Modeling Linkages Between Effective Impervious Surface and Urban Vegetation Productivity in Semi-arid Environments

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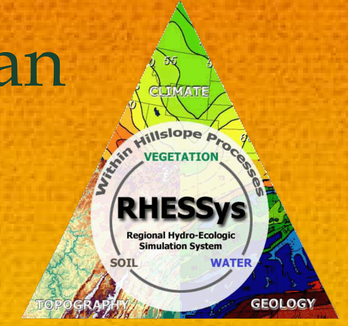


Urban areas, vegetation, and semi-arid environments

Urban areas are home to an increasing portion of the world's population, their structure and function have the potential for a large impact on both environmental and human well-being despite the small land areas they occupy. Urban vegetation can provide benefits such as aesthetic value, shade, cooling, erosion control, and potential uptake and retention of nutrients such as nitrogen (N).

In semi-arid environments, the benefits of vegetation must be weighed against the cost of providing the water needed to maintain productivity. As populations expand, demands on water increase, and irrigation can become an increasingly unsustainable practice. Maximizing vegetation productivity while minimizing irrigation inputs is therefore a priority. We use an ecohydrologic model (RHESSys) to explore the impacts of connections between impervious surface and vegetation on productivity.


photo: inhabitat.com

Landscape patchiness in natural and urban environments

Natural Environments

- ✧Landscape heterogeneity and patchiness are linked to ecosystem productivity
- ✧Runoff from bare patches can be routed to vegetation, boosting productivity
- ✧Connectivity of bare and vegetated patches can be more important than total vegetated area (Bautista *et al* 2007)


Mission Creek catchment near Rocky Nook Park

Urban environments

- ✧Also highly heterogeneous, mix of vegetated and bare (impervious) surfaces)
- ✧Patches are engineered by humans rather than by natural conditions
- ✧Precipitation is augmented by irrigation

How does connectivity in the urban environment affect productivity?

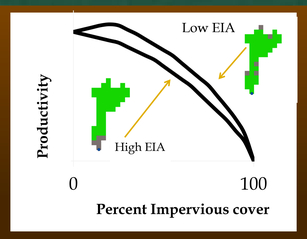
Total vs. Effective Impervious Surface

Total impervious area (TIA): any surface through which water cannot infiltrate

Effective impervious area (EIA): impervious surfaces with a direct hydrologic connection to the stream.

Questions and hypotheses

- What is the influence of effective impervious area (EIA) compared to total impervious area (TIA) on vegetation productivity?
- Does lowering EIA compensate for increasing TIA?
- We hypothesize that increasing EIA as a fraction of TIA can mitigate negative impacts of increasing TIA.



RHESSys model

- ✧Spatially distributed ecohydrologic model
  - ✧Accounts for *where* as well as *how much is input and how much is used*
- ✧Catchment is divided into patches based on elevation
- ✧Water moves both vertically and laterally through the catchment
- ✧In this application, five calibrated parameters

Two shallow subsurface flow parameters

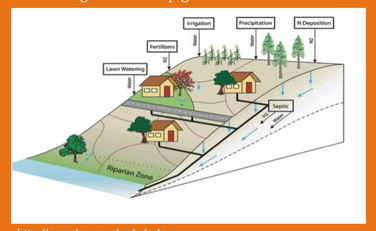
k: saturated hydraulic conductivity *m*: decay of *k* with depth

Three parameters to define bypass flow and ground water drainage rate

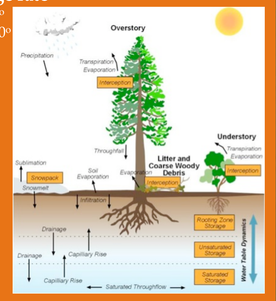
$GW1_{steep}$: fraction of precipitation automatically routed to groundwater, slope>20°

$GW1_{shallow}$: fraction of precipitation automatically routed to groundwater, slope<20°

GW2: drainage rate of deep groundwater to stream

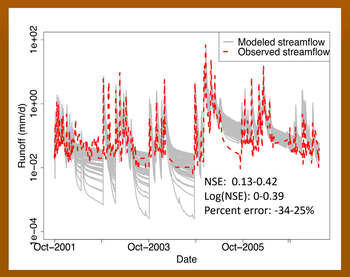


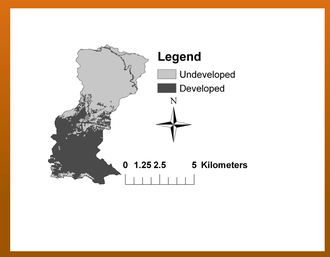
http://www.bren.ucsb.edu/~rhessys



Study site: Mission Creek catchment

- •Located in Santa Barbara, CA
- •Has been steadily urbanizing over the past century
  - •Urbanization has been shown to affect streamflow (*Beighley, et al.*)
- •Semi-arid climate (~500 mm/yr rainfall)
- •Model has been calibrated for the catchment

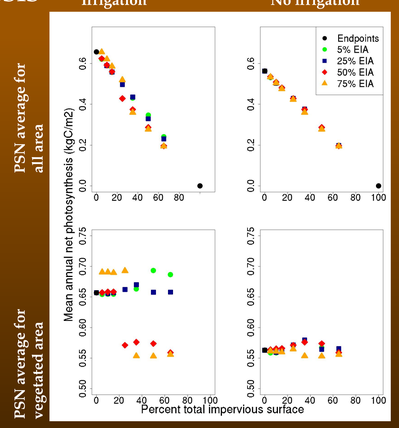




- •We use a small (~0.5 km²) hillslope to evaluate the role of TIA
- •Generate a range of TIA and EIA scenarios
  - •5-65% TIA
  - •5-75% of TIA classed as EIA
- •Irrigated and non-irrigated lawn vegetation
- •Does the model show an EIA effect?

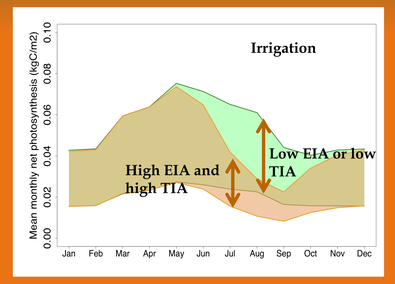
Results: annual photosynthesis

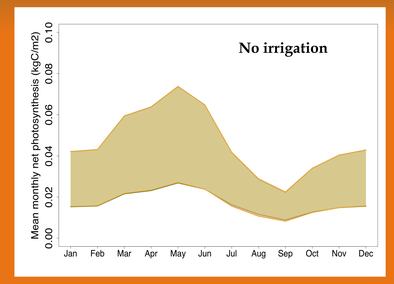
- •Increasing impervious surface decreases photosynthesis
- •Irrigated scenarios show more variability between EIA levels, lowest PSN for high TIA/high EIA scenarios
- •Declines in photosynthesis largely due to decrease in vegetated area, lower EIA appears to slightly offset impact of increased TIA
- •When PSN is calculated per unit vegetated area irrigation does not increase PSN for high EIA/high TIA scenarios.



Results: seasonal trends

With irrigation, not all scenarios show sharp summer PSN decline
Sustained summer PSN in lower (5,25%) EIA scenarios, and for lower TIA values in high EIA scenarios
No separation of summer PSN trend evident without irrigation





EIA and irrigation effectiveness

Why do higher EIA scenarios not see a consistent irrigation PSN boost?

- ✧Higher EIA = faster routing of water out of the hillslope
- ✧Less water stored during rainy season
- ✧Without irrigation, water stores are too low to sustain high summer PSN, regardless of EIA fraction
- ✧With current average irrigation inputs, sustained summer PSN is possible if water stores from precipitation are maximized (low EIA), otherwise (high EIA), they are too far below critical threshold for a summer PSN boost to be realized
- ✧Future simulations will vary irrigation inputs to quantify the difference in irrigation inputs required to sustain summer PSN under low and high EIA scenarios.

Other factors may be at play

- ✧No obvious EIA effect at lower levels of TIA
- ✧Specific spatial location of impervious surface seems most likely variable unaccounted for
  - ✧With less TIA, more opportunity for spatial variability in placement
  - ✧Opportunity for variability declines as TIA increases, EIA effect more noticeable
  - ✧Controlling more strictly for location of all impervious surface or creating several different impervious surface layouts for each EIA/TIA combination could help to isolate the contributions of specific geographic location to modeled productivity.

Conclusions

- ✧While TIA is a key control on total system productivity, its influence is largely due to total decline in vegetated area
- ✧Decreasing EIA may increase effectiveness of management practices such as irrigation
- ✧Multiple factors likely contribute to productivity of urban vegetation

References

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Acknowledgements

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