Integrating Social Equity into Multi-Objective Optimization for Urban Low Impact Development

Robert Seth Herbst[1] ,Teresa Culver[1],Lawrence Band[1,2]

1. Department of Engineering Systems and Environment, University of Virginia, Charlottesville, Virginia
2. Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia

Introduction

- Increasing access to stormwater low impact development (LID) and other green infrastructure in underserved areas is a prominent environmental justice issue and becoming an important priority in the planning of future locations for urban LIDs.[1,2,3]
- Race is a major predictor of environmental inequity in the US, as black and other minority groups have historically been intentionally disenfranchised from neighborhood investment, the infrastructure planning processes, and other arenas of public decision making.[4]
- This has led to great disparities in the distribution of LIDs and other green infrastructure within cities.
- LIDs can provide a range of other benefits outside the scope of hydrologic and ecologic improvements that are pertinent to public health. LIDs can contribute to the beautification of urban environments often associated with improved mental health.[5,6]

Methods

- A genetic algorithm was developed and used to identify near-optimal locations, types, and sizes of stormwater LIDs to minimize peak flow and total runoff production, while maximizing implementation in more marginalized communities.
- The specially formulated genetic algorithm was linked to the stormwater management model (SWMM) application programming interfaces (PySWMM[7] and SWMMIO[8]) to discover near optimal locations, types, and sizes of LIDs for the Meadow Creek Watershed.
- Presented LID optimization results are based on a single design storm (SCS type II 24-hr 1 inch) simulated in SWMM.

Creating a social equity index for the Meadow Creek Subbasins

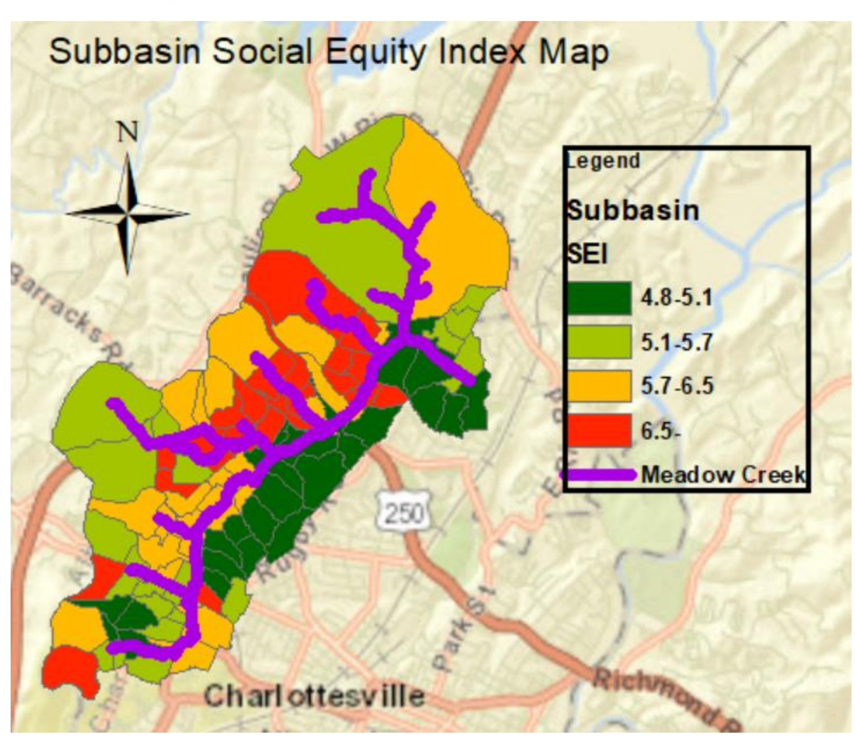
- Geospatial demographic census, landcover, and urban environmental risk data was integrated into a "social equity index" by which each Meadow Creek subbasin was weighted (prioritized) in the algorithm for LID allocation/implementation in SWMM.
- Higher index scores indicate higher levels of marginalization, environmental risk, and need for green infrastructure.

Social Equity Data

- Low Income
- Minority Population
- Over 64
- Under Age 5
- Below High School Education
- Ozone
- PM 2.5
- Traffic Proximity
- Linguistically Isolated
- Stormwater LID Density
- % Impervious
- Tree Canopy

$$SEI_i = \sum_{j}^{k} \frac{\%\, Env\ Indicator_{j,i}}{\max\,(\%Env\ Indicator_j)}$$

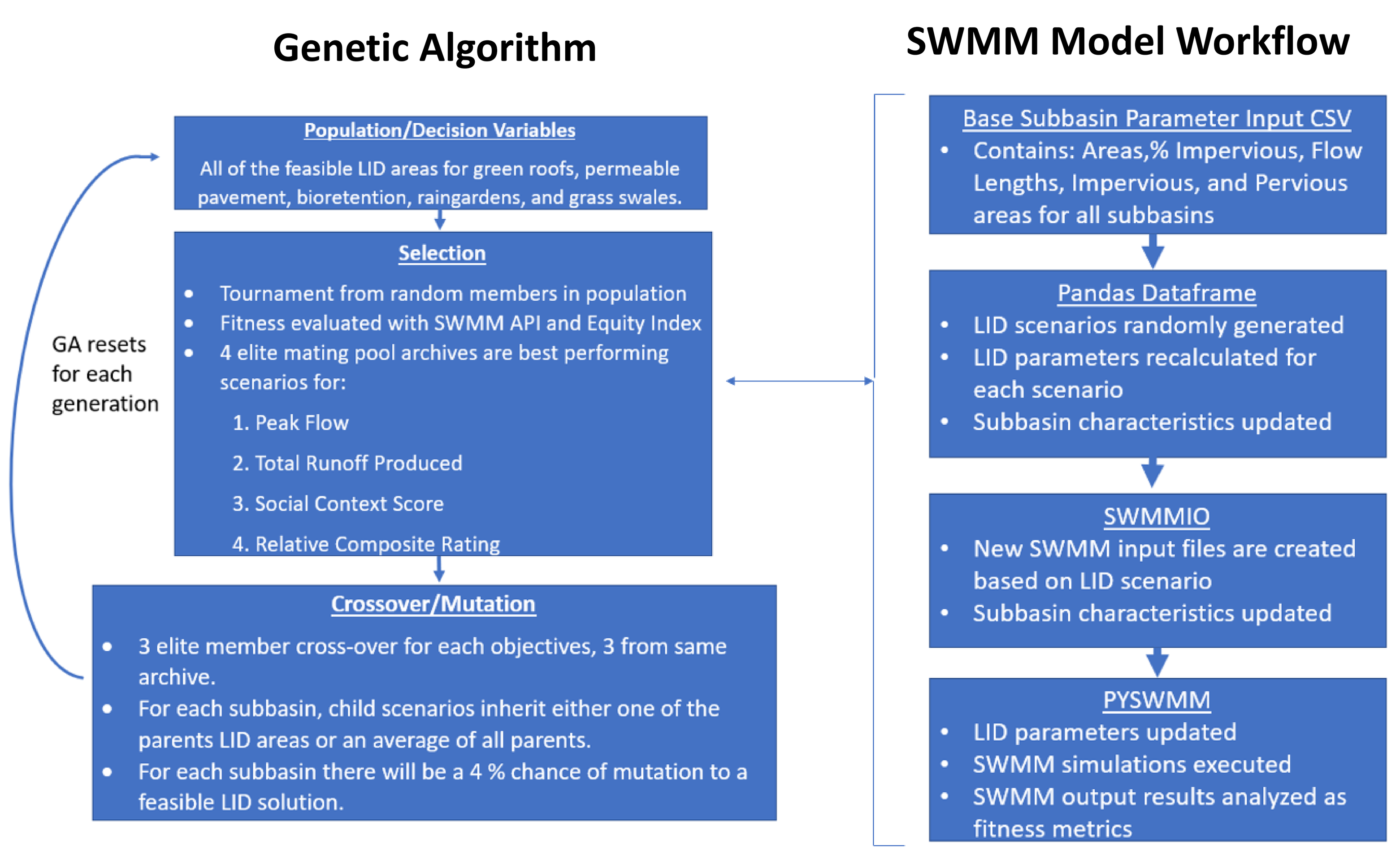
Max SEI_i = 12 (# of indicators)



- Denominator is a min function for last three social equity factors

Coupling a Genetic Algorithm and SWMM

- PYSWMM and SWMMIO allowed for LID scenarios to be rapidly generated and coupled to a genetic algorithm .



Maximizing implementation in marginalized communities and meeting multiple objectives

- Maximize total LID implementation in marginalized communities (written as a minimization summation for uniformity among objective functions):

$$\textit{Social Context Score} = \sum_{i=1}^{n} \frac{\#\ of\ Indicators - SEI_i}{(Allocated\ LID\ Area / Feasible\ LID\ Area)_i} \qquad (1)$$

where SEI_i denotes the social equity index weight for subbasin i.

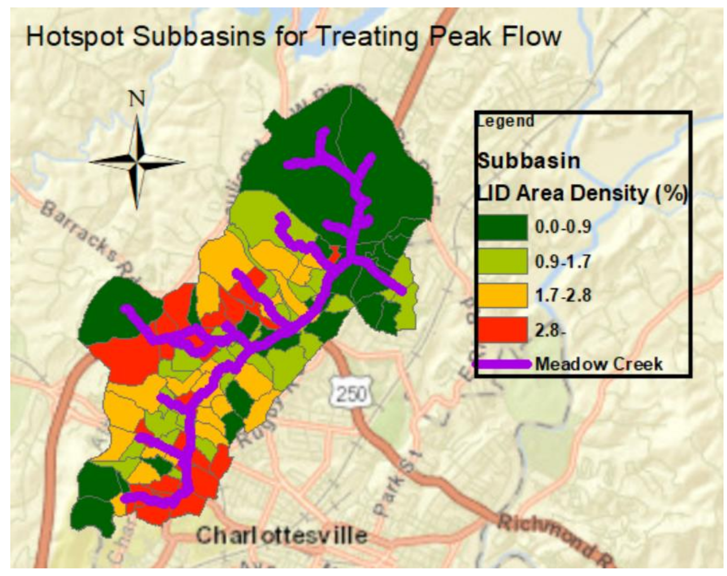
- Achieve a balance between minimizing peak flow, minimizing total runoff, and maximizing stormwater LID allocation in marginalized communities.

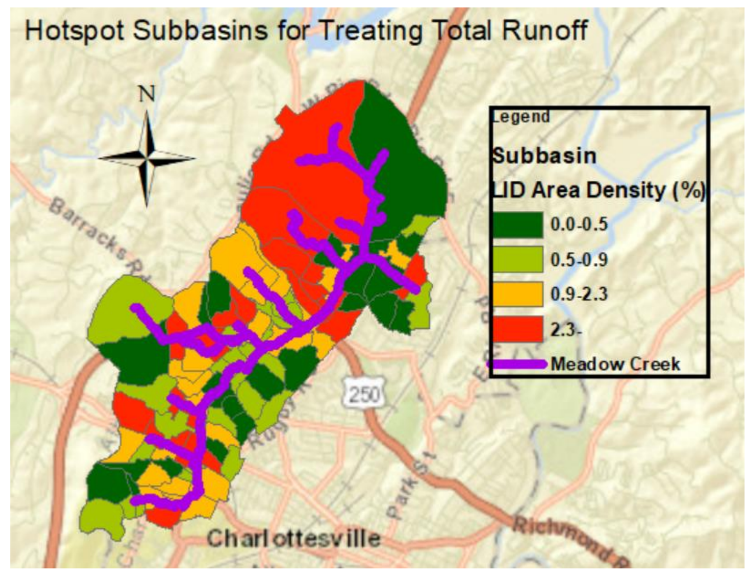
$$\textit{Relative Composite Score} = \frac{A{*}Scenario\ Peak\ Flow}{A{*}Min\ Scenario\ Peak\ Flow} + \frac{B{*}\ Senario\ Total\ Runoff}{B{*}Min\ Scearnio\ Runoff} + \frac{C{*}Scenario\ Social\ Context\ Score}{C{*}Min\ Scenario\ Social\ Context\ Score} \qquad (2)$$

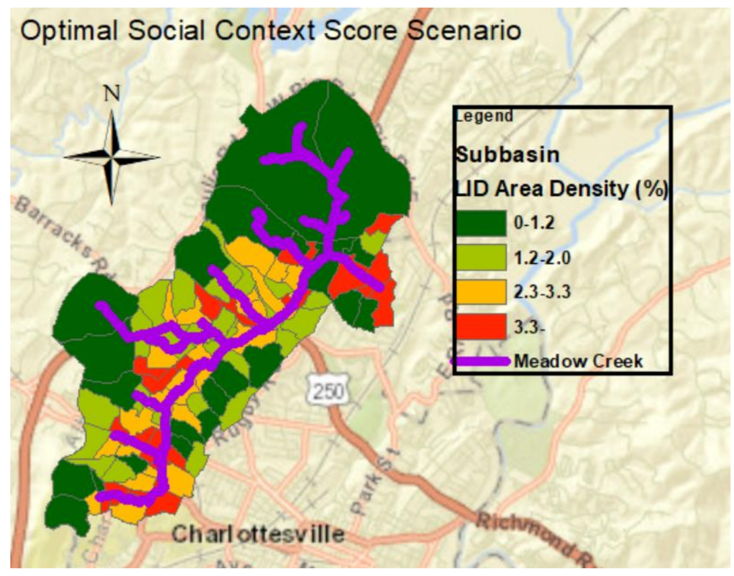
- A, B, and C are weights that determine the relative importance of each objective in the relative composite score.
- In this study, weights were chosen such that each term being summed contributes evenly to the relative composite score.
- The genetic algorithm is designed to discover LID locations, types, and sizes that minimize equation 1 and 2 along with peak flow and total runoff.

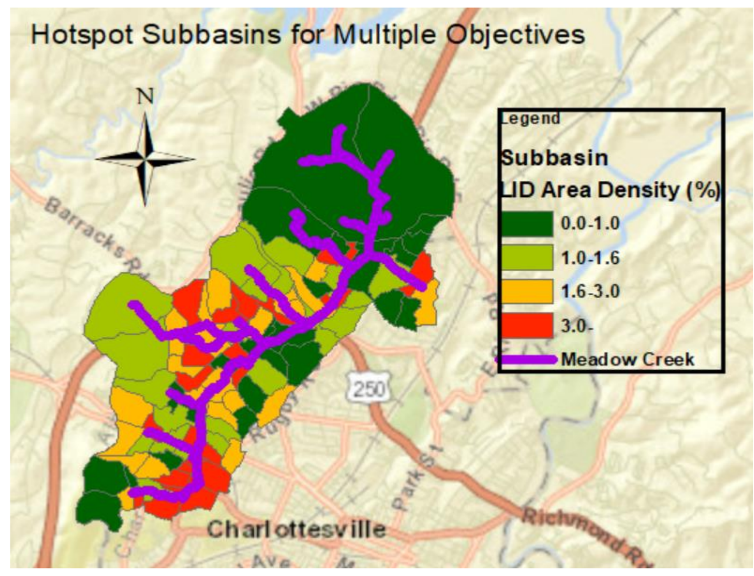
Results

- Results include near-optimal area allocations for all LIDs.
- The below 4 maps show near optimal total LID area allocations to each subbasin for all four objectives- 25 million dollar limit build cost scenario.

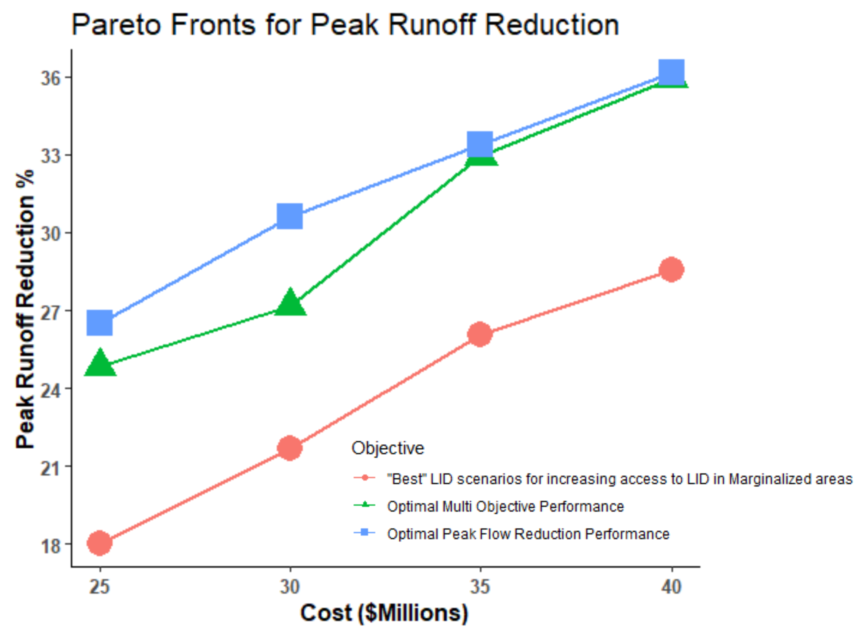


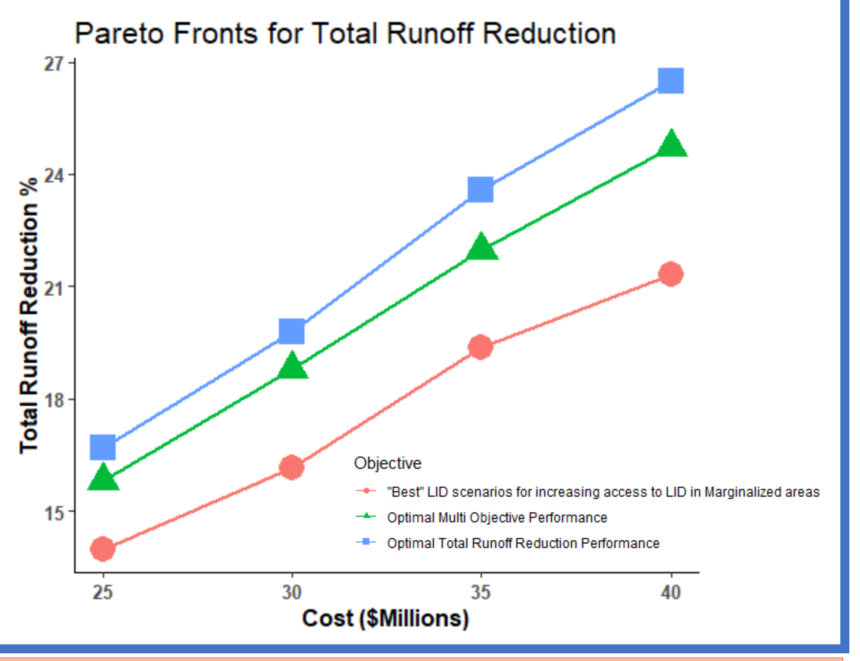






- Pareto optimal fronts allow for a cost benefit analysis and an assessment of tradeoffs across a budget range.





Conclusions

- Optimal LID allocations depends on the objective
- A social equity index can be integrated into a equation 1 or a similar equation to help optimize equitable LID allocations.
- A multi objective function such as equation 2 can be used to discover optimal LID allocations that meet local hydrological and social goals.

References

1. Garcia-Cuerva, L., Berglund, E. Z., & Rivers, L. (2018). An integrated approach to place Green Infrastructure strategies in marginalized communities and evaluate stormwater mitigation. *Journal of Hydrology*, *559*, 648–660. https://doi.org/10.1016/j.jhydrol.2018.02.066
2. Heck, S. (2021). Greening the color line: historicizing water infrastructure redevelopment and environmental justice in the St. Louis metropolitan region. *Journal of Environmental Policy and Planning*. https://doi.org/10.1080/1523908X.2021.1888702
3. Heckert, M., & Rosan, C. D. (2016). Urban Forestry & Urban Greening Developing a green infrastructure equity index to promote equity planning ☆. *Urban Forestry & Urban Greening*, *19*, 263–270. https://doi.org/10.1016/j.ufug.2015.12.011
4. Wright, W. J. (2021). As Above, So Below: Anti-Black Violence as Environmental Racism. Antipode, 53(3), 791–809. https://doi.org/10.1111/anti.12425
5. Kondo, M. C., Low, S. C., Henning, J., & Branas, C. C. (2015). The Impact of Green Stormwater Infrastructure Installation on Surrounding Health and Safety. 105(3), 114–121. https://doi.org/10.2105/AJPH.2014.302314
6. Roe, J. J., Ward Thompson, C., Aspinall, P. A., Brewer, M. J., Duff, E. I., Miller, D., Mitchell, R., & Clow, A. (2013). Green space and stress: Evidence from cortisol measures in deprived urban communities. International Journal of Environmental Research and Public Health, 10(9), 4086–4103. https://doi.org/10.3390/ijerph10094086
7. McDonnell, Bryant E., Ratliff, Katherine M., Tryby, Michael E., Wu, Jennifer Jia Xin, & Mullapudi, Abhiram. (2020, April 14). PySWMM: The Python Interface to Stormwater Management Model (SWMM). Zenodo. http://doi.org/10.5281/zenodo.3751574
8. Erispaha, Adam (2021). *SWMMIO* version 0.4.8. MIT LICENSE.https://pypi.org/project/swmmio/