Evaluating Urban Ecological Infrastructure for Stormwater Management in Phoenix, AZ

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Long-Term Ecological Research
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Introduction & Background Information

Urban ecological infrastructure (UEI) is an inclusive term that encapsulates all infrastructure within an urban setting that exhibits ecological structure or function[1]. Because UEI is inherently more resilient and adaptable than traditional gray infrastructure, it is of interest to urban ecologists, city planners, landscape architects, engineers, and other stakeholders involved in designing, implementing, and maintaining urban infrastructure. Enhancing urban resilience is especially important in the face of climate change.

In 2017, ASU redesigned a portion of its Tempe campus, Orange Mall, to include bioretention basins for stormwater management[4]. This UEI provided us the opportunity to understand its ecohydrological impacts on the surrounding areas and the challenges of implementing and maintaining such infrastructure. Additionally, the location of the bioswales in an arid climate presents unique challenges and opportunities[3]. The functionality of stormwater UEI presents a valuable research opportunity as UEI becomes a more popular approach to stormwater management in the Phoenix area, throughout the state of Arizona, and across the United States[2,3]. This project assessed the stormwater runoff quality improvement and retention capability of a small-scale bioretention basin system utilizing xeric landscaping in the hopes that it may inform stormwater UEI design and implementation in arid regions and beyond.

Methods

This project utilized five ISCO 6712 automated pump sampler, three Onset HOBO U20L water loggers, and three Onset HOBO 10HS soil moisture probes[4]. The five ISCO samplers throughout the study site were set to automatically collect stormwater samples when at least 3 cm of water was detected in the basins (see Figs. 1 and 2). These samples were collected within 24 hours and analyzed for total nitrogen and phosphorus (TN & TP), ammonium (NH_4^+), nitrite (NO_2^-)., nitrate (NO_3^-), and phosphate (PO_4^-).

Precipitation data were obtained from public access sources. Data collected from the water loggers and data collected from the soil moisture probes were used to determine retention capabilities of the basin system. Monitoring of the site began in September 2018 and ended May 2023. We collected data from 12 storm events on the east side and 21 storm events on the west side.

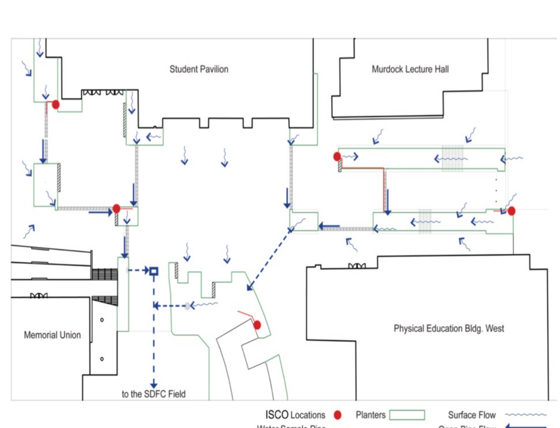

Fig. 1. Aerial map of study site with location of monitoring instruments[4]

Fig. 2. Example of Orange Mall bioswale

Results & Discussion

Overall, the system effectively removed nitrogen constituents from stormwater runoff and prevented flooding within the area for all but four storm events. A percent change analysis of the constituents from inflow to outflow demonstrated that the bioretention basin system significantly reduced nitrogen constituents but was not effective in phosphorus removal (Tables 1 and 2). As nitrogen is the limiting nutrient in Arizona ecosystems, these results indicate that the basins are successful in improving stormwater runoff quality.

Table 1. Percent Change in Analyte Concentration from Inflow to Outflow, East Basin using T-test to Determine Significance (- indicates decreasing concentration and + indicates increasing concentration)

Analyte	Mean (%)	Median (%)	Standard Deviation	Number of Samples	Number of Storm Events	Significant P-values
TN	-3	-17	69	73	12	<0.01 (Sample 1) 0.03 (Sample 2)
TP	161	96	233	97	12	0.08 (Sample 1) 0.03 (Sample 4) 0.03 (Sample 5) 0.03 (Sample 6) 0.01 (Sample 7)
NO_2^-	15	-44	238	67	9	None
NO_3^-	-37	-66	103	67	9	<0.01 (Median) 0.02 (Sample 1) 0.02 (Sample 2) 0.02 (Sample 3) <0.01 (Sample 4) 0.04 (Sample 5)
NH_4^+	-130	-83	280	70	9	<0.01 (Sample 1)
PO_4^+	352	228	513	61	9	0.04 (Sample 3) 0.02 (Sample 4) 0.02 (Sample 5)

Table 2. Percent Change in Analyte Concentration from Inflow to Outflow, West Basin using T-test to Determine Significance (- indicates decreasing concentration and + indicates increasing concentration)

Analyte	Mean (%)	Median (%)	Standard Deviation	Number of Samples	Number of Storm Events	Significant P-values
TN	-23	-41	98	170	21	<0.01 (Median) 0.04 (Sample 2) <0.01 (Sample 3) <0.01 (Sample 4) <0.01 (Sample 5) <0.01 (Sample 6) <0.01 (Sample 7) <0.01 (Sample 8)
TP	33	-12	119	205	20	0.01 (Sample 1)
NO_2^-	6	-45	190	120	17	None
NO_3^-	-15	-43	109	131	17	0.02 (Sample 7) <0.01 (Sample 8)
NH_4^+	-11	-41	101	134	17	0.04 (Sample 6) <0.01 (Sample 7) <0.01 (Sample 8) <0.01 (Sample 9)
PO_4^+	172	89	496	141	17	<0.01 (Sample 1) 0.02 (Sample 2) <0.01 (Sample 3) 0.02 (Sample 4) <0.01 (Sample 5) 0.02 (Sample 6) 0.03 (Sample 7)

Even in cases where overall analyte concentration reduced, the actual concentration throughout a storm event may have varied. Analyte concentration may have initially increased at the beginning of a storm event before decreasing at the end of the storm, and vice versa (Fig. 4).

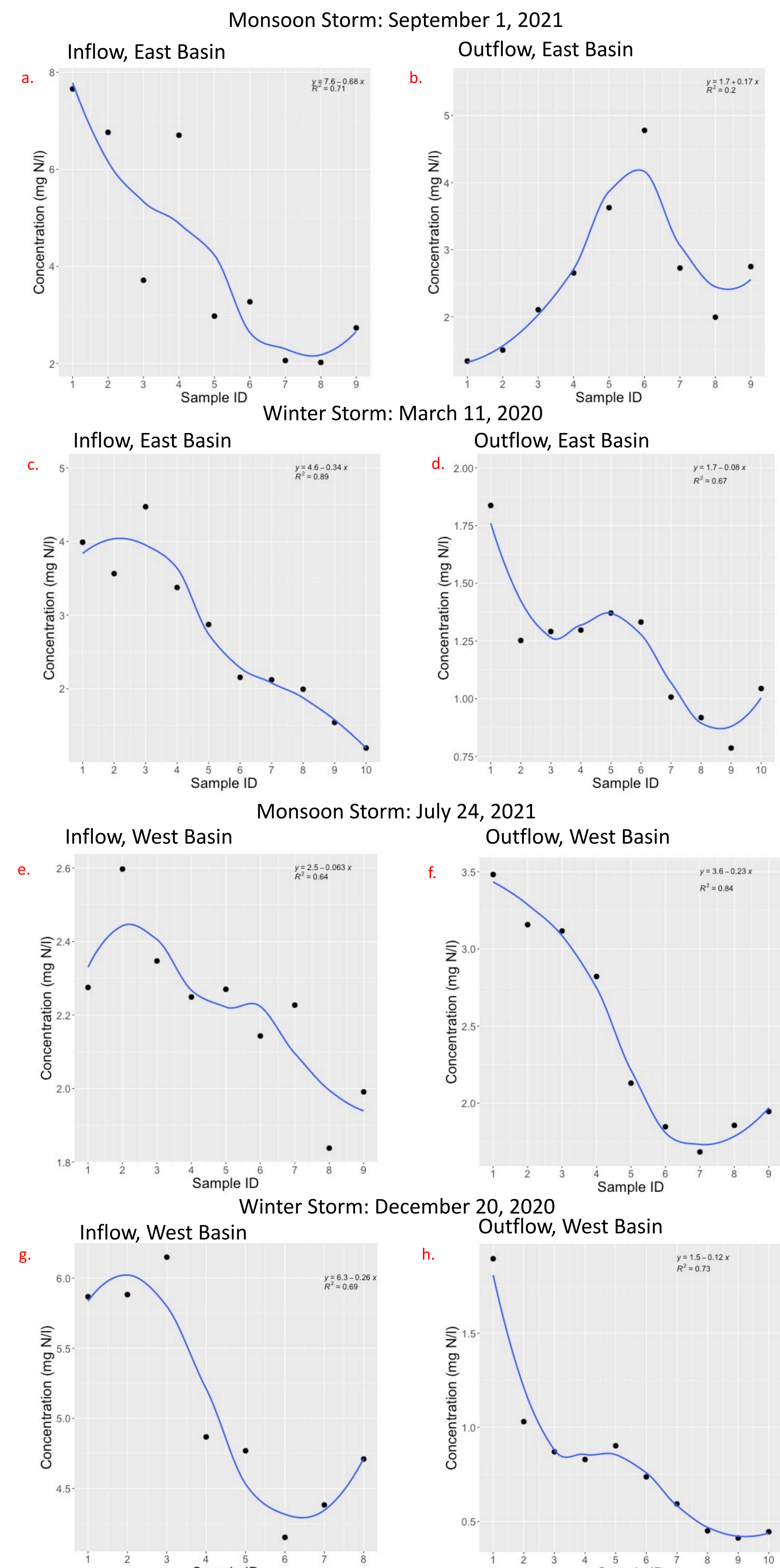

Fig. 4. Concentration of TN at inflow and outflow throughout four storm events

Fig. 3. a) Overflowing basin after heavy precipitation events from July 24-26, 2021. b) Example of water accumulating on impervious surfaces in Orange Mall.

The water loggers recorded four out of twelve storm events in which overflow occurred in the east basin system, which was also observed visually (see Fig. 3). No flooding occurred in the west basin system.

While the basins successfully retained nitrogen constituents across multiple storm events, there were some cases where precipitation amount, intensity, and duration limited or enhanced retention abilities, indicating potential weaknesses and strengths. Soil data indicated that soil water content levels remained elevated for approximately fourteen days after a storm event occurred, which can impact the soils' ability to retain water and nutrients. These findings present opportunities for consideration when designing future bioretention basin systems.

Conclusions

Our findings indicate that UEI is a viable method of stormwater management in arid cities, especially for water quality capabilities. Past research on bioretention basin systems and stormwater UEI more broadly found that land cover type, basin area, soil and vegetation types, and precipitation characteristics may impact the functionality of the system[2]. However, much of this research has been performed in the non-arid environments; more experimental research related to these factors in an arid environment should be carried out to understand the mechanisms and design limitations of stormwater UEI[3].

Beyond stormwater UEI performance, research should focus on stormwater infrastructure policy and education as well. This project includes plans to perform content analysis on stormwater standards and undergraduate engineering curriculum to understand if UEI designs are being incorporated in current and future infrastructure systems.

References

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