water costs and conflicts among adjacent communities, the importance of communication of watershed-scale managers and city-scale planners, the impact of assuming agent rationality / Markov property / Stackelberg in understanding the overall socio-hydro dynamics, what this means on overall water policy as GIs become more popular, interaction between urban and irrigation water use and demand, what this study informed us about social equity in water decisions, etc.

Response:

Thank you for your valuable feedback. We appreciate your suggestion to improve the clarity and readability of the discussion section.

In response to your comment, we will rewrite and re-arrange the discussion part in the Results and Discussion section. We will remove any redundant and unimportant parts to make the discussion more focused and easier to understand. Additionally, we will include a concluding paragraph with bullet points highlighting the main takeaways that can be widely applied. We believe these changes will enhance the discussion and provide clearer and more actionable insights for the readers.

- The Conclusions section is too convoluted for me. I recommend removing a lot of the technical jargon and focusing on the bigger picture here.

Response:

Thank you for your suggestion regarding the Conclusions section. We appreciate your feedback and understand the need for clarity and focus on the bigger picture.

In response to your comment, we will rewrite the Conclusions section to remove redundancy and unnecessary technical details. We will ensure that the revised section highlights the broader implications and key insights of our study, making it more accessible and easier to understand.