Designing and Installing Newark’s Green Infrastructure to Capture and Treat Combined Sewer Discharge, Diminish Air Conditioning Use, and Reverse Urban Heat Island

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Newark Elevation

Land cover in Newark

Land use in Newark

Land Use here = 70% Impervious

Source: City of Newark Municipal Stormwater Management Plan
K-Sat Values of Newark Soils

- 1”/hr
- 4-8”/hr
- 11-12”/hr
Available Water Storage - Newark

- 22-27 cm/cm
- 15-20 cm/cm
- 9.5 cm/cm
The Availability of Water Powers Terrestrial
Thermal Regulation
Vegetated Surfaces and Water Partition Incoming Energy

\[ R_n - H - G - LE - R - P = 0 \]

\( R_n \) = radiation load on an area
\( H \) = sensible heat
\( G \) = heat moved into air, soil and water
\( LE \) = evaporative heat loss
\( R \) = respiration
\( P \) = photosynthesis

<table>
<thead>
<tr>
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<tbody>
<tr>
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<td>10</td>
</tr>
<tr>
<td>Urban areas</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Irrigated field (Winter)</td>
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</tr>
<tr>
<td>Douglas fir stand</td>
<td>0.66</td>
</tr>
<tr>
<td>Wheat field(summer)</td>
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</tr>
<tr>
<td>Forest (Indiana) annual average</td>
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<tr>
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<tr>
<td>Soybean field(summer)</td>
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<tr>
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Table 2: Bowen ratios reported for a range of ecosystems and vegetated environments (references 4 – 12). The green vertical arrow indicates the range we estimated for the Penn State green roofs during July 2003.
Energy Balance Equation

\[ R_n = H + LE + G + R + P \]

\( R_n \) = Total Radiation
\( H \) = Sensible Heat
\( LE \) = Latent Heat, evaporative heat loss
\( G \) = Heat moved into surrounding materials, buildings & soil, atmosphere & water
\( R \) = Respiration (max \( \leq 1\% \))
\( P \) = Photosynthesis (max \( \leq 1\% \))
**Bowen Ratio** = $H/LE$

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The Simple Story......

Plants a half-meter and taller:

A) Partition sensible and latent heat between upper and lower leaf cover

B) Regulate local temperature
Fig. 1.1. The temperatures of leaves $A$ and $B$ are below the air temperature. At 12:30 leaf $B$ was severed and the flow of water through the stem was interrupted. Without the influence of transpiration leaf $B$ became warmer than the air. (Measurements with *Citrullus colocynthis* under desert conditions in Mauretania, Africa; after Lange, 1959.)
Leaves in layers filter density, lowering light intensity on leaves below

- Shade is eliminated as these layers approach optimal spacings. This partitions radiation, energy and heat loads.
- Upper leaves re-radiating more sensible heat.
- Lower leaves have higher levels of evaporation, latent heat and water vapor production.

Figure 4.2. Shadow of a leaf layer. Leaves in the first layer would completely obscure the sun from parts of leaves in a layer at A, but not from any part of a layer at B.
Evapotranspiration, Phase Change of Water and Power

- Evapotranspiration - water moves through roots and shoots – leaves through leaves

- 6 mm of water changes phase over 2.5 acres energy = 15 tons of dynamite!

- 33 gallons of water phase change moves the energy equivalent of a ton of air conditioning

The geometry of the spatial array of sensible and latent heat loss allows vegetation to effectively regulate heat flux and to locally drop temperature below ambient
City of Newark 8,893.68 acres:
Approx 3442 acres of building footprint = ~ 2-3 times that in wall area,
945 acres of roadway, 75 acres of open water,
4126 acres open space, 377 acres vacant land
Linda Tool Green Roof

- regulates temperature
- reduced air conditioning cost by 33%
Linda Tool Green Roof

Components:

• Native wetland plant communities

• Ultra lightweight green roof medium with high water holding capacity
Roof membrane design to hold water to facilitate capillary uptake and storage
Linda Tool Green Roof

Observations:
• 12,000 sq.ft. roof can evapotranspire ≈ ¼” water per day
• 1” rain captured over 12,000 sf. = 1,000 cu.ft. water
• ¼” evaporation = 250 cu.ft. = 1,875 gal
• 33 gal = 1 ton AC, so 1,875 gal ≈ 57 tons AC -- enough to cool ≈ 23,000 sq.ft. -- almost twice the area of the 12,000 sq.ft. Linda Tool building.
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<td>12,000</td>
<td>3,000</td>
<td>22,500</td>
<td>$90</td>
<td>$7.50</td>
</tr>
<tr>
<td>Area (sq.ft.)</td>
<td>Daily Warm Season Evaporation (inches)</td>
<td>Cu.ft. of Daily Warm Season Evaporation</td>
<td>Daily Warm Season Evaporation (cu.ft.)</td>
<td>Daily Evapor transpiration (tons AC at 33 gal/ton AC)</td>
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Eliminated Treatment Cost and Urban Cooling Value

Linda Tool green roof is worth $8 per day by treating 250 cu.ft. of water.

Same Linda Tool green roof is worth $1,000 a day for reversing urban heat island and lowering local temperature.

Heat flow data and utility bills show a 33% air conditioning cost reduction.
Rain ~ 4ft/yr
Greywater ~ 1ft/yr
Commonly Flooded Streets
Water in capillary films in soil

• In temperate zone, roots are not deep, they are shallow and branched

• 40% to 50% of fine roots occur in the top 10 cm of soil

• 90%+ of water absorption may take place in shallow fine roots

Water moves down a concentration gradient

but upwards and into roots and shoots
Soil Systems Connected to Root Structures

Larger organisms such as nematodes may be physically excluded from dense soil. Alternatively, some macrofauna such as insects, termites and earthworms may burrow through dense soil and make pores where roots and other organisms can grow and move (Fig. 2A). Roots of many species including the branch roots of maize (McCully, 1999) and Arabidopsis (Malamy and Benfey, 1997) are thinner than 100 μm. Field-grown seminal and branch roots of wheat can have both thick (1000 μm) and thin (100 μm) regions along their lengths, possibly to fit into spaces in the soil (Watt et al., 2005).

Root hairs are around 10 μm in diameter but can flatten to fit into pores of less than 2 μm (M. Watt, unpublished observation).

Distances and characteristic time for diffusion of solutes Distances between roots and other soil organisms determine how far solutes must move if the roots and the organisms are to influence each other. Here we present examples from wheat and barley roots (Table 2). The bacteria on the root surface can reside within a mucilage film approx. 30 μm thick, and are clustered on average 80 μm apart, but often are in direct contact with each other.
Water moves down gradient, but upward from soil through roots to atmosphere through regulatory cells, stomata.

Coverages range from 100 to 1,000 stomata per square millimeter.

Paired stomatal cells can close and open, depending on hydration level and physiological condition of the plant.

Stomata can be from about 15 X 15 to 80 X 40 microns.
18 cubic centimeters of liquid water expands to 22,400 cubic centimeters of water vapor
- 1,000 fold increase
- 5 mm depth equivalent to a 20 foot column of air

Explosive Water Use Transforms and Regulates Local Climate
Opportunities and Benefits of Green

Peak Load of Newark: 10,090 MW

Gallons of water to reduce peak load

Area of GI that can eliminate peak load: 22 sq miles

Avoided costs – stormwater or greywater-- water diverted from the combined sewer is taken to be $3 per 100 cubic feet

Value added to the cooling in Newark is taken to be $13.60 per 84.4 kW energy, the quantity produced by evapo-transpiring 33 gallons of water per day.
Value added of 380,000 tons AC = $6,650,000 per day

Avoided cost of removing 1,666,667 cu.ft. from the combined sewer @ $3/100 cu.ft. = $50,000

100,000,000 sq.ft. green wall

100,000,000 sq.ft. green roof
Return on a two billion dollar investment in green infrastructure Value added of 380,000 tons AC = $6,650,000 per day

Cooling-value added $2 b/$6,650,000 per day ≈ 300 warm season days
Avoided treatment. $2,000,000,000 / $50,000 ≈ 40,000 days (100 years)

100,000,000 sq.ft. green wall

100,000,000 sq.ft. green roof
A $2 billion investment in NYC green infrastructure @ $20 per square foot for green roof or green wall installation:

$2,000,000,000/($20/sq.ft.) = 100,000,000 sq.ft.

100,000,000 sq.ft. green wall

100,000,000 sq.ft. green roof
At typical temperate zone evapotranspiration rates of 1/5" per day, 1,000,000,000 sq.ft. will move 1,666,667 cu.ft., or 12,500,000 gallons into the atmosphere.
The avoided cost of removing 1,666,667 cu.ft. from the combined sewer @ $3/100 cu.ft. = $50,000

100,000,000 sq.ft. green wall

100,000,000 sq.ft. green roof
The value added of producing 380,000 tons of air conditioning by evapotranspiring 12,500,000 gallons of into the atmosphere is $6,650,000 per day

100,000,000 sq.ft. green wall  
100,000,000 sq.ft. green roof
Questions?