

SCIENTIFIC NOTE

GREENING UP FOR MOSQUITOES: A COMPARISON OF GREEN STORMWATER INFRASTRUCTURE IN A SEMIARID REGION

HEIDI E. BROWN,¹ LADD KEITH,² VALERIE MADERA-GARCIA,¹ ANISSA TAYLOR,³ NICHOLAS RAMIREZ³
AND IRENE OGATA⁴

ABSTRACT. Green stormwater infrastructure provides environmental, economic, and health benefits as a strategy for building resilience against climate change impacts. However, it may inadvertently increase vulnerability due to improper design and construction or lack of maintenance. We engaged city stakeholders and a diverse student group to investigate possible maladaptation. After rain events, student interns collected data at green stormwater infrastructure, identified in partnership with city stakeholders, for both water retention and mosquito larvae, if present. During the sampling period in 2018, 24 rain events occurred, with 28 sites visited 212 times including visits to basins (63%), curb cuts (34%), and a bioswale (2%). The largest basin consistently retained water (mean: 3.3 days, SD: 2.3 days) and was a positive site for *Culex quinquefasciatus*, a West Nile virus vector. We found that while basins can become mosquito breeding habitat, there was no evidence that curb cuts were collecting and retaining water long enough. As cities turn to green stormwater infrastructure to address climate change impacts of increasing drought, flooding, and extreme heat, these findings can help in the selection of appropriate infrastructure design typologies.

KEY WORDS Climate adaptation, green stormwater infrastructure, maladaptation, resilience, West Nile virus

Rainwater harvesting techniques such as green stormwater infrastructure (GSI) are a strategy for building a sustainable community and resilience against a range of climate change impacts (Boelee et al. 2013). The GSI focuses on the retention of urban stormwater runoff to promote infiltration in porous surfaces or collection more closely to where it falls (Golden and Hoghooghi 2018). As cities aim to address climate change and pursue strategies to increase their resilience, well-designed GSI provides several benefits, including decreasing urban flooding, mitigating heat, conserving precious water sources required for urban landscapes, and even supporting local food production (Demuzere et al. 2014). Among the public health benefits, a recent review listed improvement to physical, mental, and economic well-being (Nieuwenhuijsen 2021).

However, when GSI is improperly designed and constructed or not adequately maintained, it may be maladaptive (Barnett and O'Neill 2010). Maladaptation is a climate adaptation that unintentionally directly increases “vulnerability for the targeted

and/or external actor(s), and/or eroding preconditions for sustainable development by indirectly increasing society’s vulnerability” (Juhola et al. 2016), and maladaptive GSI may become a source of mosquitoes (Löhmus and Balbus 2015).

Herein, we present a project that engaged city stakeholders and students from diverse disciplines to assess a potential maladaptation GSI across a semiarid urban environment in the USA. We focus on curb cuts and basins, 2 types of GSI increasingly used in Tucson, AZ (MacAdam 2012). The lack of data on the performance of GSI as an adaptive strategy in semiarid and arid urban environments makes this work particularly salient (Meerow et al. 2021).

Tucson, AZ, is a semiarid climate in the US Southwest that has been in megadrought conditions since 2000. Summer temperatures regularly exceed 100°F, with an average of 68 days a year reaching at least 100°F (Davis 2021). The GSI, including curb cuts, low-curb traffic circles, bioswales, and bio-retention basins (Fig. 1), is promoted to reduce flooding, capture rainwater for urban landscaping, and more recently to help mitigate heat (MacAdam 2012). Until 2020, when the Green Stormwater Infrastructure fee was adopted for utility services (City of Tucson, AZ, <https://www.tucsonaz.gov/gsi>), the City of Tucson installed GSI throughout the city but did not have the funds available to maintain them.

In Tucson, vector control falls under the jurisdiction of the Pima County Health Department, and GSI are often installed by Tucson Water, a utility of the City of Tucson (Witcher 2021). We engaged

¹ University of Arizona, Mel and Enid Zuckerman College of Public Health, Department of Epidemiology and Biostatistics, 1295 N Martin Avenue, PO Box 245210, Tucson, AZ 85724.

² University of Arizona, College of Architecture, Planning, and Landscape Architecture, 1040 N Olive Road, PO Box 210075, Tucson, AZ 85721.

³ Pima County Health Department, 3950 S Country Club, Tucson, AZ 85714.

⁴ Tucson Water, Public Information & Conservation Office, 310 W Alameda Street, PO Box 27210, Tucson, AZ 85726.

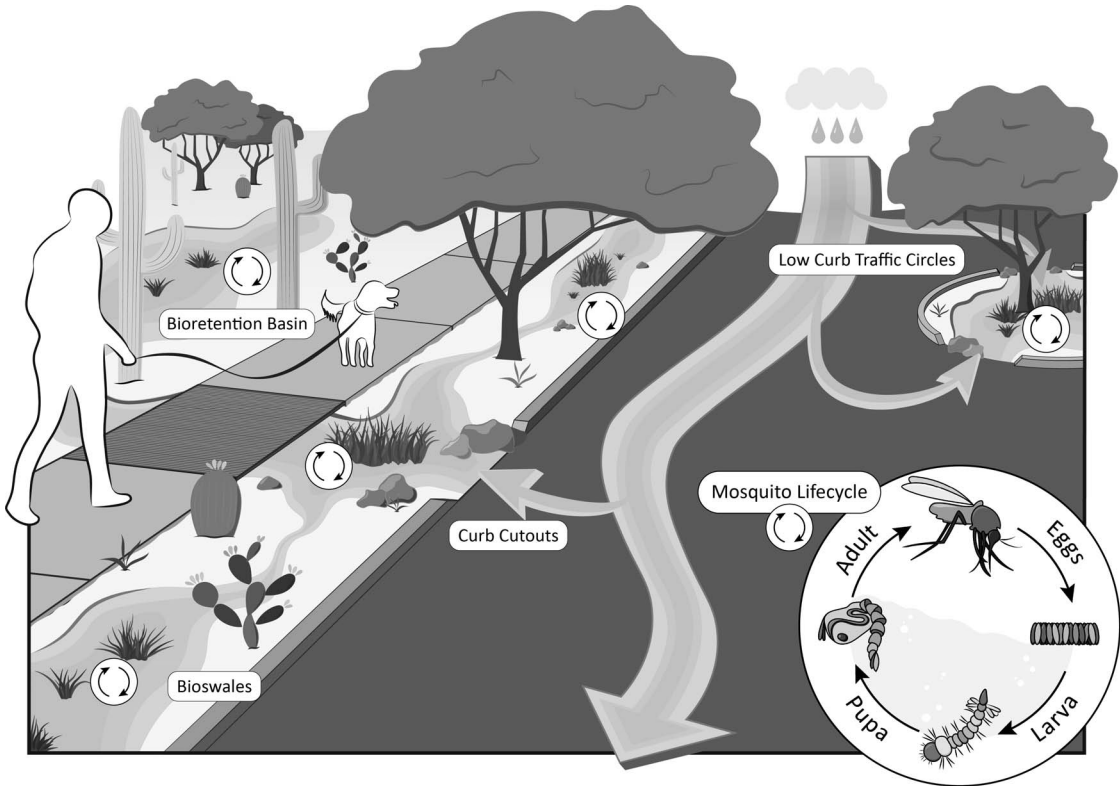


Fig. 1. Schematic of green stormwater infrastructure with generic mosquito life cycle embedded. Green stormwater infrastructures (GSIs) where stormwater pools for longer periods may become a source for mosquito emergence. Image credit: Erika Lynn Schmidt.

stakeholders in these organizations at the onset of the project to understand the limitations, challenges, and potential maladaptation of GSI in this semiarid urban environment. Students were trained in GSI design and planning and taken on a field trip to identify various types of GSI. In collaboration with the Pima County Health Department, the student interns also participated in a 2-day ride-along with the Vector Control Unit, where they assisted setting and retrieving mosquito traps, counting, and identifying mosquitoes.

After identifying the GSI types of most interest to the city, principal investigators and student interns selected both basins and curb cuts along their daily travel routes. The GSI types were confirmed by the lead investigator. During the monsoon, the region's rainiest season, students visited their sites as soon as possible after each rain event from June to October. Sites were visited and data collected until no water was present at the site. If water was available, attempts were made to collect a sample of immature mosquitoes using standard mosquito dippers. Samples were returned to the laboratory and larvae identified to species using light microscopy. Identification, environmental, and mosquito data were entered using REDCap (Research Electronic Data

Capture; Vanderbilt University, Nashville, TN) using personal devices (Supplemental Material). Summary statistics were calculated using Stata v15 (StataCorp LLC, College Station, TX).

Tucson recorded 7.02 inches of rain, approximately 1 inch more than average, during the 2018 monsoon season, making it the 37th wettest on record. It was also the 4th warmest year on record, with an average temperature of 71.8°F and 71 days reaching at least 100°F. A total of 28 GSI sites were visited 212 times in 2018, with 63% of the visits to basins (134 visits to 12 sites), 34% of visits to curb cuts (73 visits to 15 sites), and 2% of visits to a bioswale (5 visits to 1 site). While curb cuts were the most common type of GSI sampled, there was water during only one visit. One basin (Fig. 2) consistently retained water 2–9 days after a rain event (mean: 3.3 days, SD: 2.3 days). This site was assessed 27 times over the 2018 study period and was the only positive site for mosquito larvae, specifically, *Culex quinquefasciatus* Say.

Cities are turning to GSI to improve the health and adapt for the changing climate by reducing flooding, utilizing rainwater, and mitigating heat. Climate resilience is more than infrastructure, it is also the social phenomena that underlie its successful imple-



Fig. 2. Images of the green stormwater infrastructure sampled in 2018: 6 days post-rain event of the basin that retained water and produced mosquito larvae (left 6 images) and 2 examples of curb cuts that did not retain water (right 2 images).

mentation (Staddon et al. 2018). Successful implementation of an urban greening initiative requires collective responsibility by all concerned parties (Paul et al. 2014).

Tucson, a hot and semiarid urban environment in a region with a history of climate extremes, serves as an example of adaptations for climate change with its increasing support for the installation of GSI (Gerlak et al. 2021). We found that, even in a semiarid urban environment, retention basins can inadvertently result in mosquito breeding. This reinforces the need for incorporating knowledge of vector ecology into the design, construction, and maintenance of GSI to avoid the maladaptation of mosquito breeding (Gingrich et al. 2006, Jackson et al. 2009) and postconstruction structural or managerial changes may be required for existing sites where mosquitoes are found (Metzger et al. 2018).

Building a climate-ready future requires new interdisciplinary work (Mustelin et al. 2013). This project included student interns from diverse disciplines and engaged vector control, health department, and urban planners. The model has also been successfully used elsewhere, including researchers in Montana recently reporting on the benefits of incorporating vector control as an experiential learning experience that has been successful at supporting vector surveillance capacity (Hokit et al. 2013). This project shows the potential for better integrating students into vector control activities to broaden the reach of vector control and also engaging students in climate change research.

We found that larger basins, even in a semiarid urban environment, may be maladaptive and can become suitable mosquito breeding habitats. In contrast, curb cuts and small basins designed to drain within 12 h (Phillips 2005) presented no mosquito production issues for rainwater harvesting. The GSI design, construction, and maintenance can benefit from an interdisciplinary approach that includes vector control considerations. The GSI can be a tool to address climate change effects of increasing drought, flooding, and extreme heat. Our findings support ensuring that GSI does not unintentionally become a maladaptation and increase mosquito breeding habitats.

This work was supported in part by the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessments (RISA) program through grant NA17OAR4310288 with the Climate Assessment for the Southwest program at the University of Arizona. HEB and LK acknowledge funding support from the Pacific Southwest Regional Center of Excellence for Vector-Borne Diseases funded by the US Centers for Disease Control and Prevention (Cooperative Agreement 1U01CK000516).

REFERENCES CITED

- Barnett J, O'Neill S. 2010. Maladaptation. *Glob Environ Change* 20:211–213.
- Boelee E, Yohannes M, Poda JN, McCartney M, Cecchi P, Kibret S, Hagos F, Laamrani H. 2013. Options for water storage and rainwater harvesting to improve health and

- resilience against climate change in Africa. *Reg Environ Change* 13:509–519.
- Davis S. 2021 May 14. *Tucson experiences first 100-degree day Thursday* [Internet]. Tucson, AZ: Tucson.com [accessed July 31, 2021]. Available from: https://tucson.com/news/local/tucson-experiences-first-100-degree-day-thursday/article_1ab361b6-b419-11eb-a850-1bf3800b8c77.html.
- Demuzere M, Orru K, Heidrich O, Olazabal E, Geneletti D, Orru H, Bhawe AG, Mittal N, Feliu E, Faehnle M. 2014. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. *J Environ Manage* 146:107–115.
- Gerlak AK, Elder A, Pavao-Zuckerman M, Zuniga-Teran A, Sanderford AR. 2021. Agency and governance in green infrastructure policy adoption and change. *J Environ Policy Plan* 23:599–615.
- Gingrich JB, Anderson R, Williams G, O'Connor L, Harkins K. 2006. Stormwater ponds, constructed wetlands, and other best management practices as potential breeding sites for West Nile virus vectors in Delaware during 2004. *J Am Mosq Control Assoc* 22:282–291.
- Golden HE, Hoghooghi N. 2018. Green infrastructure and its catchment-scale effects: an emerging science. *Interdiscip Rev Water* 5:e1254.
- Hokit G, Alvey S, Geiger JMO, Johnson GD, Rolston MG, Kinsey DT, Tall Bear N. 2013. Using undergraduate researchers to build vector and West Nile virus surveillance capacity. *Int J Environ Res Public Health* 10:3192–3202.
- Jackson MJ, Gow JL, Evelyn MJ, Meikleham NE, McMahon TJS, Koga E, Howay TJ, Wang L, Yan E. 2009. *Culex* mosquitoes, West Nile virus, and the application of innovative management in the design and management of stormwater retention ponds in Canada. *Water Qual Res J* 44:103–110.
- Juhola S, Glaas E, Linnér BO, Neset TS. 2016. Redefining maladaptation. *Environ Sci Policy* 55:135–140.
- Löhmus M, Balbus J. 2015. Making green infrastructure healthier infrastructure. *Infect Ecol Epidemiol* 5:30082.
- MacAdam J. 2012. *Green Infrastructure for southwestern neighborhoods* [Internet]. 1.2. Syracuse T, Deroussel J, Roach K, eds. 2021. Tucson, AZ: Watershed Management Group [accessed September 6, 2021]. Available from: <http://www.watershedmg.org/green-streets>.
- Meerow S, Natarajan M, Krantz D. 2021. Green infrastructure performance in arid and semi-arid urban environments. *Urban Water J* 18:275–285.
- Metzger ME, Harbison JE, Burns JE, Kramer VL, Newton JH, Drews J, Hu R. 2018. Minimizing mosquito larval habitat within roadside stormwater treatment best management practices in southern California through incremental improvements to structure. *Ecol Eng* 110:185–191.
- Mustelin J, Kuruppu N, Kramer AM, Daron J, de Bruin K, Noriega AG. 2013. Climate adaptation research for the next generation. *Clim Dev* 5:189–193.
- Nieuwenhuijsen MJ. 2021. Green infrastructure and health. *Annu Rev Public Health* 42:317–328.
- Paul A, Downton PF, Okoli E, Gupta JK, Tirpak M. 2014. Does adding more lettuce make a hamburger truly green? A metaphor behind the green movement paradigm in designing cities. *Environ Syst Decis* 34:373–377.
- Phillips AA, ed. 2005. *Water harvesting guidance manual City of Tucson* [Internet]. Tucson, AZ: City of Tucson [accessed February 16, 2022]. Available from: <https://www.tucsonaz.gov/files/water/docs/Water-Harvesting-manual.pdf>.
- Staddon C, Ward S, De Vito L, Zuniga-Teran A, Gerlak AK, Schoeman Y, Hart A, Booth G. 2018. Contributions of green infrastructure to enhancing urban resilience. *Environ Syst Decis* 38(3):330–338.
- Witcher TR. 2021 Jun 10. Arizona city pilots small green infrastructure projects. *Civ Eng Source* [Internet] [accessed September 16, 2021]. Available from: <https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/article/2021/06/arizona-city-pilots-small-green-infrastructure-projects>.