The i-Tree Cool River Model to Guide Restoration of Thermal Pollution with Riparian Forests & Nature-Based Solutions

Section - Vegetation Benefits: Environmental and Social Benefits

Workshop - Vegetation On Levees: Information, Data, and Approaches to Inform Best Practices

Coordinator - US Army Corps of Engineering

Date & Location - May 2-3, 2023, Arlington, Virginia

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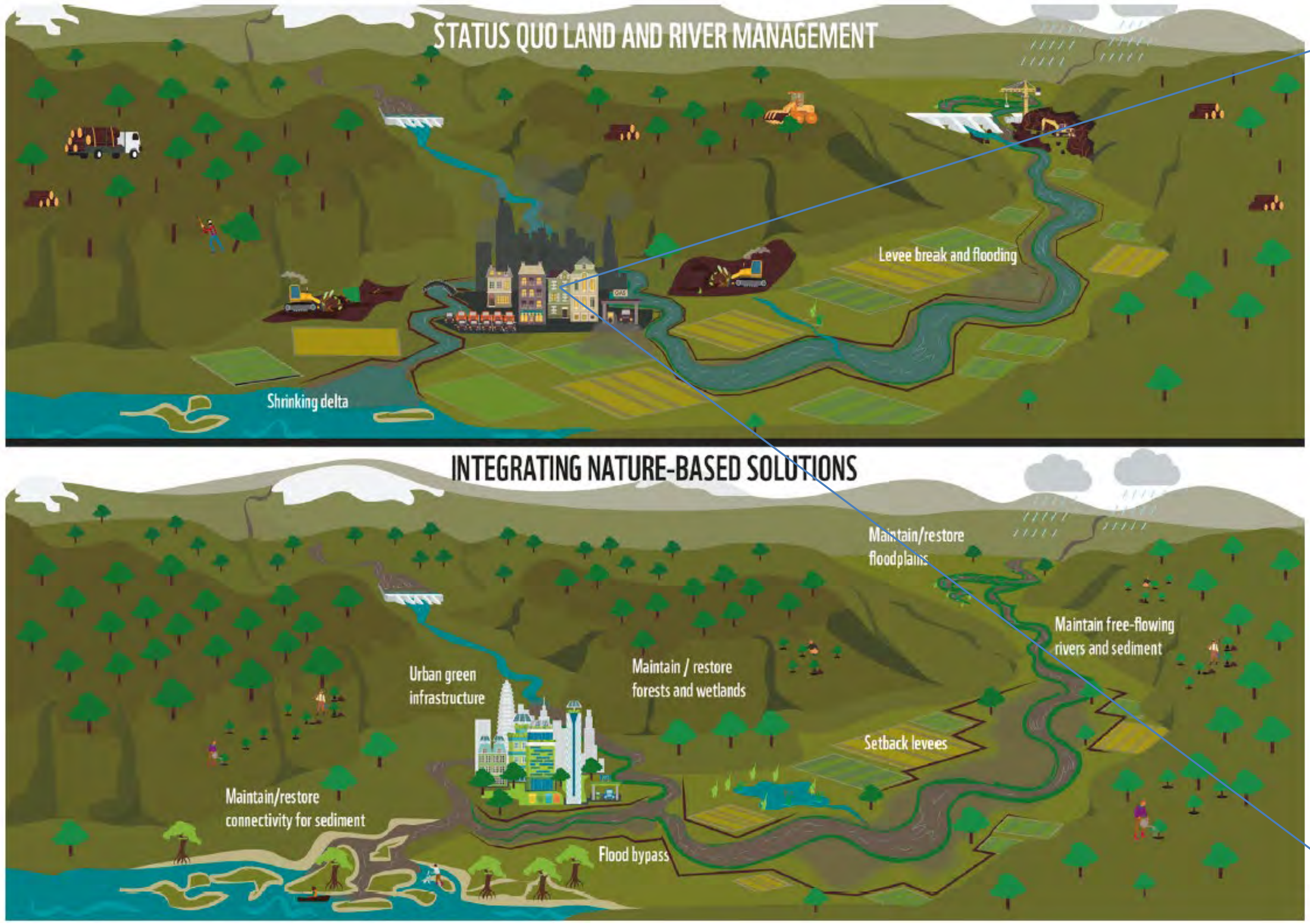
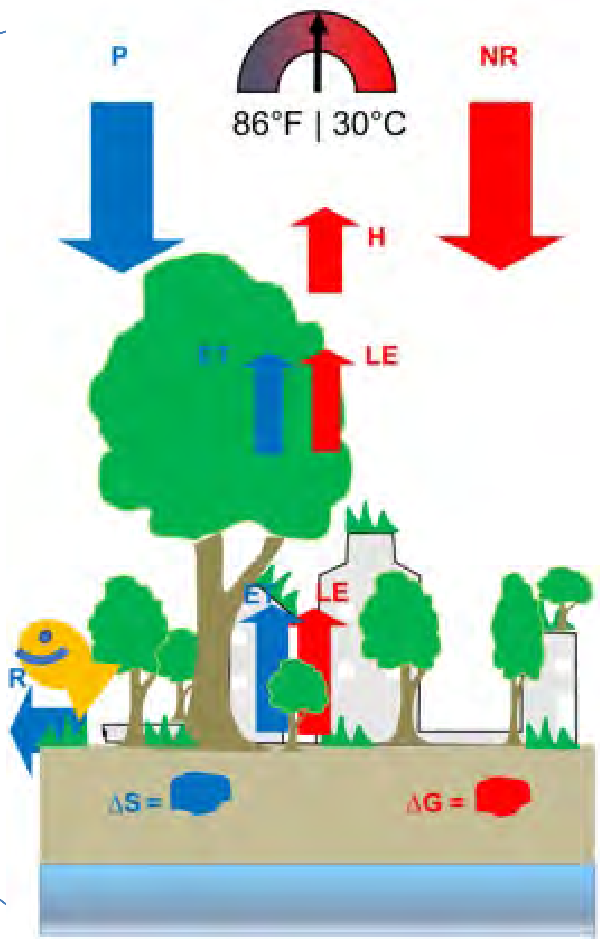
i-Tree is a Cooperative Initiative

Motivation: Sustaining Riparian Corridors with Nature-based Solutions



Opperman, J.J. and G.E. Galloway. (2022). Nature-based solutions for managing rising flood risk and delivering multiple benefits . *One Earth*. https://doi.org/10.1016/j.oneear.2022.04.012



Legend:
P = precipitation
R = runoff
ET = evapotranspiration
ΔS = change in water storage
NR = net radiation,
H = sensible energy
LE = latent energy
ΔG = change in energy storage
λ = latent heat of vaporization
ρ_w = density of water

Water Balance: P=R+ET+ΔS
Energy balance: NR=H+LE+ΔG
ET = LE / (λ ρ_w)

Endreny, T. A. (2022). i-Tree Tools Assist with Strategically Designing Tree Cover and Improving Community Resilience. *Clear Waters - New York Water Environment Association, 52*(1), 46-50.

Methods: i-Tree Tools for Nature-Based Solutions

User Support

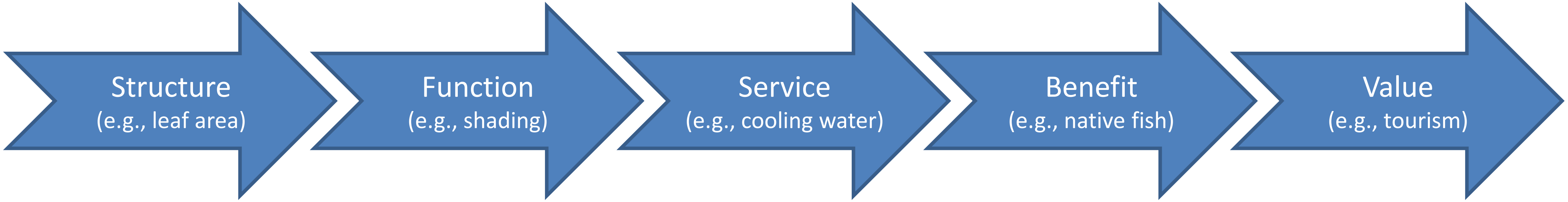
City Benefits Viewer	City Benefits Calculator	Block Benefits Calculator	Site Benefits Calculator	Land Cover & Benefits Estimator	Tree Species Selection
i-Tree Landscape	i-Tree Eco	i-Tree Planting	i-Tree My Tree	i-Tree Canopy	i-Tree Species

Research Suite HydroPlus

Managing Stormwater	Cooling Heat Islands	Cooling River Waters	Reducing Energy Use	Mapping Nutrient Runoff
i-Tree Hydro	i-Tree Cool Air	i-Tree Cool River	i-Tree Energy	i-Tree Buffer

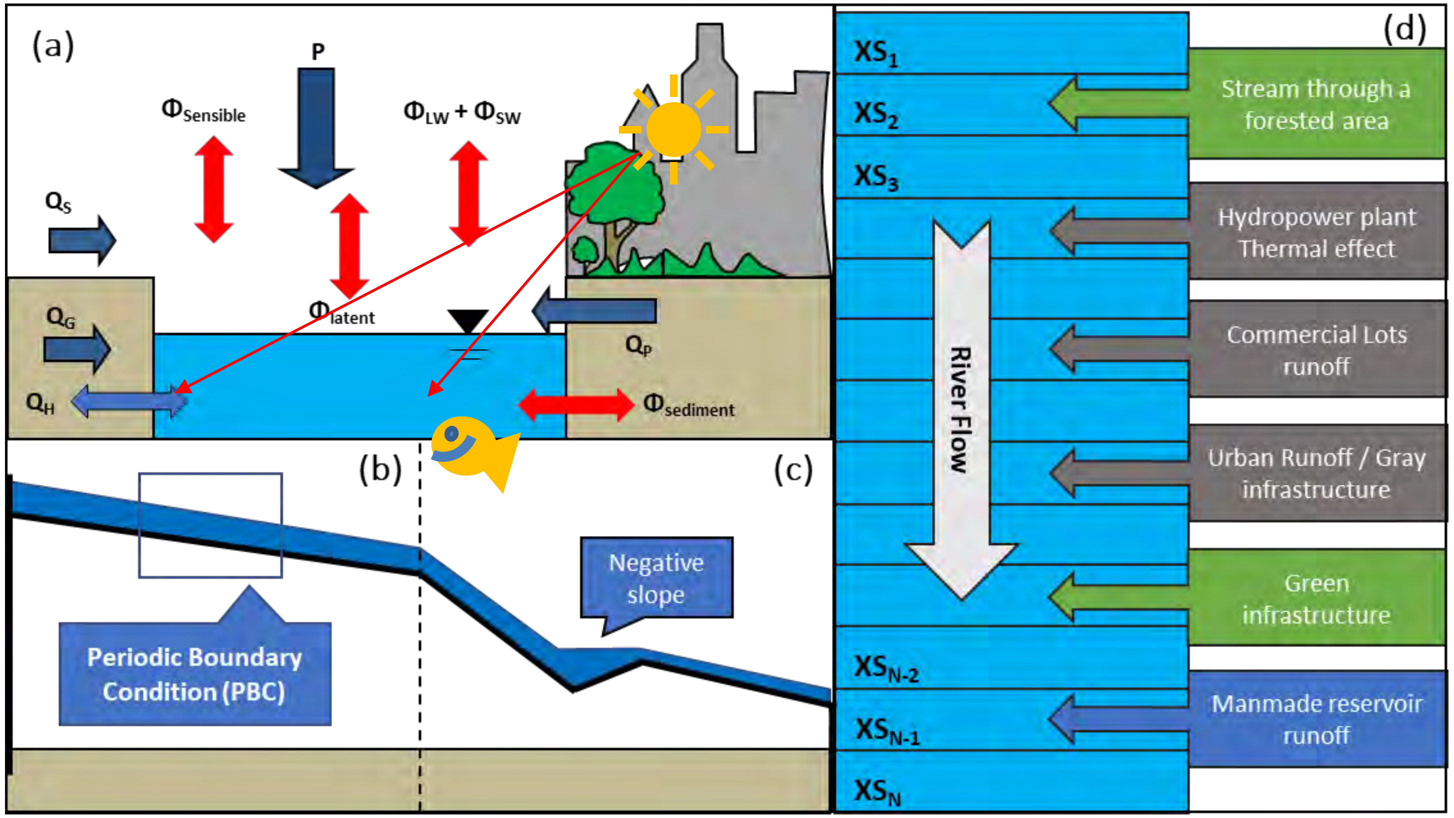
i-Tree Tools as Numerical Models: Structure to Value

- i-Tree Vision:
  - To improve forest and human health through user-friendly technology that engages people around the world in enhancing forest management and resiliency.
- i-Tree Goals:



  - Calculate how changes in forest structure will lead to changes in functions, ecosystem services, and tradeoffs among benefits and values
  - Determine the best tree species, locations, and planting rates to optimize ecosystem services and values through time and across space to enhance human health and well-being

i-Tree Cool River Model: Basic Concepts



Legend: (a) Cross-section view, (b) Longitudinal view w/ (c) Pools and riffles, (d) Planform view

P = precipitation, Q_G = groundwater flow, Q_H = hyporheic exchange flow, Q_P = pipe or lateral flow

ΦSensible = sensible heat flux, ΦLatent = latent heat flux, ΦSediment = sediment heat flux,

ΦLW = long wave radiation, ΦSW = short wave radiation, ΦTotal = Sum of all Φ terms, XS = cross section, N = Total XS

Eq 1. Advection, Dispersion, Reaction

$$\frac{\partial T_w}{\partial t} = -U\frac{\partial T_w}{\partial x} + D_L\frac{\partial^2 T_w}{\partial x^2} + R_h + R_i$$

Eq 2. Reaction via Heat Transfer

$$R_h = \frac{\Phi_{Total}}{\rho_w C_p d_w}$$

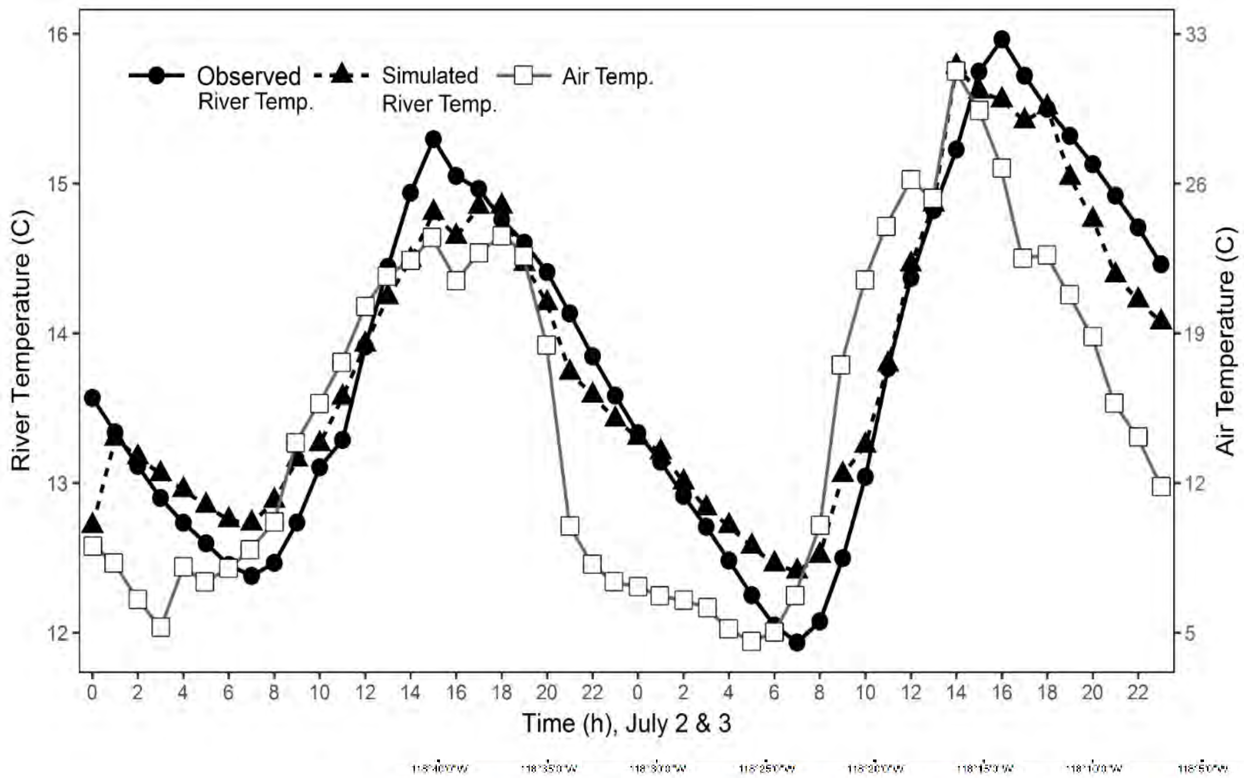
Eq 3. Reaction via External Flows

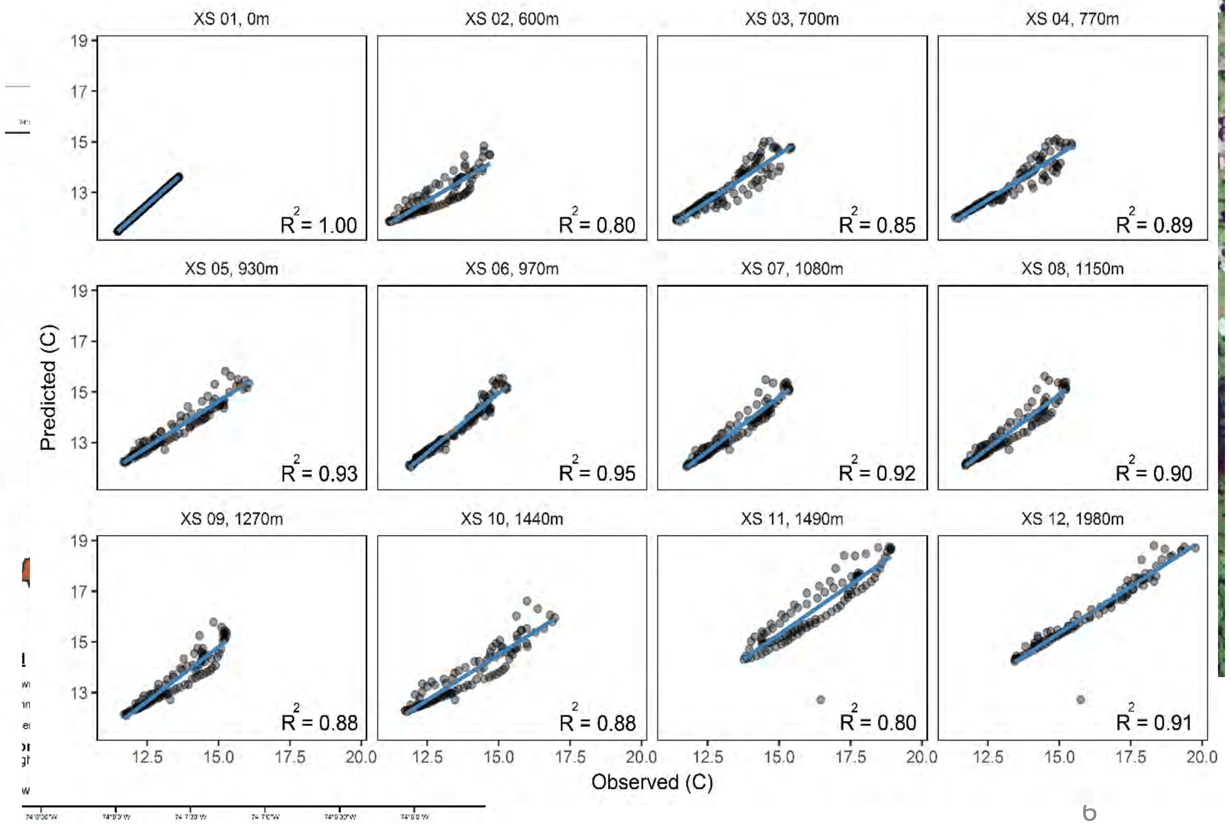
$$R_i = \frac{Q_G T_G + Q_S T_S + Q_H T_H}{\partial t\left(Q_G + Q_S + Q_H\right)}$$

Legend:
T_w = Temperature of Water, dt = time increment forward, U = velocity in streamwise, dx = distance increment along streamwise, D_L = Dispersion Longitudinal, R_h = Reaction via Heat Transfer, R_i = Reaction via External Inflows, Φ_{total} = Total heat transfer (net radiation, latent, sensible, sediment), ρ_w = density of water, C_p = Specific heat capacity of water constant pressure, d_w = depth of water, Q = discharge or volumetric flow rate, T = Temperature where subscripts G = Groundwater, S= Storm Sewer or Lateral Stream, H = Hyporheic

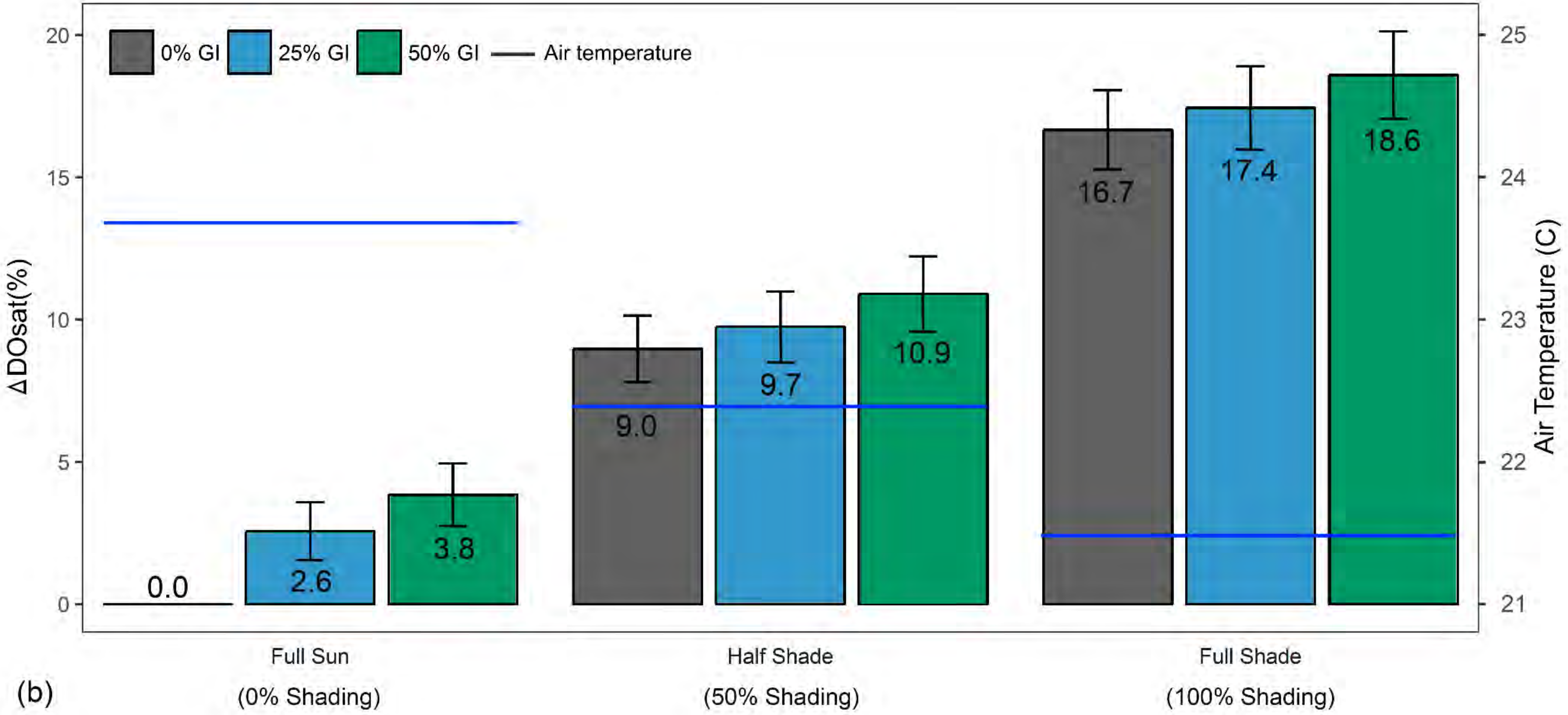
Abdi, R., & Endreny, T. (2019). A River Temperature Model to Assist Managers in Identifying Thermal Pollution Causes and Solutions. Water, 11(5). doi:10.3390/w11051060; Abdi, R., Endreny, T., & Nowak, D. (2020). A model to integrate urban river thermal cooling in river restoration. Journal of Environmental Management, 258, 110023. doi:https://doi.org/10.1016/j.jenvman.2019.110023

i-Tree Cool River: LA River & Sawmill Creek, NY Fisheries



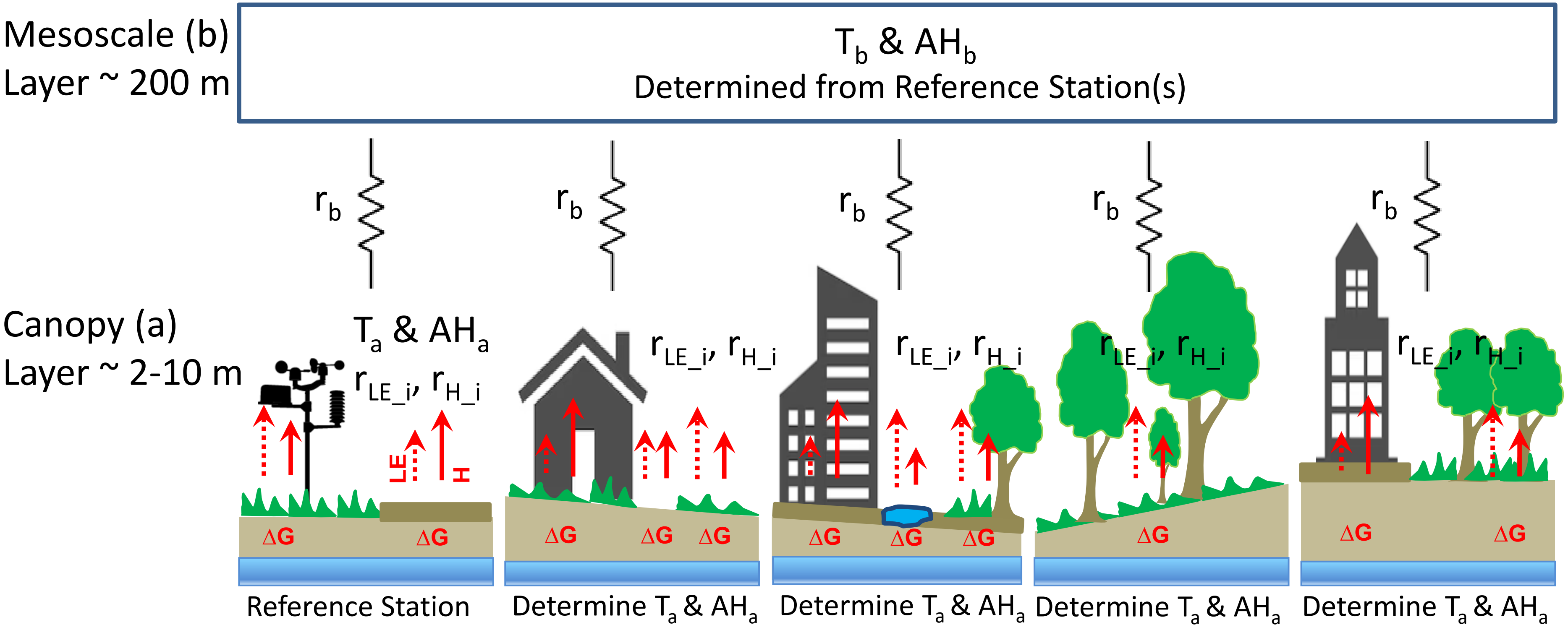


i-Tree Cool River Prediction of Dissolved Oxygen (DO) with Tree Shade & Green Infrastructure (GI), LA River



Abdi, R., Endreny, T., & Nowak, D. (2020). A model to integrate urban river thermal cooling in river restoration. Journal of Environmental Management, 258, 110023. doi:https://doi.org/10.1016/j.jenvman.2019.110023

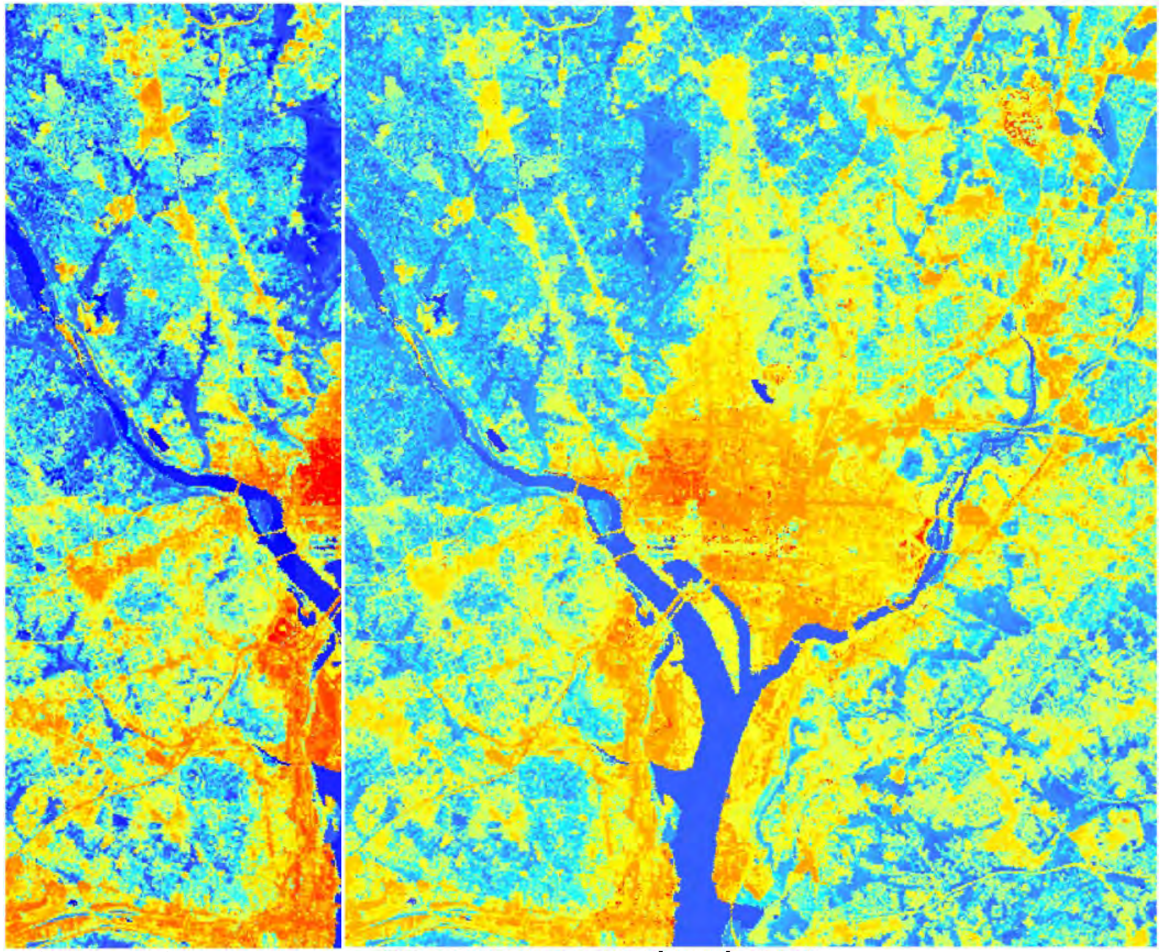
i-Tree Cool Air Model: Basic Concepts



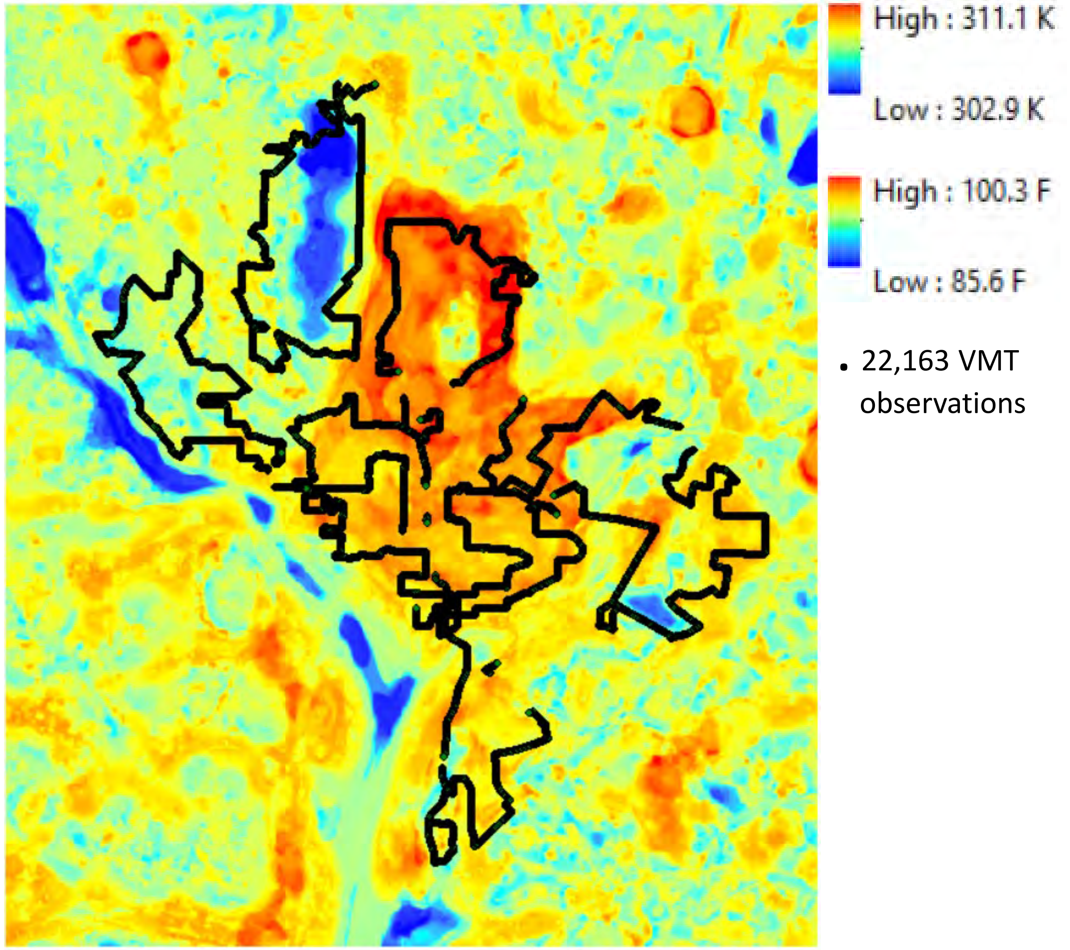
Legend: T = air temperature, AH = absolute humidity, r = aerodynamic resistance, a = canopy layer, b = mesoscale layer, LE = latent heat flux, H = sensible heat flux, ΔG = ground heat flux

Yang, Y., Endreny, T. A., & Nowak, D. J. (2013). A physically based analytical spatial air temperature and humidity model. *Journal of Geophysical Research-Atmospheres, 118*(18), 10449-10463. doi:10.1002/jgrd.50803

i-Tree Cool Air: Washington, DC Heat Wave



iTCA Air Temperature at 3 pm 8/28/18

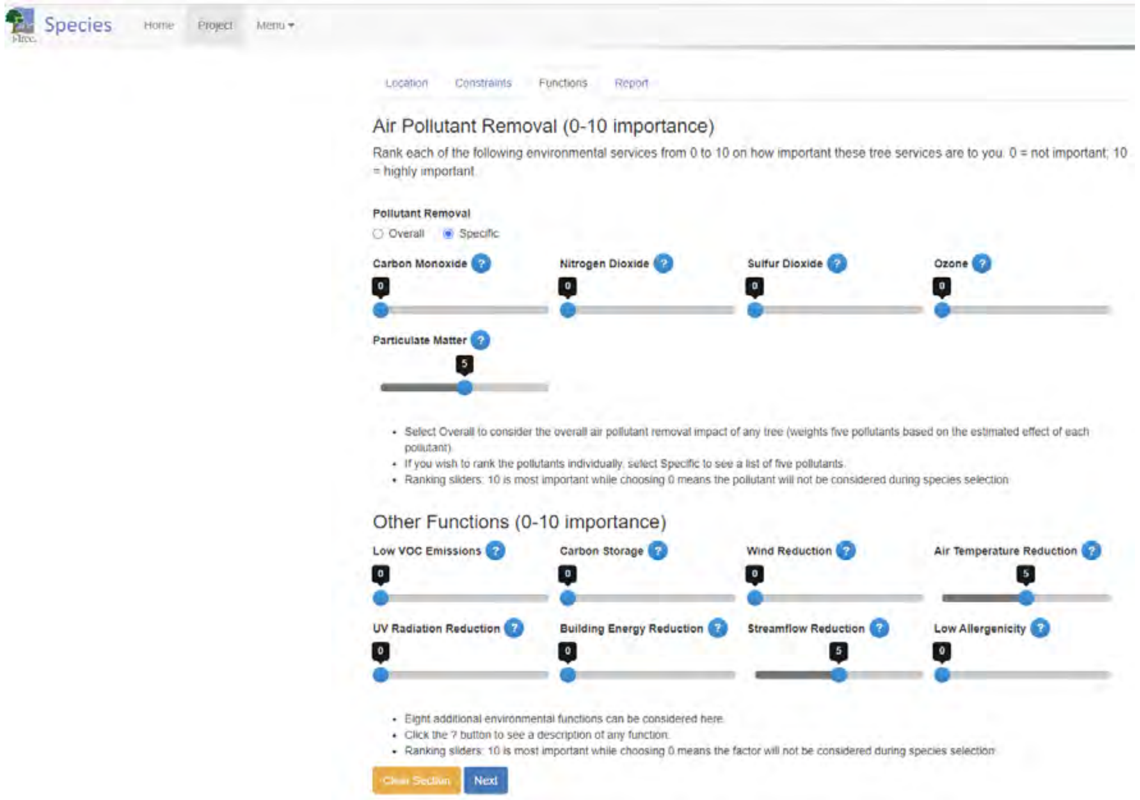


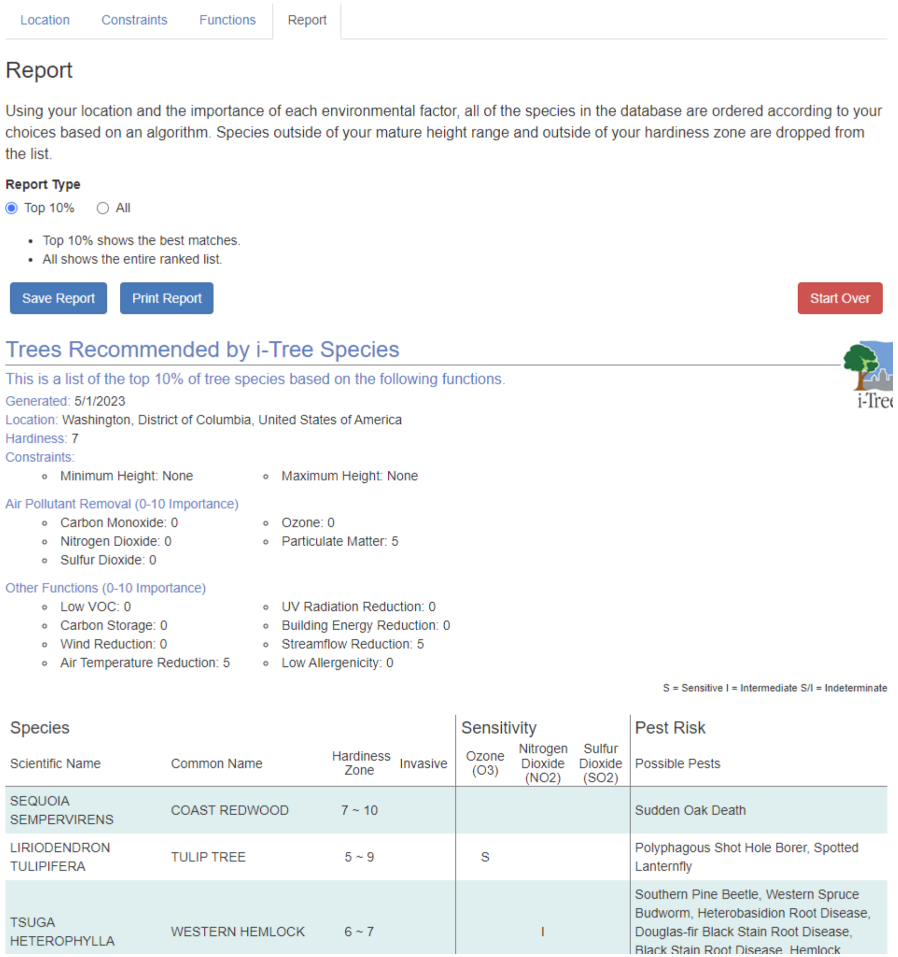
VMT Air Temperature at 3 pm 8/28/18 via Shandas

- 22,163 VMT observations

Shandas, V., Voelkel, J., Williams, J., & Hoffman, J. (2019). Integrating Satellite and Ground Measurements for Predicting Locations of Extreme Urban Heat. *Climate, 7*(1), 5.
Yang, Y., Endreny, T. A., & Nowak, D. J. (2013). A physically based analytical spatial air temperature and humidity model. JGR-Atmospheres, 118(18), 10449-10463. doi:10.1002/jgrd.50803

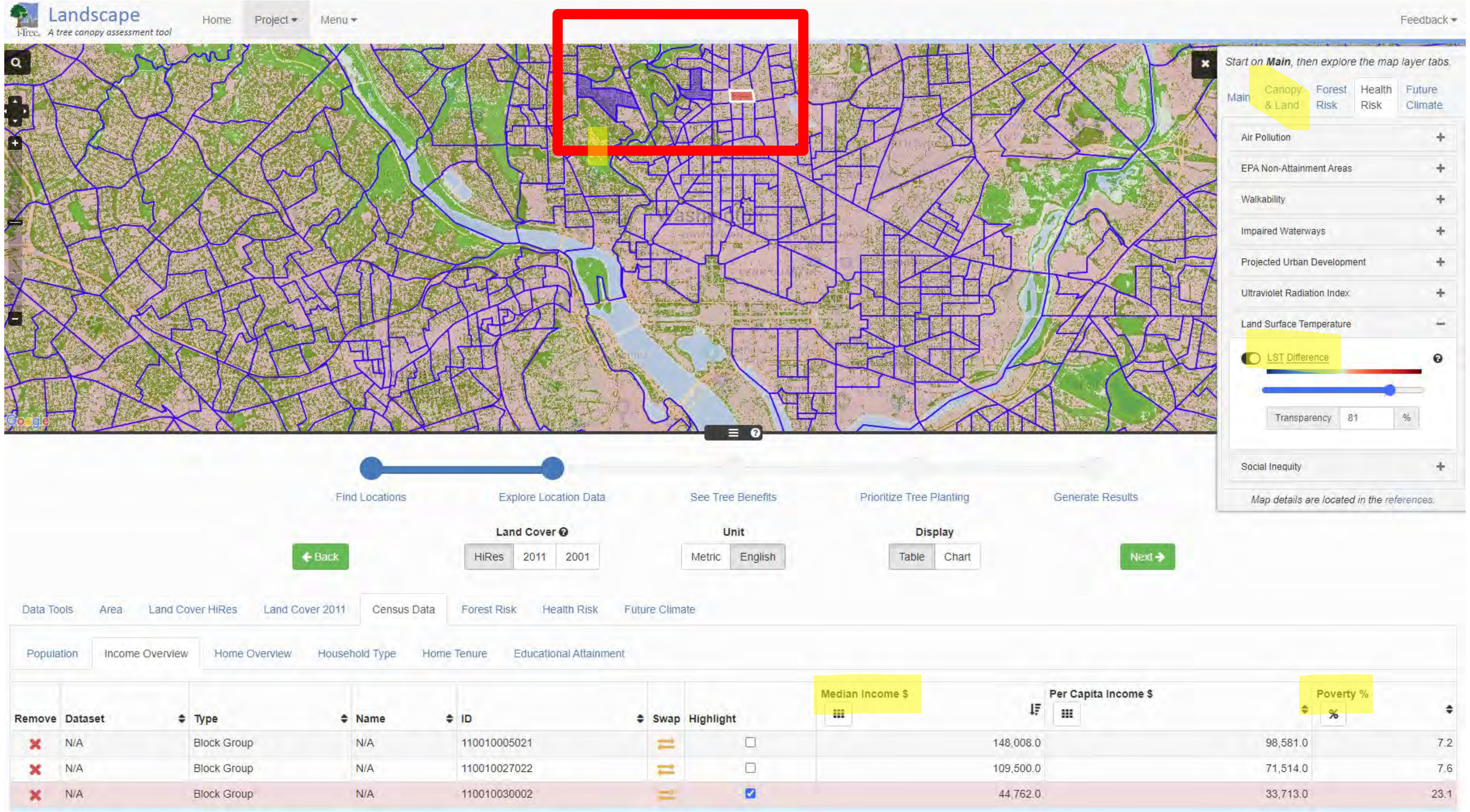
Discussion: i-Tree Species Suggests Specimens to Plant by Ranking Ecosystem Service Priorities





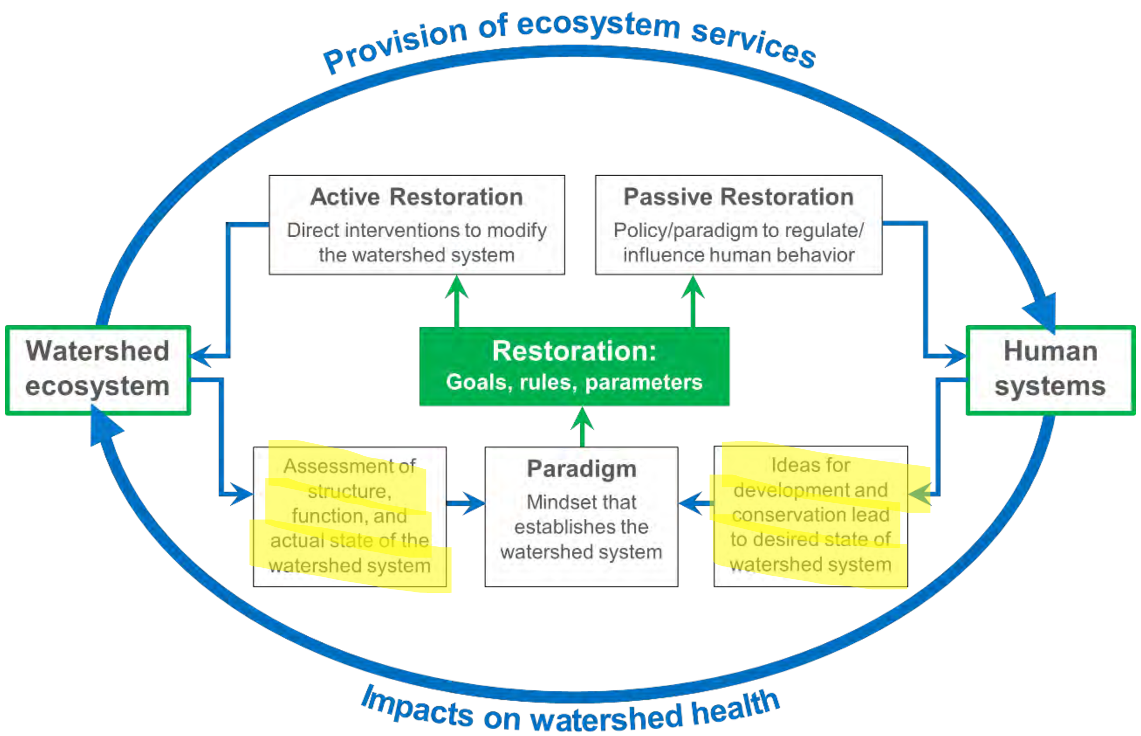
Software Needs to Work with Other Services and their Valuation: Native Species, Pollinators, Food, Biodiversity, Climate Disruption, Forest Bathing, …

Discussion: i-Tree Landscape Finds Vulnerability via Overlay of Demographic Data & Ecosystem Services



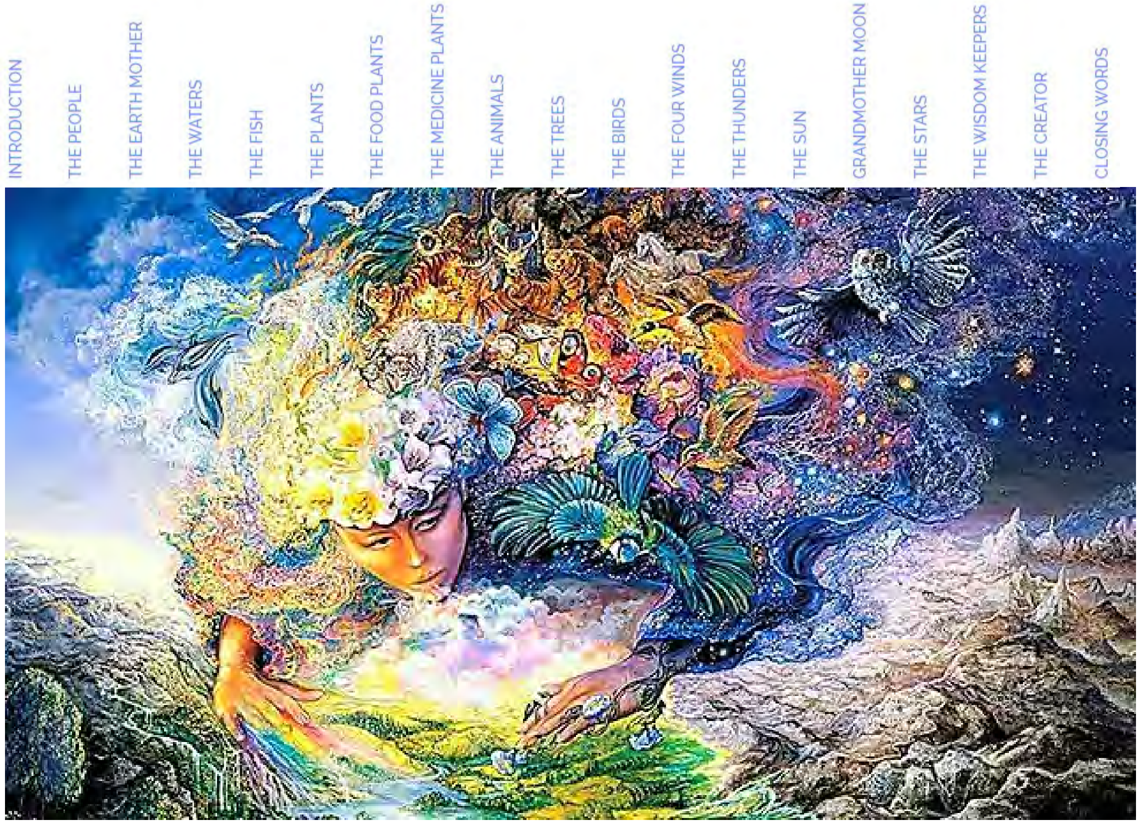
Exploring 3 Census Block Groups w/ Table of Income Overview & Map Overlay w/ HiRes Tree Cover, LST (Land Surface Temperature) Difference from Median of LandSAT scene. Map & Table show Vulnerability.

Discussion: Leverage Points to Improve the State of our Watershed; Resetting our Paradigms



Watershed state or conditions reveals its purpose.

Endreny, T. A. (2020). Leverage Points Used in a Systems Approach of River and River Basin Restoration. *Water, 12*(9). doi:10.3390/w12092606



https://danceforallpeople.com/haudenosaunee-thanksgiving-address/haudenosaunee-thanksgiving-address-2/

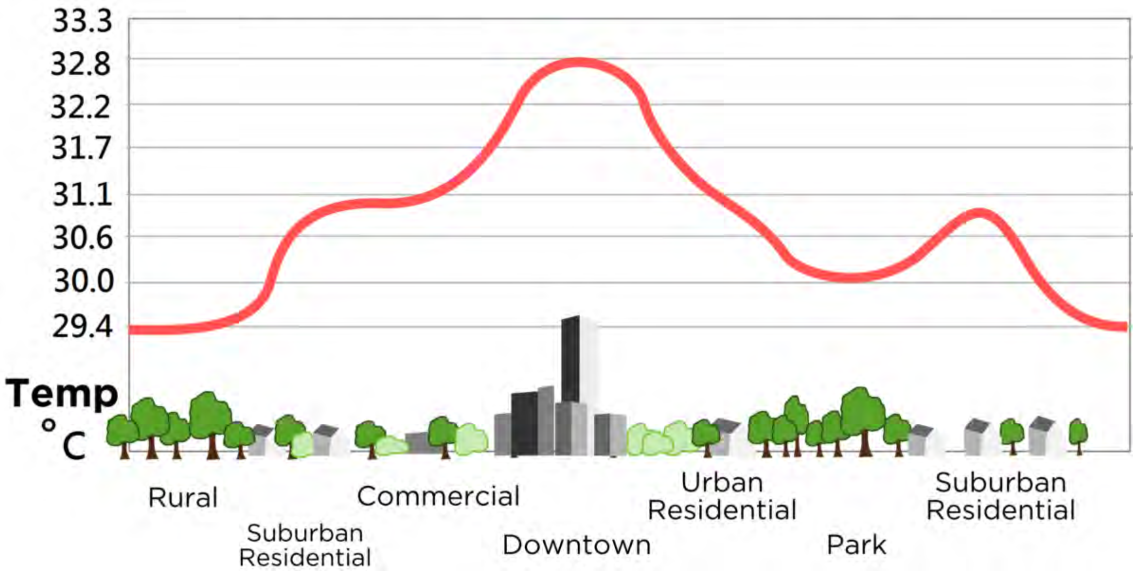
Today we have gathered and we see that the cycles of life continue.

…

Now our minds are one.

Conclusions

- Riparian forests restore water & energy balance
- Forest expansion improves human well-being



i-Tree is a Cooperative Initiative

i-Tree

Do you?

Extra Material: Challenges of Modeling Complex (Mal)Adaptive Systems

- Two types of complex adaptive system (CAS):
  - CAS1 systems of nature that adaptively evolve with holistic selection
    - CAS1 systems include individual organisms, or eusocial insect colonies, ecosystem-level microbiomes.
  - CAS2 systems of humans (e.g., socioeconomic system) that may mal-adaptively evolve due to separate agents pursuing separate goals
    - Can CAS2 internally self-organize into CAS1 or
    - Can CAS2 somehow externally organize into CAS1

Wilson, D.S and Madhavan, G. (2021) Complex Maladaptive Systems, The Bridge SI on Complex Unifiable Systems, National Academy of Engineering, Washington, DC.