Empirical Analysis and HEC-HMS Modeling of Green Stormwater Infrastructure: Stormwater Capture, Ponding, and Infiltration in Urban Tucson

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I. Introduction

- Green Stormwater Infrastructure (GSI) provides an opportunity to mitigate urban flooding while supporting vegetation growth and urban recharge.
- Observational research on GSI however remains limited. GSI systems are complex and highly dependent on local urban heterogeneity.

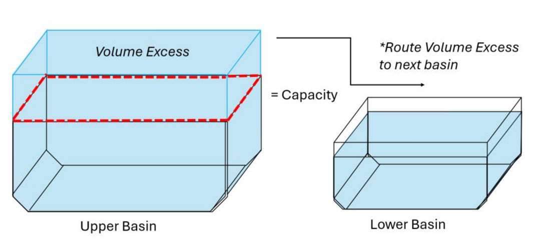
Figure 1 (left): Seneca Park retention basin hours after rainfall. Figure 4 (right): Discharge into Seneca Park during rain event.

- Four GSI sites within Tucson Arizona were investigated, including: Richey Park, Cherry Park, Seneca Park, and Alvernon Park.

Research Objectives: Estimate the stormwater harvested over the study period, investigate GSI infiltration capabilities, and apply HEC-HMS to small scale urban watersheds.

II. Methods

- Pressure transducers (PTs) were placed within the basins, collecting time series stage data for a period of over two years. Drone surveys had also been conducted, providing high resolution DEM's for each park. These were used to generate stage-storage functions for each basin.
- A Storage-Routing Model was developed in Python, which converted stage data to storage values. If storage exceeded ponding capacity (the point at the overflow crest), excess storage was routed to the next reservoir. Once routed, volume harvested estimates could be calculated.



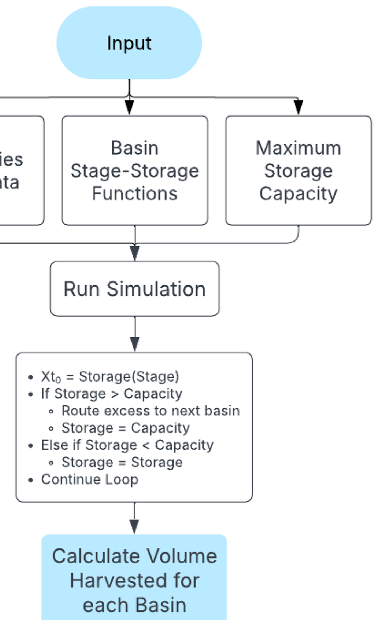
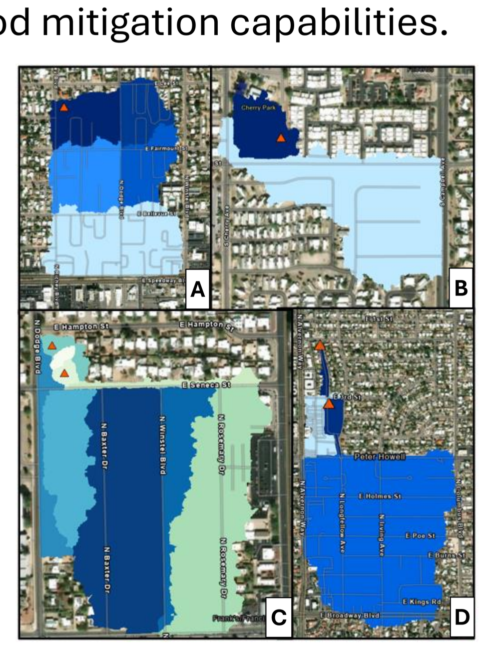


Figure 3 (left): Conceptual figure illustrating rules for basin overflow in model. Figure 4 (right): Workflow for Storage-Routing Model

- HEC-HMS models were then developed to predict GSI response to various design storms, as well as investigate flood mitigation capabilities.
- Basin model development was accelerated with ArcGIS integration, enhancing HEC-HMS's flexibility and enabling its application to small-scale urban-watersheds.
- Runoff generation and hydrograph transformation were modeled using the SCS Curve Number (CN) and SCS Unit Hydrograph method.
- Time-series inputs for model calibration included PT reservoir stage data and rainfall measurements from nearby tipping-bucket rain gauges.



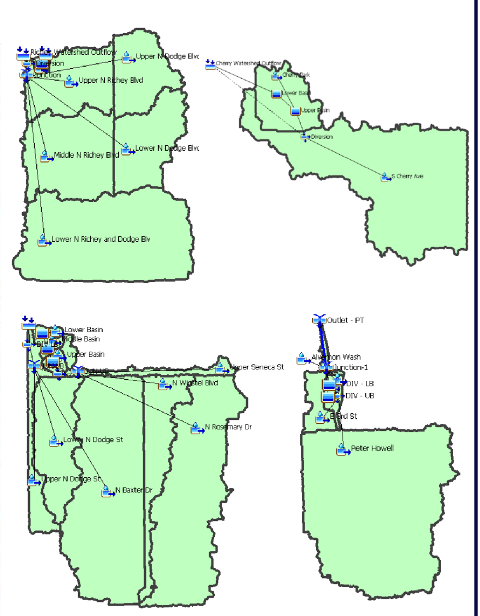


Figure 5 (left, A-D): Watersheds delineated in ArcGIS—A: Richey, B: Cherry, C: Seneca, D: Alvernon. Figure 6 (right): The same watershed shapefiles after import into HEC-HMS.

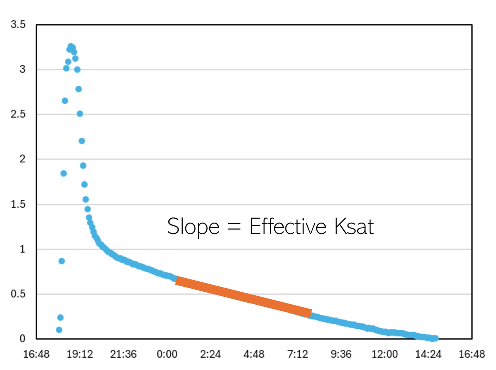


Figure 7 (above): Example of PT drawdown rate used for effective Ksat.

- To monitor GSI infiltration capabilities overtime, the late time drawdown rate of the PT data was collected in response to large rainfall events that covered the entire surface volume of the basin. This rate represents the effective Ksat of the basin, avoiding issues with spatial heterogeneity compared to field measurements.

III. Storage Routing Model Results

- Seneca Park captured the most stormwater compared to the other GSI sites, with a total of 1.39 acre-ft. This is due to Seneca consisting of three retention basins, as well as receiving stormwater into both the upper and lower basins, which has been confirmed from site visits during storm events.
- Richey Park also captured a considerable amount of stormwater. Cherry Park's second lower basin received little to no overflow. Alvernon's PT is located within a channel, thereby it cannot be treated as a reservoir.

GSI Parks	PT Recording Period	Watershed Area	Weighted CN
		mi^2	[]
Richey	7/23/2022 - 4/22/2024	0.083	92.8
Cherry	3/1/2023 - 9/4/2024	0.027	94.0
Seneca	7/1/2022 - 2/10/2024	0.053	91.6
Alvernon	7/1/2022 - 7/22/2023	0.255	91.9

GSI Parks	Total Volume Harvested Estimate [acre-ft]
Richey	0.6
Cherry	0.2
Cherry - LB	0.0
Seneca - UB	0.53
Seneca - MB	0.20
Seneca - LB	0.66
Seneca - Total	1.39
Alvernon	N/A

Figure 8 (left): List of GSI sites and characteristics of the watersheds, as well as the PT recording period. Figure 9 (right): Python output for total stormwater harvested over the recording period estimate for each basin.

IV. HEC-HMS Model Calibration

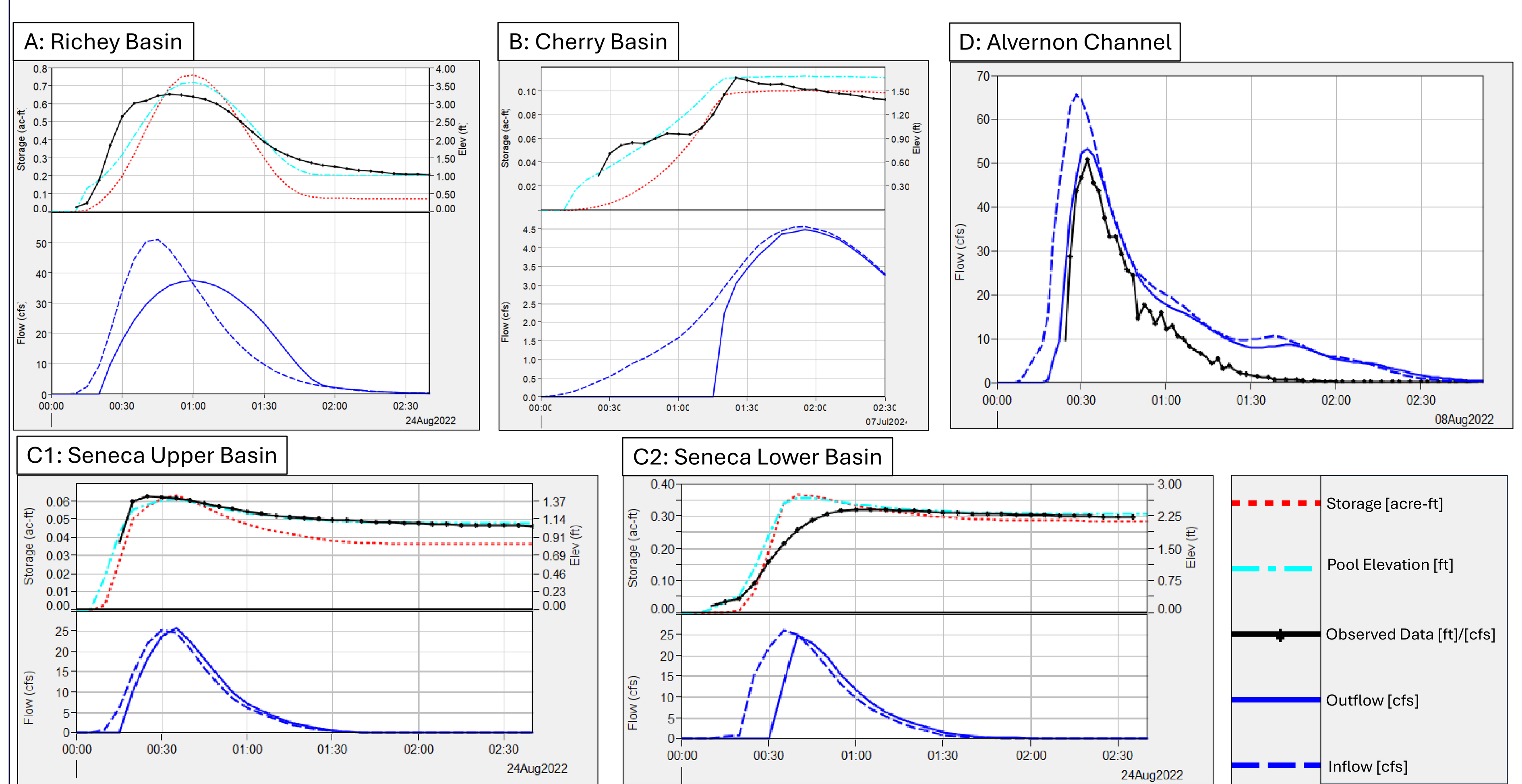


Figure 10 (above, A-D): Comparison of the predicted HEC-HMS reservoir elevation to large storm events from the rain-gage data versus the observed stage from the PT data. For Alvernon, the PT stage was converted to channel discharge using triangular channel equations. Figure 11 (right): Goodness of fit metrics for calibration results. Model Calibration is still undergoing.

GSI Site:	RMSE Std Dev	Percent Bias	Nash-Sutcliffe
Richey Park	0.4	-4.73%	0.857
Cherry Park	0.6	10.02%	0.693
Seneca Park - UB	0.3	-0.14%	0.906
Seneca Park - LB	0.4	8.09%	0.824
Alvernon Park	0.4	57.59%	0.827

V. HEC-HMS Model Results

100 Year 1-Hour Storm/5-min Intensity Duration								
GSI Site:	Richey	Cherry - UB	Cherry - LB	Seneca - UB	Seneca - MB	Seneca - LB	Alvernon - UB	Alvernon - LB
Peak Inflow [CFS]	131.6	22.1	22	61.8	62	64.6	289.5	48.3
Peak Discharge [CFS]	131.5	22	21.9	61.8	62	63.9	291.2	48
Inflow Volume [acre-ft]	8	2.6	2.5	2.6	2.6	2.8	11.7	2
Discharge Volume [acre-ft]	7.9	2.5	2.4	2.5	2.5	2.5	11.4	1.9
Peak Elevation [ft]	4	1.8	2.2	1.6	1.6	3	3.2	2.9
Peak Storage [acre-ft]	0.9	0.1	0.1	0.1	0.1	0.4	0.4	0.2
Time to peak Inflow [hrs]	0.93	1.48	1.48	0.75	0.77	0.77	0.78	0.78

100 Year 24-Hour Storm/6-hour Intensity Duration								
GSI Site:	Richey	Cherry - UB	Cherry - LB	Seneca - UB	Seneca - MB	Seneca - LB	Alvernon - UB	Alvernon - LB
Peak Inflow [CFS]	26.6	8.6	8.5	7.8	7.9	9	51.4	8.6
Peak Discharge [CFS]	26.5	8.5	8.4	7.8	7.9	9	51.4	8.6
Inflow Volume [acre-ft]	13.9	4.5	4.2	4.3	3.35	4.7	22.7	3.8
Discharge Volume [acre-ft]	13.7	4.2	4	4.2	3.3	4.4	22.6	3.7
Peak Elevation [ft]	2.3	1.7	2.1	1.2	1.3	2.5	2.9	2.2
Peak Storage [acre-ft]	0.4	0.1	0.1	0.05	0.1	0.3	0.3	0.1
Time to peak Inflow [hrs]	15	15	15	15	15	15	15.00	15.00

Figure 12 (top): Results for a short-duration, high-intensity storm event. Extreme peak inflow, discharge, elevation, and storage values are predicted, as expected for such conditions. Figure 13 (bottom): Results for a long-duration, lower-intensity storm event. Although every basin exceeds its crest elevation, peak elevation remains lower, for many staying within the basin's maximum capacity.

- Two types of 100-Year events have been simulated:
- 100-Year 1-Hour Storm/5-min Intensity
  - This is a short, very intense event which will lead to runoff almost immediately.
- 100-Year 24-Hour Storm/6-hour Intensity
  - This is a longer, less intense event which over time will lead to runoff as precipitation exceeds soil moisture capacity.

VI. Infiltration Rate Analysis

A: Richey Basin

Event Date	Peak Stage	Effective Ksat
-	[ft]	[ft/day]
7/23/2022	1.87	1.5
8/8/2022	3.28	2.0
8/24/2022	3.26	1.6
10/5/2022	1.93	1.8
1/17/2023	3.43	1.9
7/17/2023	2.54	1.8
7/31/2023	2.28	1.4
1/23/2024	0.69	1.4

B: Cherry Basin

Event Date	Peak Stage	Effective Ksat
-	[ft]	[ft/day]
6/21/2024	0.62	3.2
6/28/2024	1.62	2.0
7/25/2025	1.66	2.0

C2: Seneca Lower Basin

Event Date	Peak Stage	Effective Ksat
-	[ft]	[ft/day]
7/23/2022	0.92	1.1
8/8/2022	0.76	1.0
8/24/2022	2.40	0.9
1/18/2023	1.39	0.9
7/18/2023	1.48	0.9

C1: Seneca Upper Basin

Event Date	Peak Stage	Effective Ksat
-	[ft]	[ft/day]
7/1/2022	1.22	1.4
7/23/2022	1.53	1.7
8/8/2022	1.43	0.8
8/24/2022	1.44	0.6
9/12/2022	0.60	1.0
10/5/2022	1.19	1.9
1/17/2023	1.26	0.8
5/16/2023	0.95	1.0
7/17/2023	1.39	0.8
7/28/2023	1.39	1.2
7/31/2023	0.85	0.8
1/24/2024	1.18	1.1
2/6/2024	0.55	0.9

Figure 14 (above, A-C): Table of collected effective Ksat values.

- Results indicate a potential decrease in effective Ksat over time in certain basins. However, significant reductions in infiltration abilities are not expected over such a short duration.
- While the results are inconclusive, this analysis method can reduce the time required for field testing if sufficient data is available.

VIII. Conclusions

- Observational data indicated that the GSI sites under investigation capture a significant amount of stormwater.
- HEC-HMS integration with ArcGIS enabled its application to small-scale urban watersheds.
- HEC-HMS's flexibility makes it well-suited for modeling complex GSI sites, where local-scale heterogeneity (e.g., roads, buildings, drainage infrastructure) plays a significant role.
- HEC-HMS simulations demonstrated that GSI response to large storm events is highly influenced by storm intensity—overloading these sites rapidly can quickly exceed their design capacity.
- While infiltration rate analysis results were mostly inconclusive, this method offers a relatively quick way to estimate a representative saturated hydraulic conductivity for an entire basin.
  - Increased efficiency can improve monitoring efforts as well as decrease field time.

VII. References

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