RUTGERS
New Jersey Agricultural Experiment Station

# Designed soils under pavement: what data is in and available?

Jason Grabosky

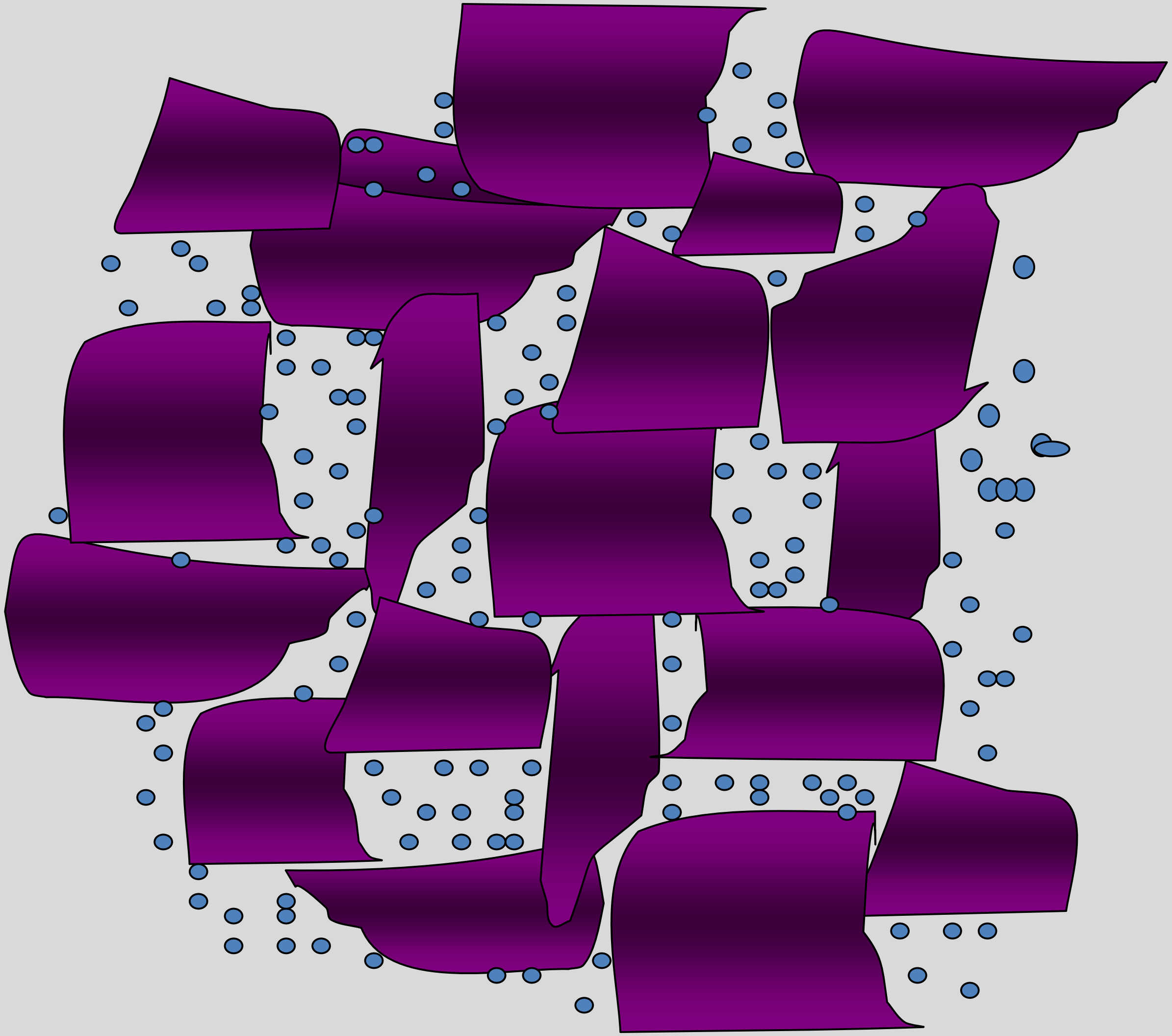
# Low Impact Development
# High Impact Design Values

- MAIN GOALS

- Trees living up to artist/design renderings
- Ability to intercept, stage and deploy water rather than conveyance
- Integration of the tree root zone and pavement support in same volume

Photo credit: Amereq

Photo credit: Amereq



# Some terms and a common strategy, the skeleton


- Grabosky J. 2015. Establishing a common method from which to compare soil systems designed for both tree growth and pavement support. Soil Science 180(4/5):207-213.
- Loh F, Grabosky J, Bassuk N. 2003. Growth response of *Ficus benjamina* to limited soil volume and soil dilution in a skeletal soil container study. Urban Forestry & Urban Greening. 2(2003): 53-62.
- Grabosky J, Bassuk N, Irwin L, van Es H. 2001. Shoot and root growth of three tree species in sidewalk profiles. Journal of Environmental Horticulture 19(4) 206-211.
- Grabosky J, Bassuk B, van Es H. 1996. Further testing of rigid urban tree soil materials for use under pavement to increase street tree rooting volumes. Journal of Arboriculture 22(6): 255-263.
- Grabosky J, Bassuk N. 1995. A new urban tree soil to safely increase rooting volumes under sidewalks. Journal of Arboriculture 21(4): 187-201.

Spomer L A. 1983. Physical amendment of landscape soils. J. Environ. Hort.I(3):77-80.
September 1983.
Spomer A. 1975. Small soil containers as experimental tools: Soil water Relations.
Communications in Soil Science and Plant Analysis 6(1): 20-26.

# Load bearing

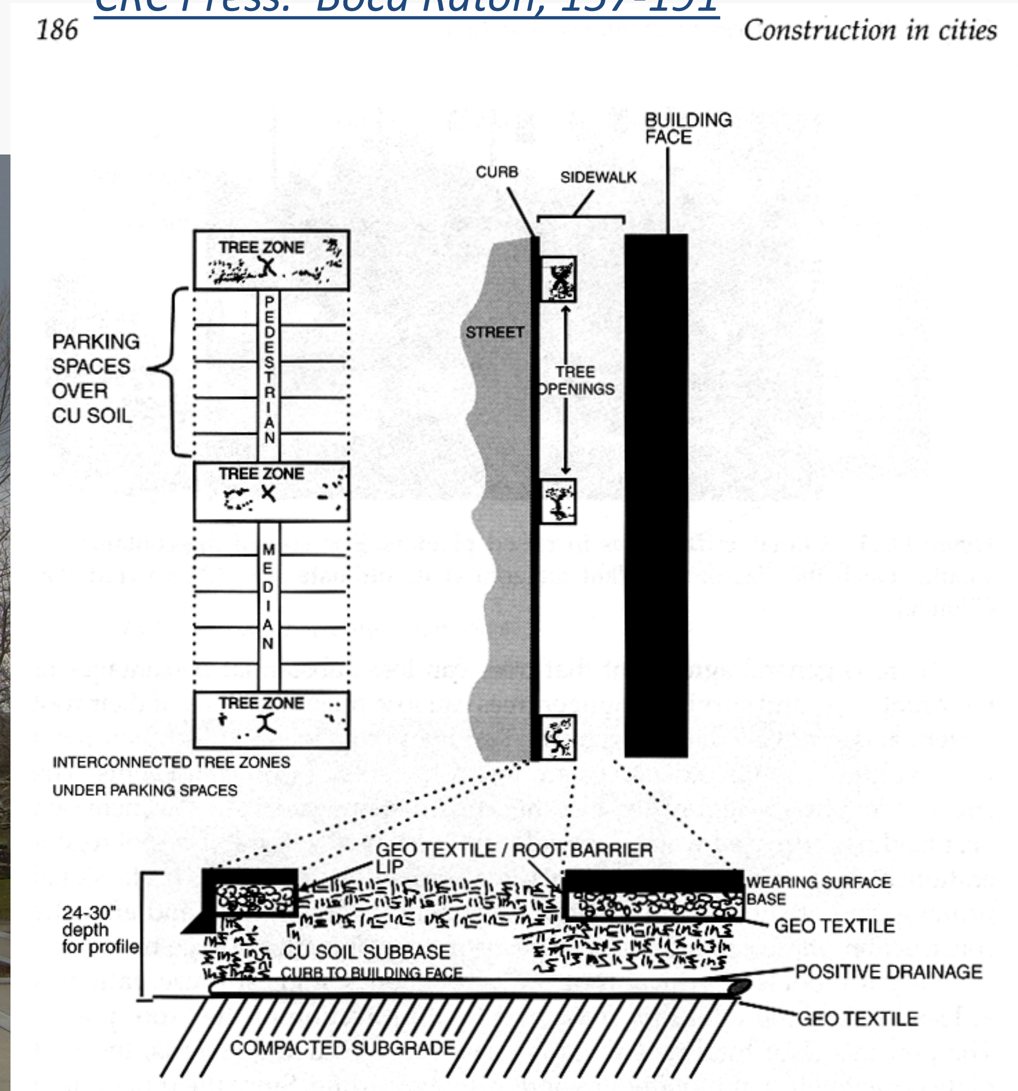
- Loading in the initial designs were to a CBR target of 90+, and later 50 for development of voids analysis method (discussed later)
- Early papers from Cornell program suggested that engineering tolerances were more sensitive than plant growth response in 2-3 year containerized studies

- Mike Mills in Canada had a more pragmatic approach

# How about water capture, access to water for roots and drainage?

Staged sheet flow interception:
Pavement support, root zone,
storm water: Integrated solution

*Chapter 13 trees in construction. 2001.*
*In P. Lancaster (Editor). Construction in Cities.*
*CRC Press. Boca Raton, 157-191*



# Defining water properties

- Can designed soils act as retention zone or detention zone "sponges" for holding or deep infiltration?
- Can use of such soil designs delay parking lot storm water flow outputs?
- How might vegetation in the lot or at the edges function as zones to dewater the designed system?

- How fast into the designed soil system -- infiltration
- How fast through the system -- permeability or conductivity
- How much pore volume -- storage capacity
- How fast out -- subgrade behavior and system drainage if flooded
- What's left for the plant after gravitational drainage -- plant available water

# Three efforts to describe hydraulic behavior:

## Getting numbers for tree management and stormwater design

- Study I: Standard definitions and bench testing of soil desorption 1996, 1999
- Study II: Planted dry-down in nursery containers with *x Cupressocyparis leylandii* 2002
- Study III: Planted dry-down in compaction cylinders with *Populus deltoides* 'Siouxland', and a field infiltration study 2006

Several papers discuss moisture and some measure plant water status and usage. I have not seen any bench-level or containerized/lysimeter works directly measuring the designed soil system hydraulic behavior

- Grabosky, J. Bassuk, N., Haffner, T. 2009. Plant available moisture behavior in stone-soil media for use under pavement while allowing urban tree root growth. Arboriculture &Urban Forestry 35(5):271-277.

- Infiltration: 60+ cm/hour (FAST)

- Permeability: 0.2 - 0.3 cm $s^{-1}$ (clean well-graded sand)

- Storage volume: Compacted porosity in range of 25-30% by volume……30-40% of total pores as gravitational pores

- Drainage potential – a function of subtending and adjacent layer potentials and/or hard drainage

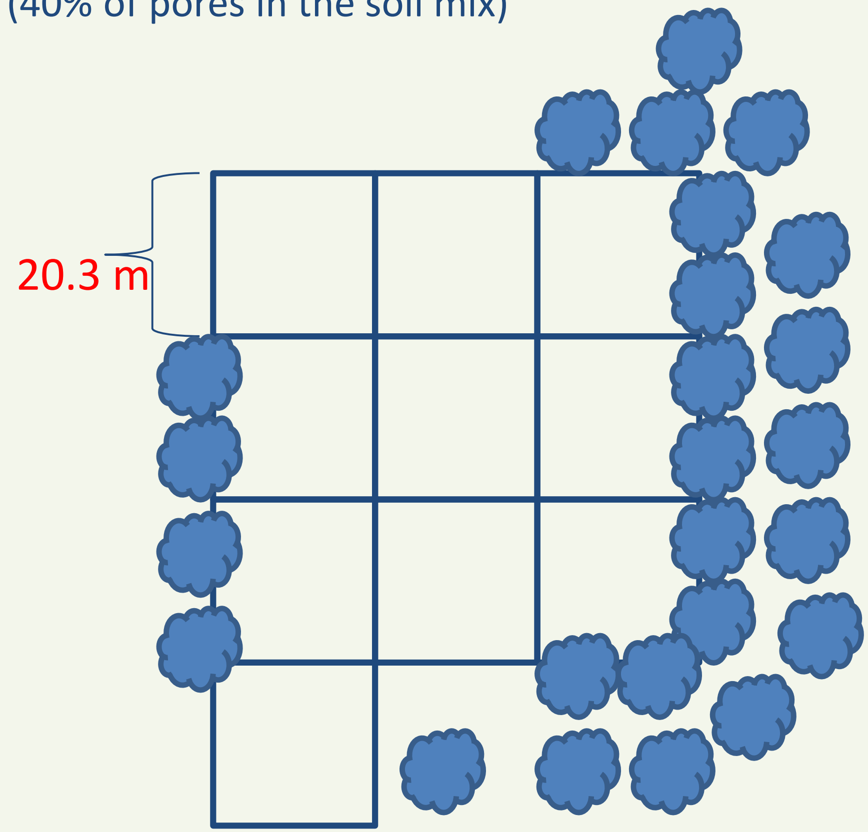
- What's left for the plant? 7-14% plant available water
- Sponges for holding or deep infiltration, delay to peak storm flow

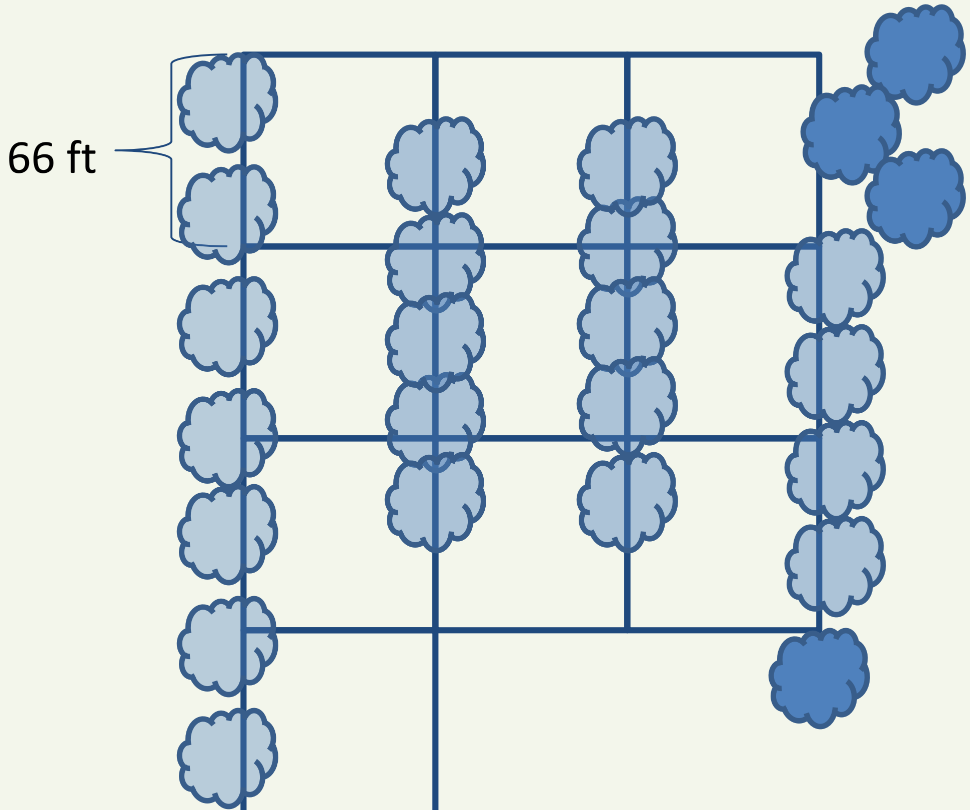
1 acre lot with a 3 inch rain event
2 ft deep catchment treatment

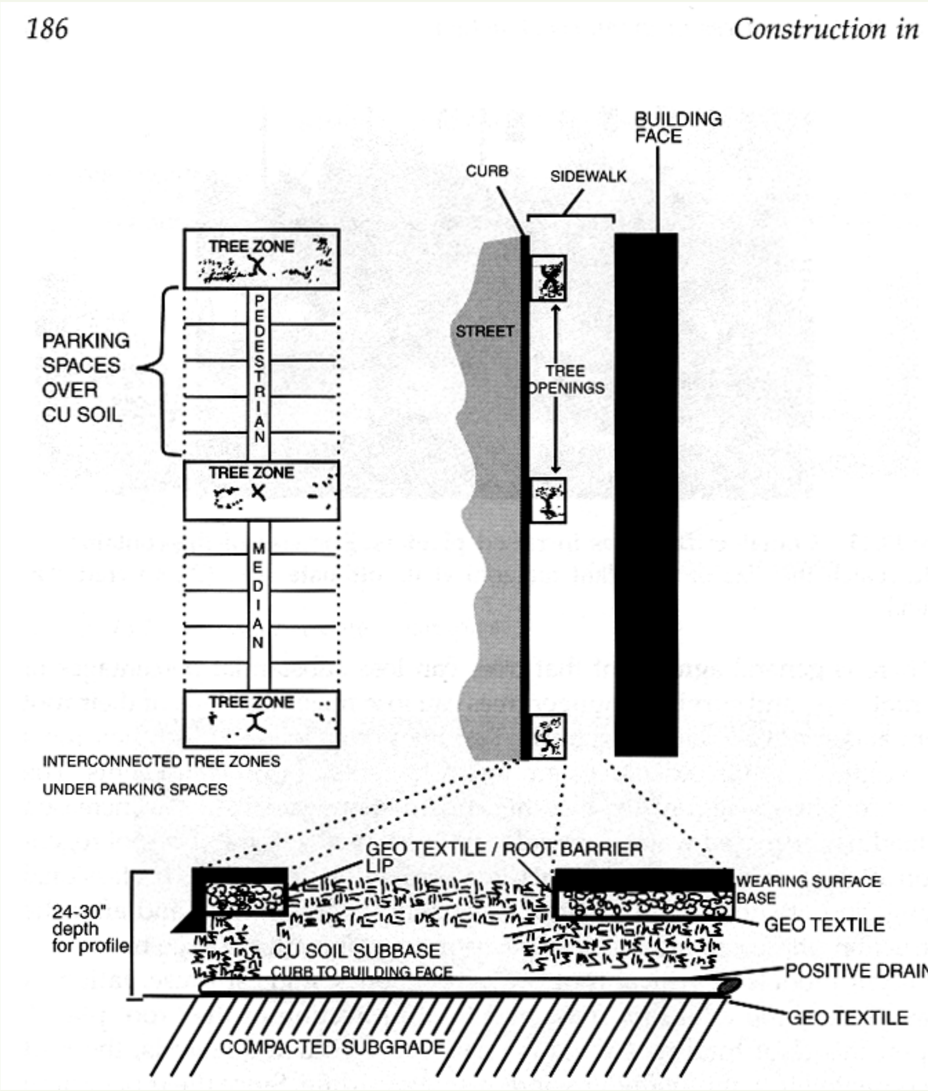
IF: soil porosity of 30%
THEN: 42% area for the chosen system

IF 9.2 m dia. tree canopy,
THEN: Ts water demand of 25 trees takes whole catchment within 10 days

There is still deep drainage and lateral drainage (40% of pores in the soil mix)




66 ft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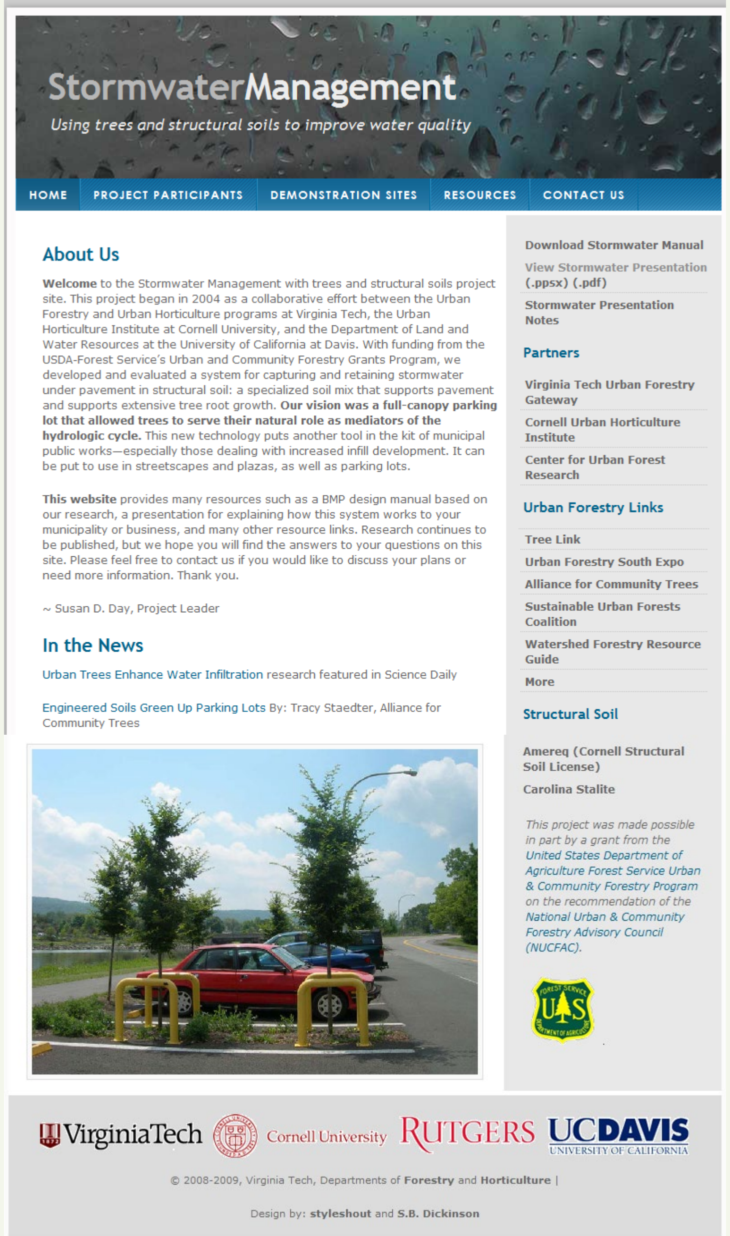
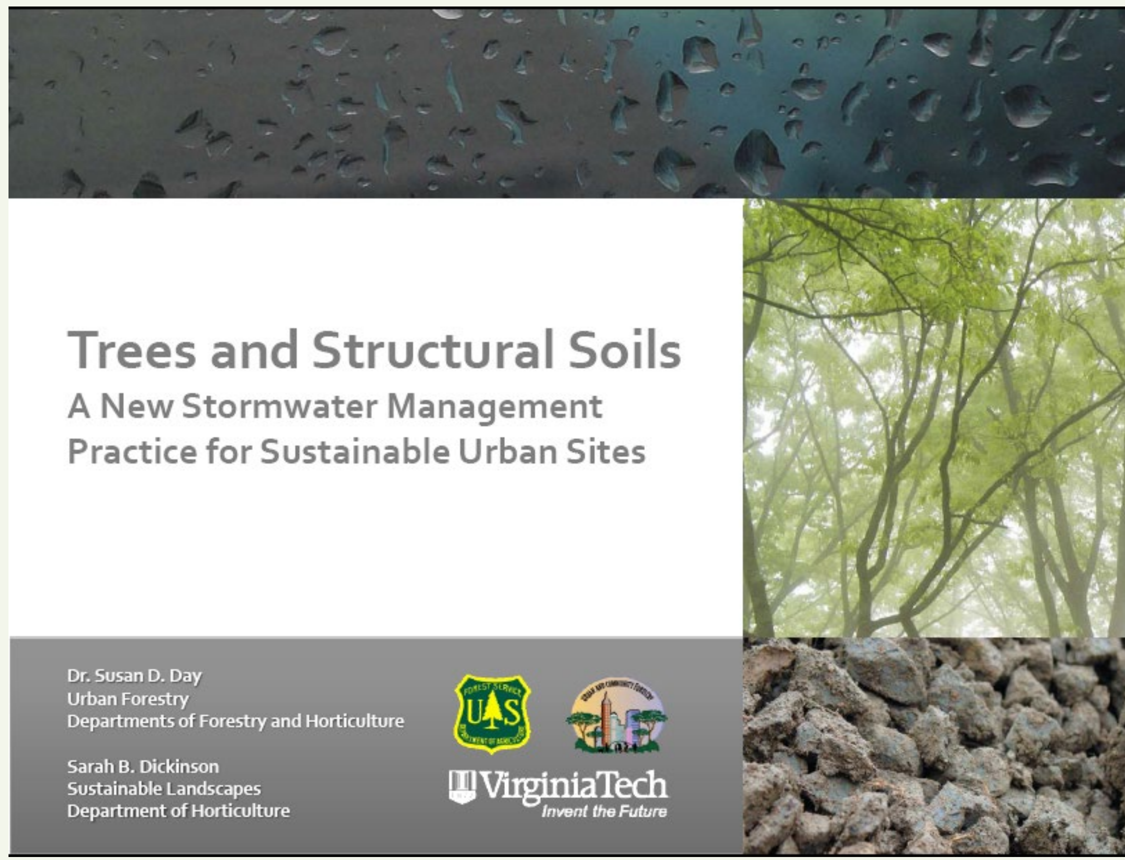
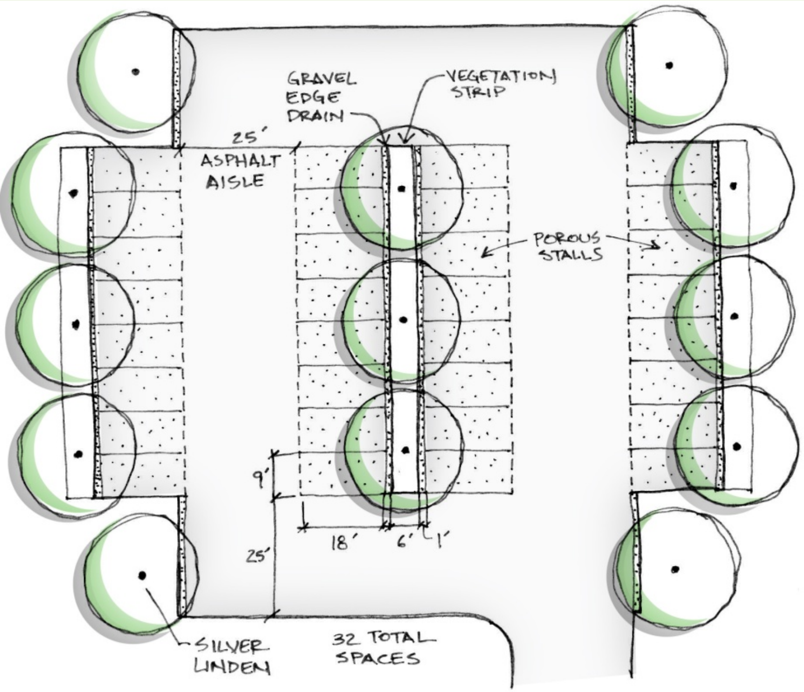
Construction in
BUILDING FACE
CURB
SIDEWALK
TREE ZONE
PEDESTRIAN
PARKING SPACES OVER CU SOIL
STREET
TREE OPENINGS
TREE ZONE
MEDIAN
TREE ZONE
INTERCONNECTED TREE ZONES
UNDER PARKING SPACES
GEO TEXTILE / ROOT BARRIER
LIP
WEARING SURFACE
BASE
24-30" depth for profile
GEO TEXTILE
CU SOIL SUBBASE
CURB TO BUILDING FACE
POSITIVE DRAIN
GEO TEXTILE
COMPACTED SUBGRADE

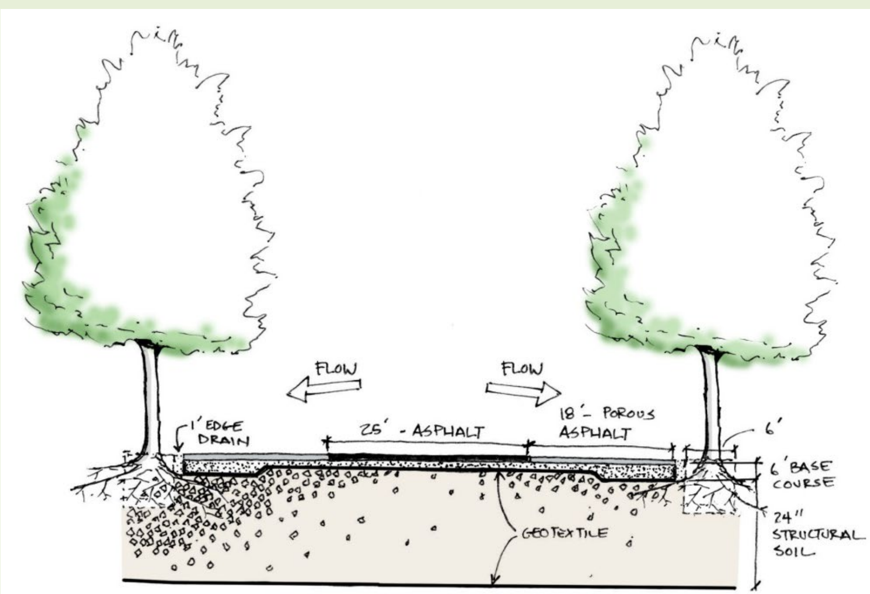



https://www.urbanforestry.frec.vt.edu/stormwater/


- Bartens, J, Harris J R, Day S D, Dove J E, Wynn T M. 2008. Can urban tree roots improve infiltration through compacted subsoils for stormwater management? Journal of Environmental Quality 37:2048-2057.
- Smith K. 2003. The effects of properties of designed soils on growth of *Corymbia maculta.* Doctoral dissertation University of Melbourne Burnley College. Pp 200.




Design research: Allyson Salisbury: Rendering Joe Chericello

# But trees take time:

Need to address herb-shrub communities and phased successional planning. It means planting the forest of the future environment now….

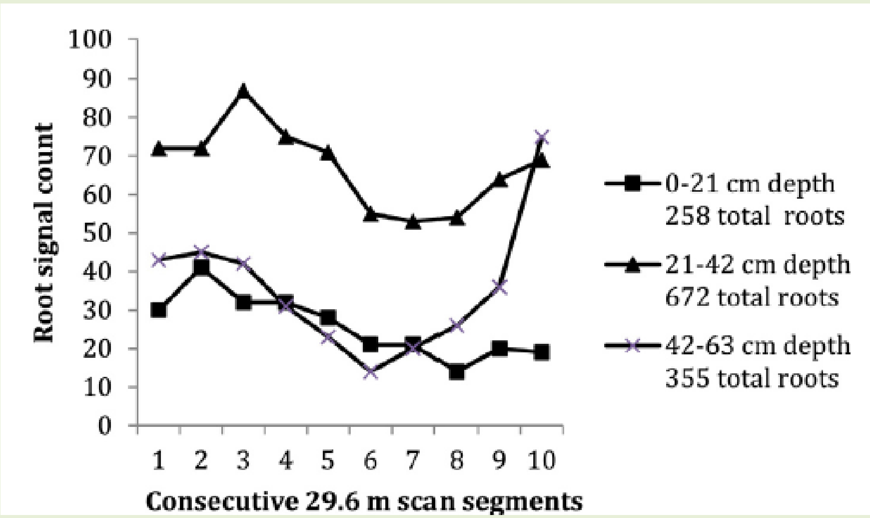
Those final trees as shown in this picture only really come on line in 2030-2060, unless we get three pavement cycles out of the lots and the trees, then they last to 2090.

The soil challenge is to give roots something to colonize and use to advantage.

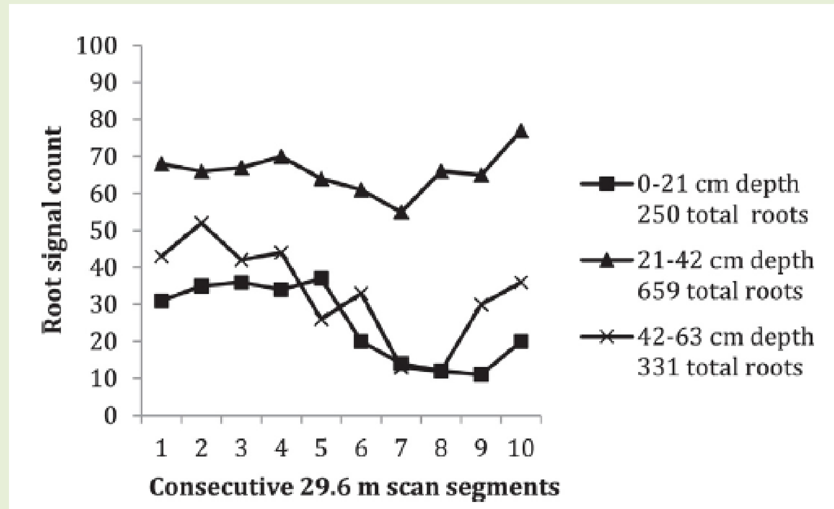
Is that realistic given our current rates of design change?

# Do the designed soils allow for root colonization? Case study McCarren Park NYC; Year 12: Ground Penetrating Radar shows roots in structural soil

1.1 m from trunk




1.7 m from trunk



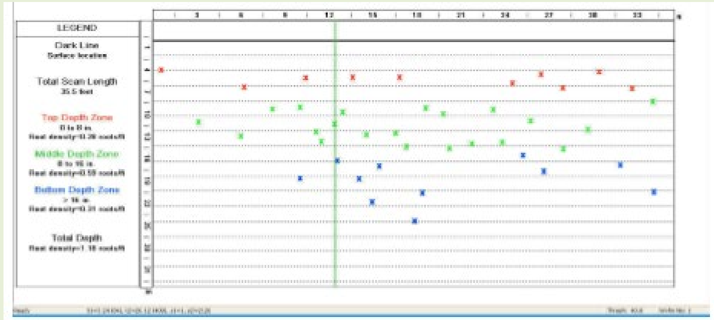

Seventeen years' growth of street trees in structural soil compared with a tree lawn in New York City

J. Grabosky[a,*], N. Bassuk[b]

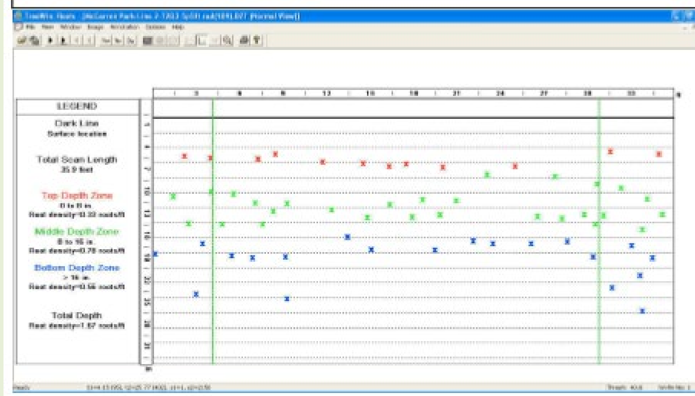
*Urban Forestry Urban Greening, 2016*


- Bassuk N, Grabosky J, Mucciardi T, Raffel G. (2011) Ground Penetrating Radar Accurately Locates Tree Roots in Two Soil Media Under Pavement. Arboriculture & Urban Forestry 37(4):160-166
- Embrén B, Alvem B-M, Stål Ö, Oversten A. 2009. Planting beds in the city of Stockholm: A handbook 2009.02.23; GH100322. Stockholms Stad. Pp83.

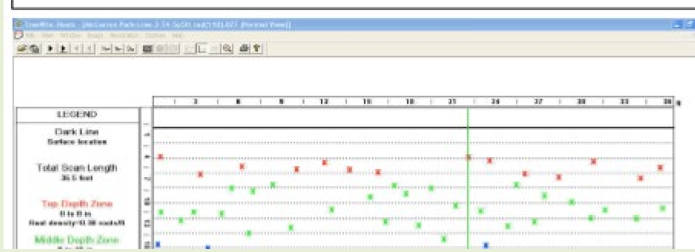





McCaron Park Scans - Scan # 2 - Length = 35.9ft - 6/22/2009




McCaron Park Scans - Scan # 3 - Length = 36.5ft - 6/22/2009

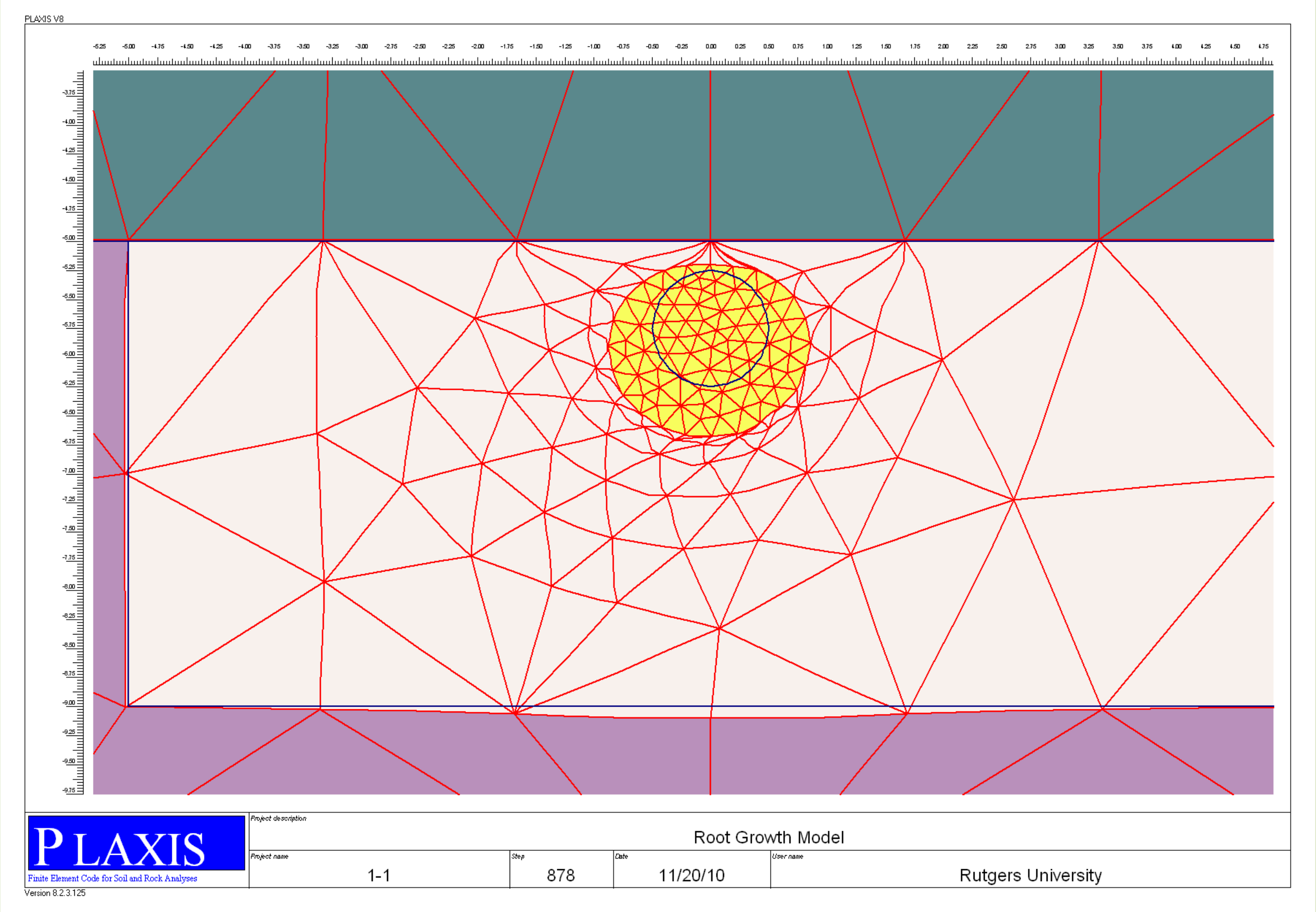


# Tree stability

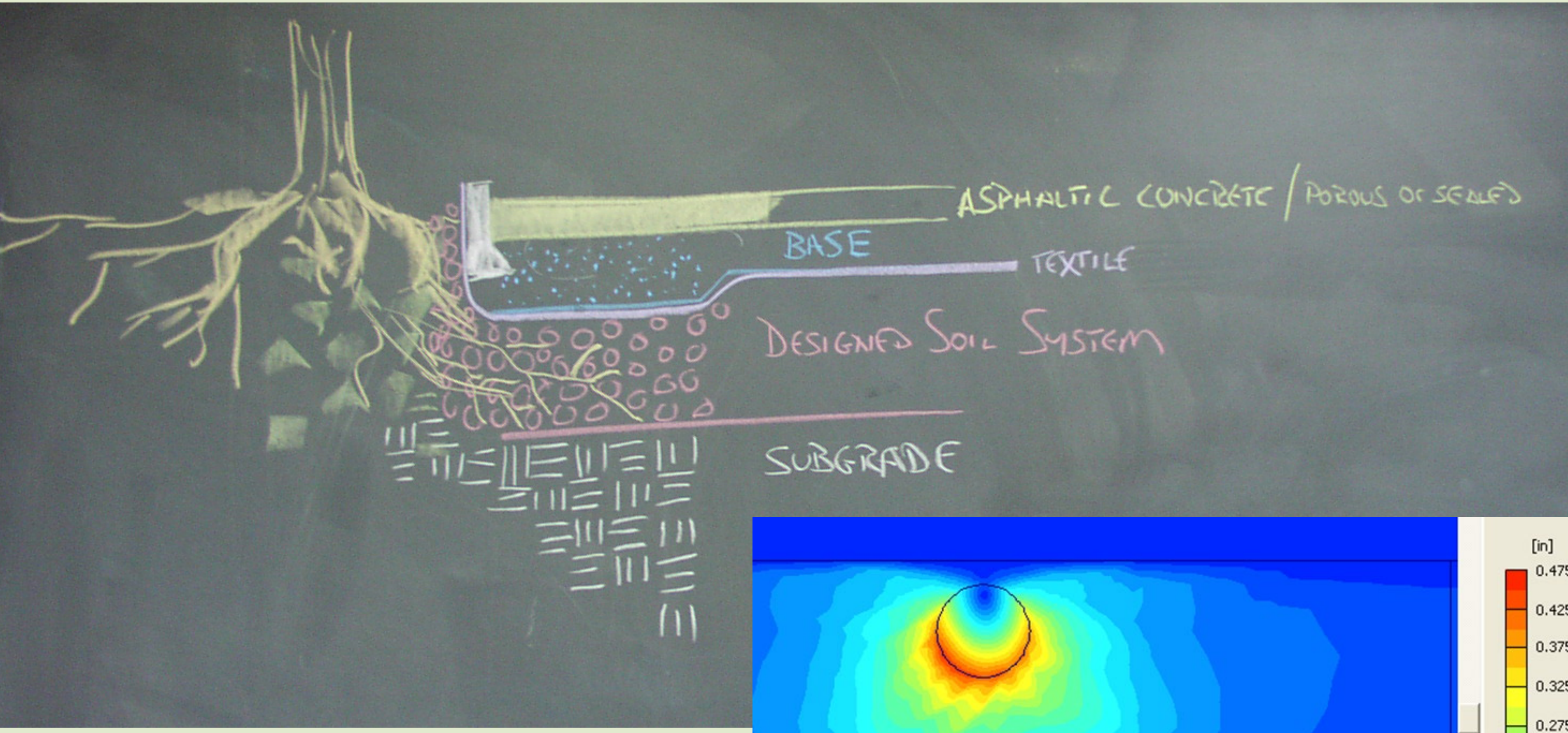
- Bartens J, Wiseman P E, Smiley E T.  2010.  Stability of landscape trees in engineered and conventional urban soil mixes Urban Forestry Urban Greening 9(4):333-338.
- Rahardjo H, Harnas F R, Leong E C, Tan P Y, Fong Y K, Sim E K.  2009. Tree stability in an improved soil to withstand wind loading. Urban Forestry & Urban Greening 8(4):237-247
- Rahardjo H, Indrawan I G B, Leong E C, Yong W K.  2008.  Effects of coarse-grained material on
- hydraulic properties and shear strength of top soil.  Journal of Engineering Geology.  101:165-173.
- ***South Pointe // Miami project /// lack of evidences in wind throw to this point***

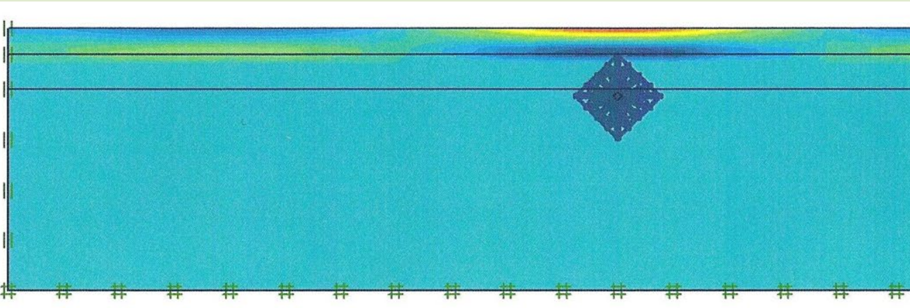
# Does the pavement suffer?

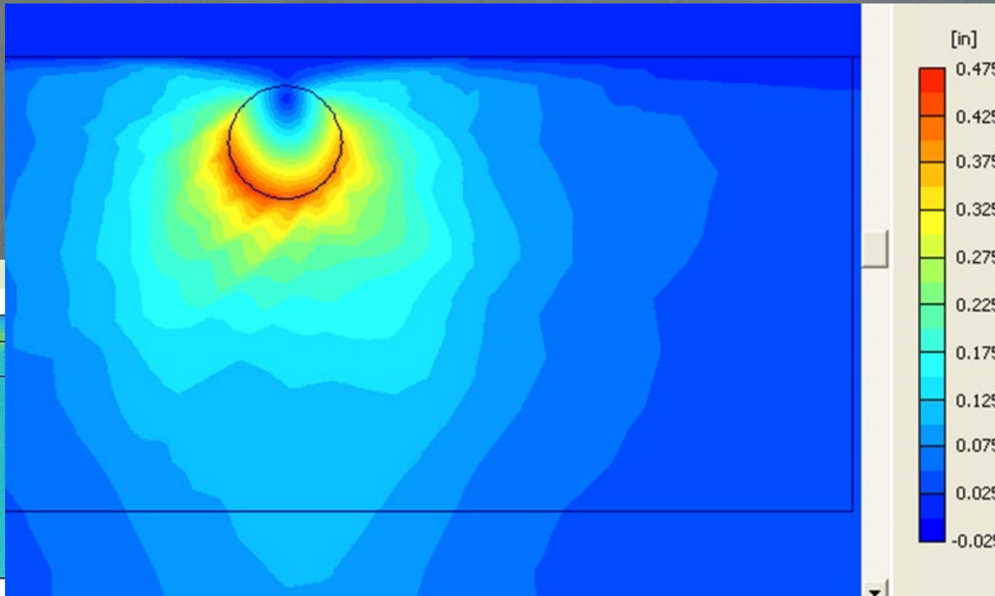
- Grabosky J and Gucunski N. 2011. A method for simulation of upward root growth pressure in compacted sand. Arboriculture & Urban Forestry 37(1):27-34.



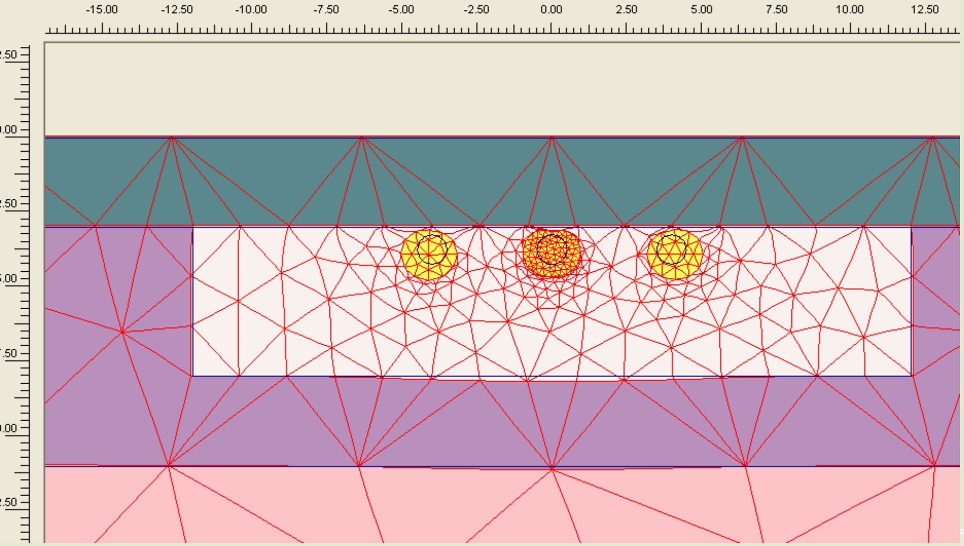
Collaboration with the Center for Advanced Infrastructure Technology
Learning the other disciplines and their languages and approaches



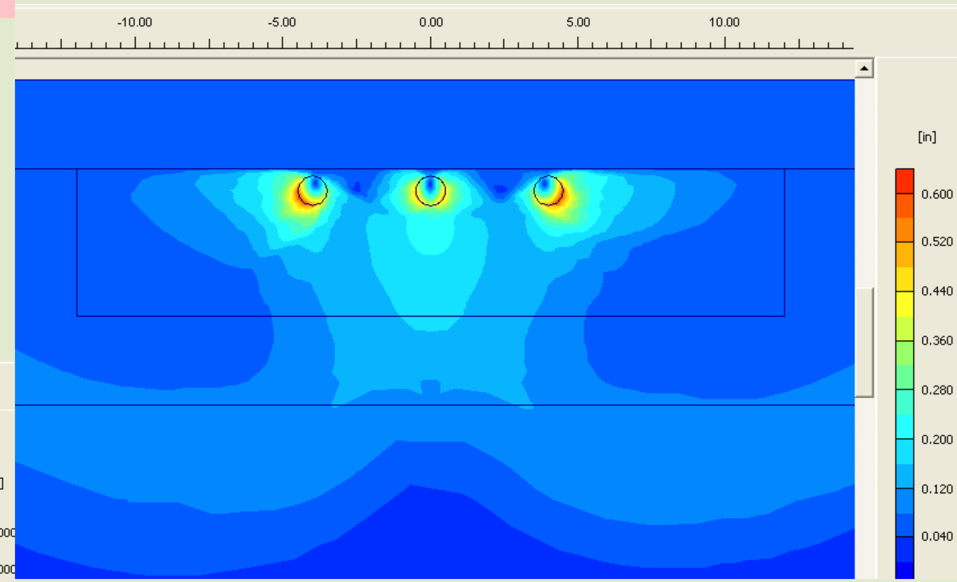





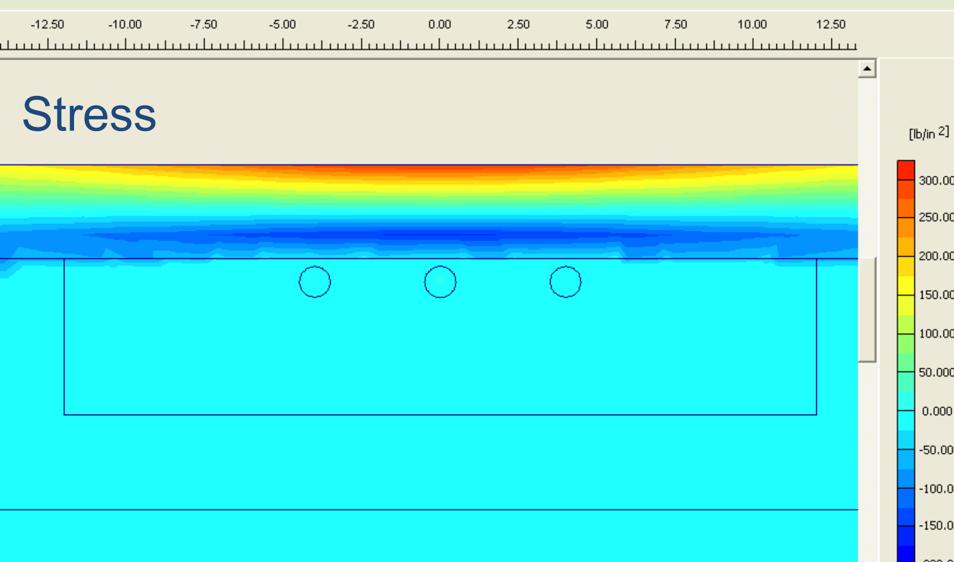
Series 4 evaluated multiple roots in the model




Mesh




Displacements




Stress

# The FEM take homes

- Surface displacements in series 2 increased when the root was positioned deeper in the profile but those scenarios also developed a greater level of growth compared to their shallow root analogues.

- The observation of higher displacement and lower tensile stress with increased rooting depth with greater growth would suggest a need to lateralize the displacements when the root is in the deeper position further decreasing surface layer tensile stress.

- By increasing the AC layer thickness, horizontal stresses and failures drastically decreased.
- Depth does not avoid damages from root growth over time as the root size increase was associated with excessive *displacements a*nd associated tensile stresses in AC independent of root position.

- In series 1 and 2, it was assumed the root was already at 2.54 cm diameter, or preexisting at the start of the model, as if the pavement surface was placed over a “conserved” the root.

- When starting from a small root size, stresses were lower and displacement similar
- Implications in systems given growth as seasonal root flushes
- Model root growth patterns need to reflect growth dissymmetry associated with near trunk Zone of Rapid Taper, to be corrected in future modelling efforts.

- Large displacements may cause local heaves that decreases the road functionality by increasing surface roughness, shortening pavement lifespan outside of cracking in the initial material behaviors post-installation

# Tree growth in designed soils systems over time

- Grabosky J and Bassuk N. 2016. Seventeen years' growth of street trees in structural soil compared with a tree lawn in New York City. Urban Forestry & Urban Greening 16:103-109.
- Grabosky J and Bassuk N. 2008. Growth of three tree species in designed stone-soil blend under pavement and non-paved lawn in a Brooklyn, New York Streetscape: tenth year data. Arboriculture & Urban Forestry 34(4):265-266.
- Grabosky J, Bassuk N, Marranca B. 2002. Preliminary findings from measuring street tree shoot growth in two skeletal soil installations compared to tree lawn plantings. Journal of Arboriculture 28(2):106-108.
- Bassuk N, Grabosky J, Mucciardi T, Raffel G. 2011. Ground Penetrating Radar Accurately Locates Tree Roots in Two Soil Media Under Pavement. Arboriculture & Urban Forestry 37(4):160-166.

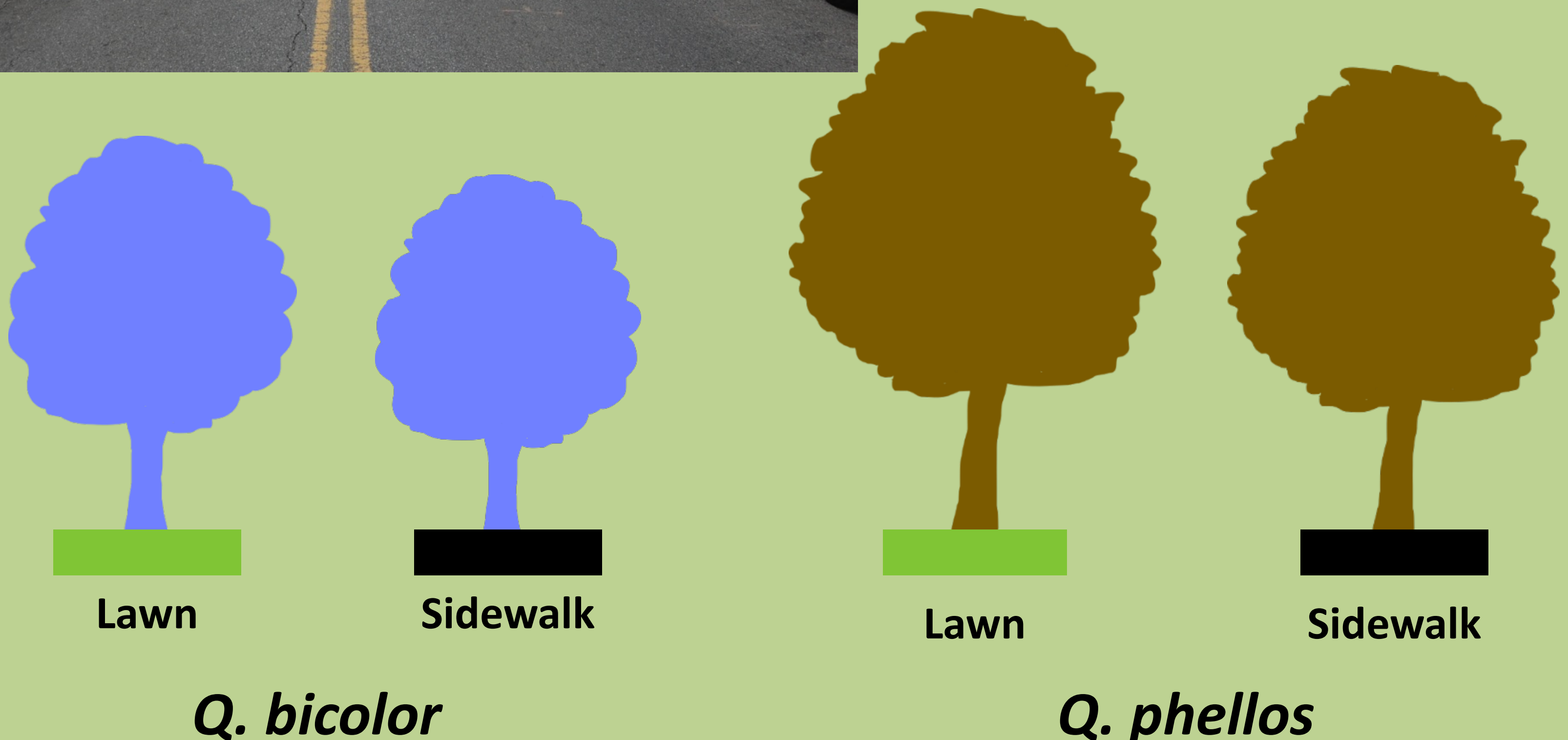

Trees in the designed pavement could be evaluated on the same growth criteria as field-grown landscape trees for the two decades

Photo Taken 2008, year 11

Photo credit J. Kalter

# Long story short …

After 20 years, sidewalk trees have generally kept up with those in the lawn.

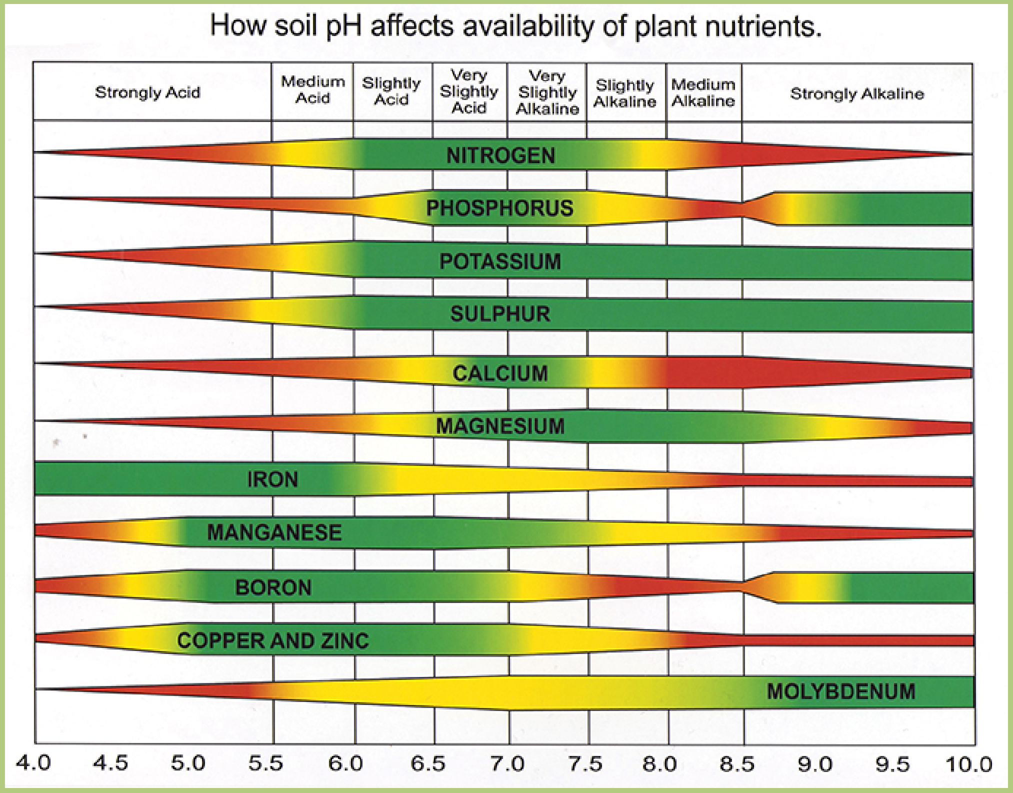


# Growth and other studies

- SIMILAR longer term work from another research team in Singapore, but I have not seen the manuscript published.


- Riikonen A, Lindén L, Pulkkinen M, Nikinmaa E. 2011. Post-transplant crown allometry and shoot growth of two species of street trees. Urban Forestry & Urban Greening 10(2):87-94.
- Bühler O, Kristofferson P, Larson S U. 2007. Growth of street trees in Copenhagen with emphasis on the effect of different establishment concepts. Arboriculture & Urban Forestry 33(5): 330-337.
- Embrén B, Alvem B-M, Stål Ö, Oversten A. 2009. Planting beds in the city of Stockholm: A handbook 2009.02.23; GH100322. Stockholms Stad. Pp83.

# Nutrition and pH




- Pederson A. 2014. Etablering av trær i rotvennlig forsterkningslag: Sluttrapport for forsØk I perioden 2003-2013. Norges miljØ- og biovitenskapelig universitet. Pp77.
- Liesecke H J, Heidger C. Substrate für Bäume in Stadtstraßen. Stadt und Grün 7(2000):463-470.
- Smith K. 2003. The effects of properties of designed soils on growth of *Corymbia maculta.* Doctoral dissertation University of Melbourne Burnley College. Pp 200.
- **Several studies looking at short term tree growth in containerized studies and short term field studies.**
- Dissertation work ; Grabosky 1999 details 3rd year tissue analysis within a paved field study

Salisbury and Grabosky in Preparation: Leaf tissue analysis in the McCarren park trees years 19 and 20.

- Scharenbroch B C, Johnson D P. 2010. A microcosm study of the common night crawler earthworm (Lumbricus terrestris) and physical, chemical and biological properties of a designed urban soil. Urban Ecosystems

Photo shamelessly stolen from the image collection of : Extension.psu.edu

# Are mix designs optimized?

# NO

- Kristofferson P. (1998) Designing urban sub-bases to support trees. J. Arboriculture 24(3):121-126
- Heidger C.  2002.  Wurzeln sind lenkbar! Optimierungsmöglichkeiten im Wurzelraum von Straßenbäumen.  Osnabrű́cker Baumpflegetage.  03-09-2002.

< Previous Abstract |

# Research Note: Establishing a Common Method to Compare Soil Systems Designed for Both Tree Growth and Pavement Support

Grabosky, Jason

Soil Science: April/May 2015 - Volume 180 - Issue 4/5 - p 207–213
doi: 10.1097/SS.0000000000000124
Technical Article

Abstract | Author Information

Abstract: Establishing and managing trees under urban conditions provide a lesson in opposing needs within limited spaces. In the same soil volume, there are competing requirements for pavement support versus biological carrying capacity. Media to support both pavements and tree growth have been used for decades. However, with several media designs being advanced and discussed, there is limited research testing to inform mix design when new component sources are considered, or when comparing different components and mixtures. Designed media need to perform an engineering function immediately, but trees require time for growth to reach the designed service size. Therefore, there is a need to understand fundamental trends prior to waiting decades for tree performance evaluation. A common evaluation rubric needs to be developed in order to compare successful and unsuccessful systems and to better target mix designs of locally available materials. The media discussed in this article is a group that establishes an aggregate skeletal matrix for load bearing with an added horticultural component for tree root growth within the matrix.

To understand both matrix development for load bearing and the critical soil component for tree biotic capacity, one convenient media evaluation method would be a voids analysis based on a four-component system of air, water, soil, and aggregate. A further adaptation from a similar method to define the critical amount of bitumen in asphalt concrete design seems contextually appropriate. This approach would use a voids analysis on a four-component system, akin to historic Marshall Testing Protocols. The term "percentage of apparent voids filled" is used as one component in a voids analysis approach. An initial voids analysis output series is suggested using peak compacted density, California bearing ratio, hydraulic conductivity, plant-available moisture/percent air voids at field capacity, percent voids in compacted mineral matrix, and percentage of apparent voids filled as measured across increasing soil-stone ratios within defined aggregate and soil pairings. Using archived data from a series of past experiments, a voids analysis example is used to illustrate a common format to reconcile the varied soil design systems into a common matrix for better comparison, understanding, and refinement.



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## Article Keywords

Keywords
Tree growth matrix, urban soil design, voids analysis

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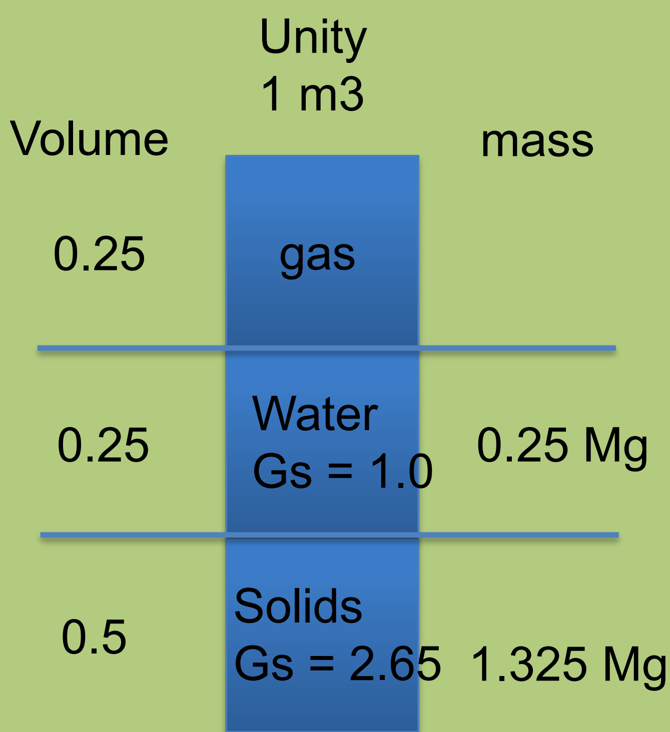
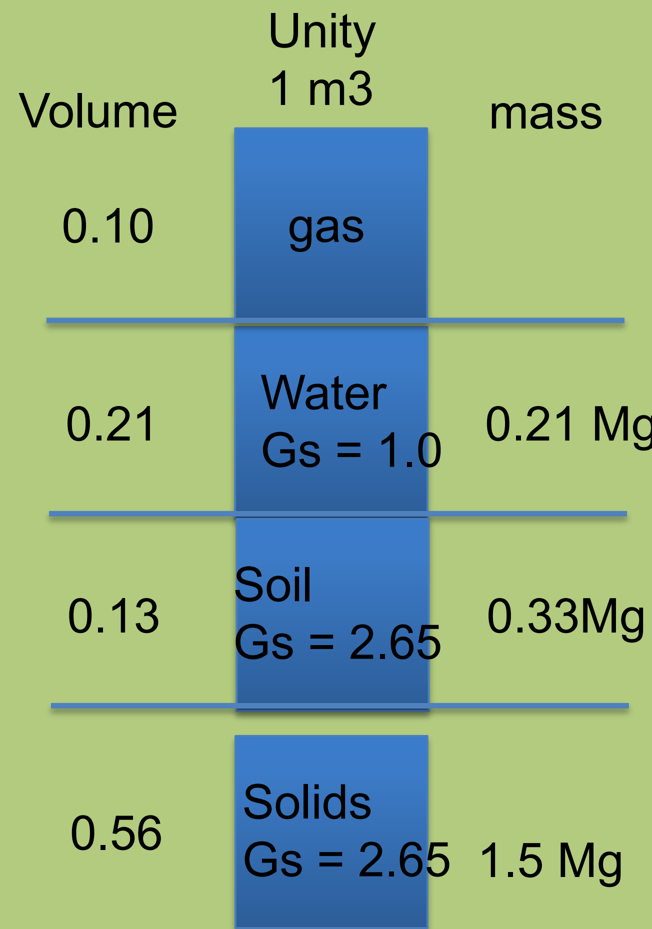
Matrix porosity assumed as maximum Shergold number




*w*, or gravimetric moisture is 18.87%

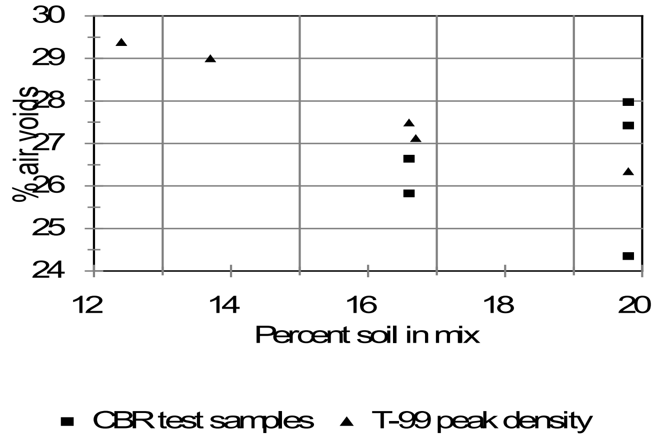


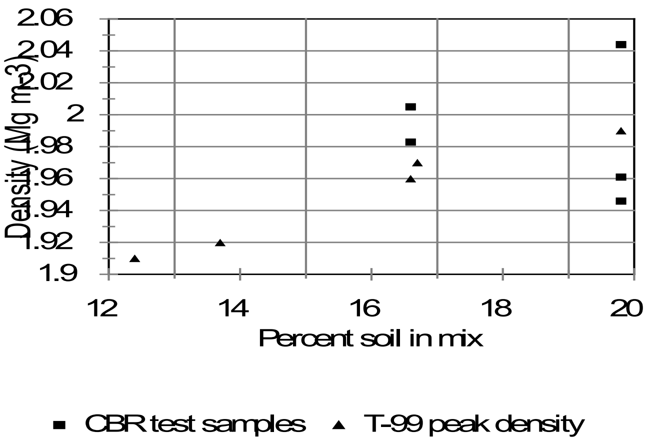

*w*, or gravimetric moisture is 11.5%
*Gravimetric Ratio stone:soil =*
*.82: .18…or about 6:1*

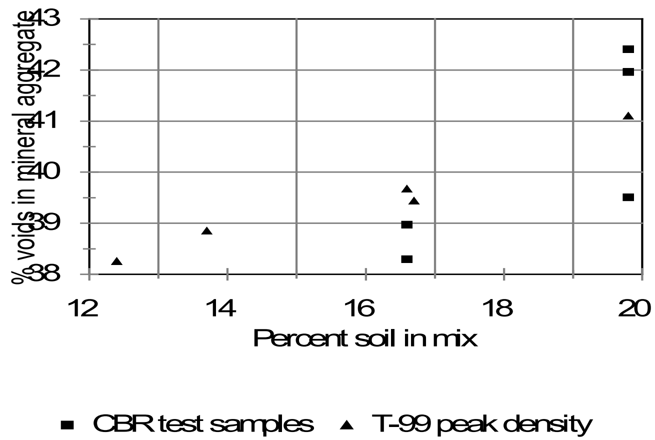
$$PAVF = \left[\left(\frac{V_{so}}{V_{vst}}\right) \times 100\right] = \left[\left(\frac{\frac{W_{so}}{(G_{so} \times \delta_{water})}}{V_{vst}}\right) \times 100\right]$$

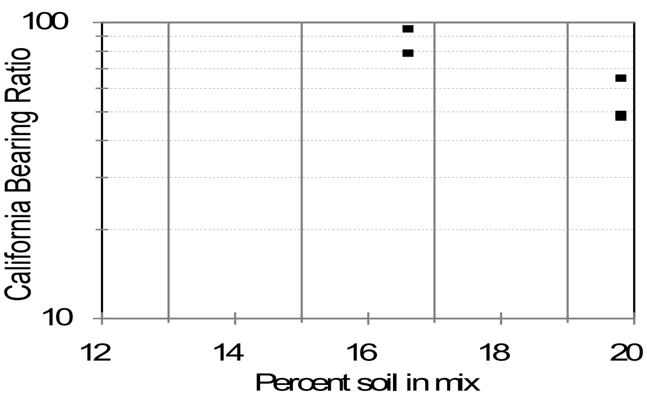
$$= \left[\left(\frac{\frac{W_{dry} - (W_{dry} \times SSR)}{(G_{so} \times \delta_{water})}}{\left(1 - \left(\frac{W_{dry} \times SSR}{(G_{st} \times \delta_{water})}\right)\right)}\right) \times 100\right]$$

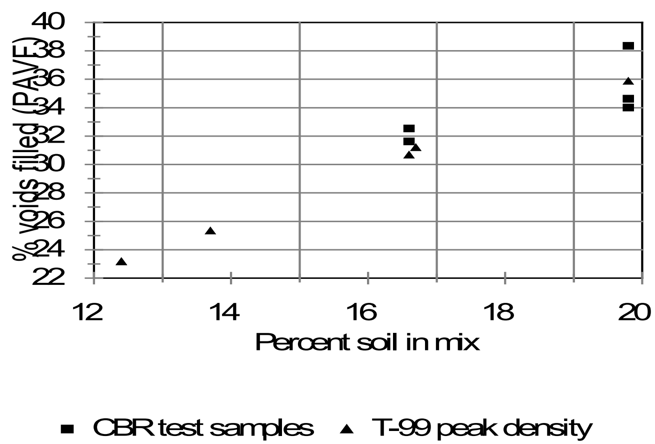
Missing plot: Hydraulic conductivity: Constant and falling head on the y axis



# Hey, if it was easy, I'd still have hair

Photo credits:
Dr. Peter May from
Peter Breen EDAW for WSUD

Denman E., May P.B., Breen P. F. 2006. "An investigation of the potential to use street trees and their root zone soils to remove nitrogen from urban storm water." Australia Journal of Water Resources 10(3):303-310.

Denman, E. C. 2009. An experimental assessment of the potential role of street trees in urban biofiltration systems. Dissertation Univ. Melbourne Burnley college.


OFF

# A cheat sheet to cross-list materials and experiences

- Stone and soil definitions, Particle size distributions, Gs
- Listed gravimetric percentage in mix design *and variability in the field*
- Installed, verified  density *and variability*

- Water data is needed on a more thorough level

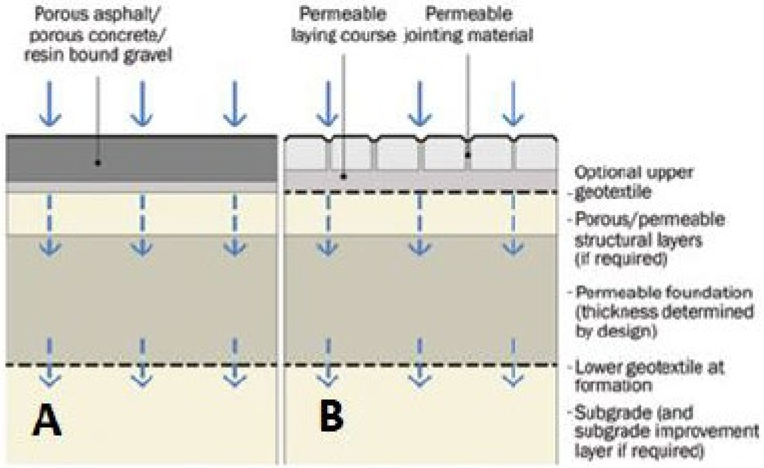



*Figure 2-1 Difference of Porous Pavements (A) and Permeable Pavements (B) (CIRIA, 2015)*

Edinburgh Napier UNIVERSITY

# Optimising the Hydrological Performance within Permeable Pavements.

Daniel Wallace

40184993

March 2017

Dissertation submitted in partial fulfilment for the Degree of
BEng (Hons) Civil Engineering

Only 380 pages.

# Trees, stormwater, soil and civil infrastructure: synergies towards sustainable urban design

by

**Timothy Johnson**

**DipHort, BAppSc, GradDipOEd, GradDipAppSc, GradDipMgt**

A thesis submitted for the degree of

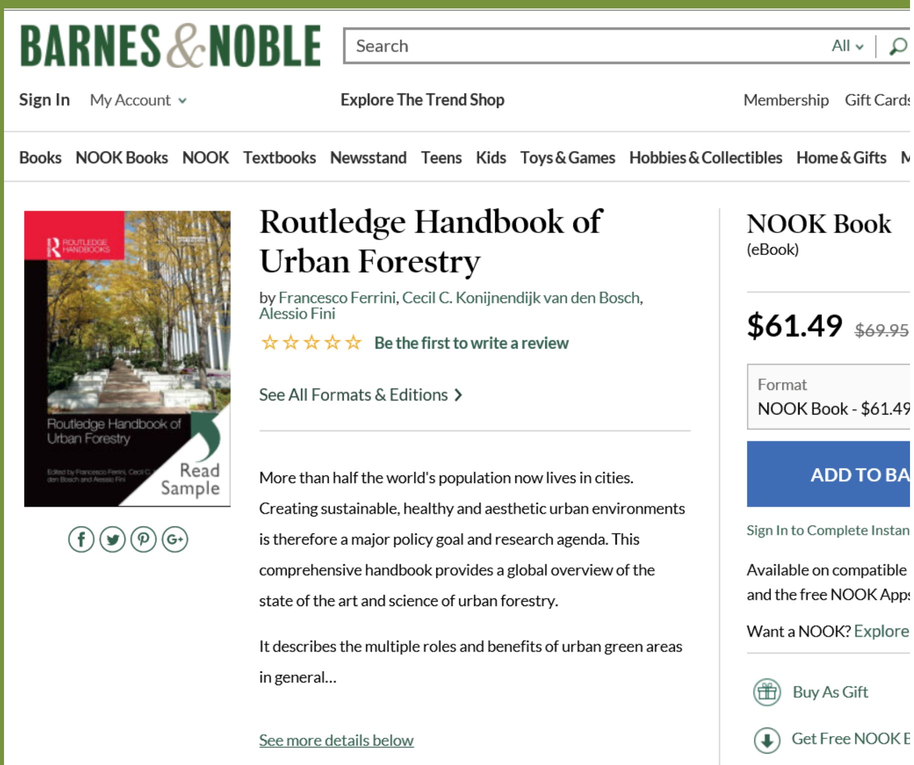
**Doctor of Philosophy in Civil Engineering**

School of Natural and Built Environments

Division of Information Technology, Engineering and Environment

University of South Australia

November 2016




# 22

# DESIGN OPTIONS TO INTEGRATE URBAN TREE ROOT ZONES AND PAVEMENT SUPPORT WITHIN A SHARED SOIL VOLUME

*Jason Grabosky and Nina Bassuk*



## The problem

Urban trees face a wide range of environmental challenges, the most significant of which is the scarcity of soil suitable for root growth (see Chapter 21). Often, soil compaction serves as the leading impediment for tree establishment. So even if there is soil present it is not available for root colonization and exploitation for growth support. While many of the problems urban trees face can be mitigated by planting species that are tolerant of a given challenge, there are relatively few tree species that can thrive within compacted soils which are prevalent throughout urban and suburban landscapes. Soil volumes are shared by grey and green infrastructure. Given a lack of space to expand and provide separate volumes for trees, there are integrating design solutions for tree soil volumes and pavement support.

In urban soils that are not covered by pavement, it is possible to break-up, amend or replace compacted soils to make them more conducive to root growth. However, where soils are covered by pavement, the needs of the tree come in direct opposition to pavement design requirements for a highly compacted supporting base on which to construct pavement. Pavement must be laid on well-draining compacted bases so that the pavement will not subside, or otherwise prematurely require replacement.

As a result, soils that must support pavement are often too dense for root growth. Pavement systems consist of a series of layers; lower layers support the materials placed in layers above. To design and support a safe, durable pavement system, soils are compacted to provide an increased load-bearing capacity, providing cost-effective support for the comparatively expensive wearing surface of the pavement. In general, sites which are expected to support pavement surfaces are compacted to a peak density as determined by a moisture-density

Questions?

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