How Water Moves in Trees

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January 19, 2022

Goals for this Presentation

1. Why trees use as much water as they do
2. Mechanisms that move water through the tree
3. How drought stress impacts the water column and the long-term health of trees

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Why Do Trees Move Water?

For photosynthesis? Nope.

1% of water used for photosynthesis

5% of water used for growth

Why Do Trees Move Water?

94% of water is lost just to absorb a few molecules of carbon dioxide (CO_2)

For each CO_2 molecule absorbed tons of water molecules are released

(except for CAM photosynthesis)

To Thirst or Starve

The cruel dilemma:

To die of thirst (stomata open)

To die of starvation (stomata closed)

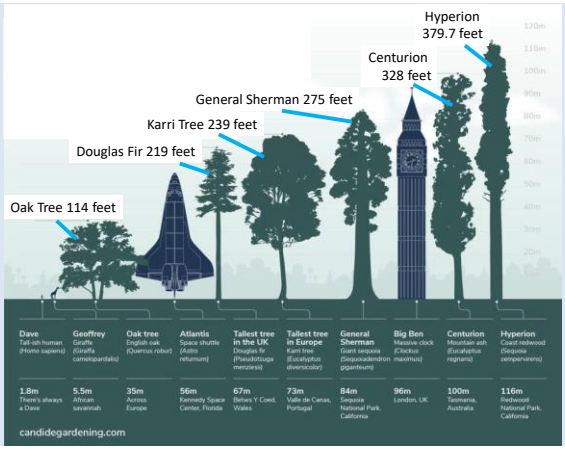
Plants chose to "waste" water

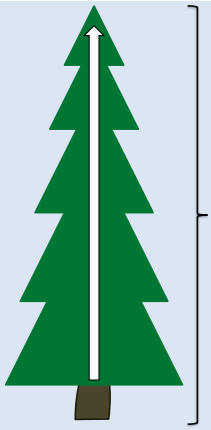
Why Are Tree-Water Relations Amazing?

Highest water can be drawn upward is 32.8 ft (10 meters)

At 32.8 ft the water is heavier than atmospheric pressure. Needs positive pressure.

How are trees able to get enough water?





How are trees able to move water above 10 m (32.8 ft)?

Tree would have to create a pressure difference of at least 10 atm (147 psi)!!!

Let's understand the properties of water…

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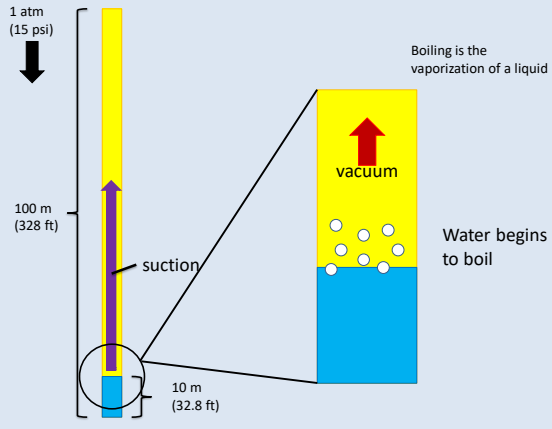
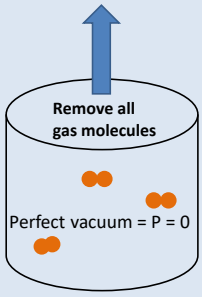


Trees Defy Physics, kind of

The lowest pressure can go is a pure vacuum (0 atm and psi) – Right?!

THAT IS TRUE FOR GASES

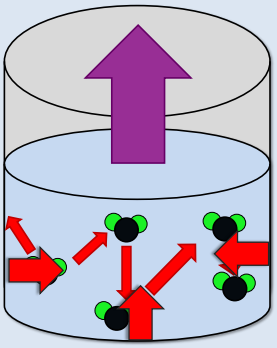


Solids and Liquids Can Go Lower

Solids and liquids can have negative pressures

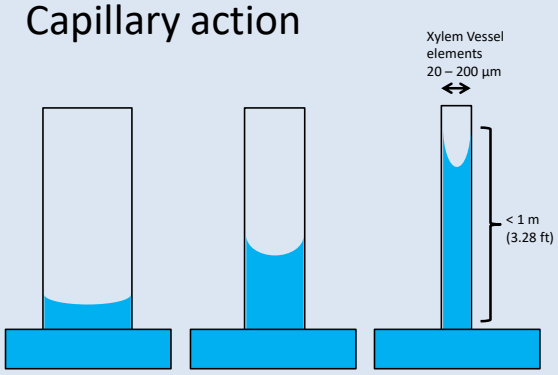
Solids = tension

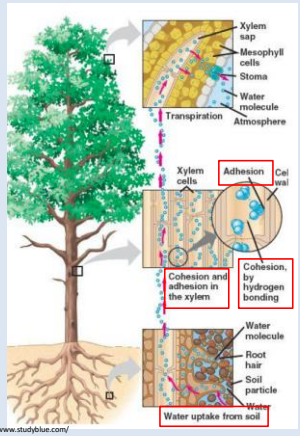
Cohesion-Tension Theory



With liquids, negative pressure causes molecules to cling to each other and their surroundings

Capillary action





Cohesion-Tension Theory in Trees

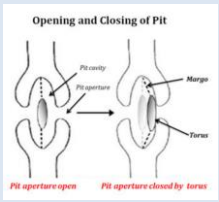
Higher evaporation in the leaves

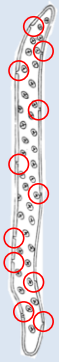
Higher absorption by the roots

Higher tension in the xylem water columns

Gymnosperms have Tracheids

- Fibers + sap movement
- Transport water and minerals
- Dead when physiologically active
- 3-5 mm long
- Closed at each end
- Have pores along entire length

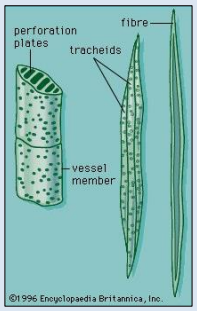


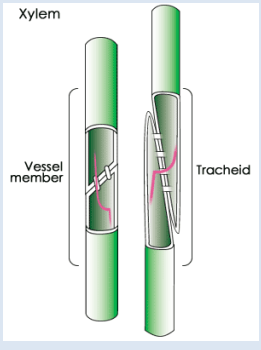


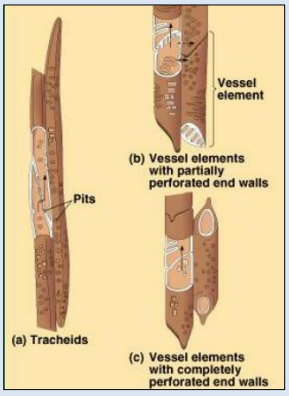
Marshall Ward H. The Oak: A Popular Introduction to Forest-Botany. – London: Kegan Paul, Trench, Trübner and Co. Ltd., 1892.

Angiosperms have Vessel Elements

- Have more specialized xylem
- Separation of water conduction (vessel elements) from mechanical support (fibers)
- Harder wood (fibers)
- More efficient sap flow







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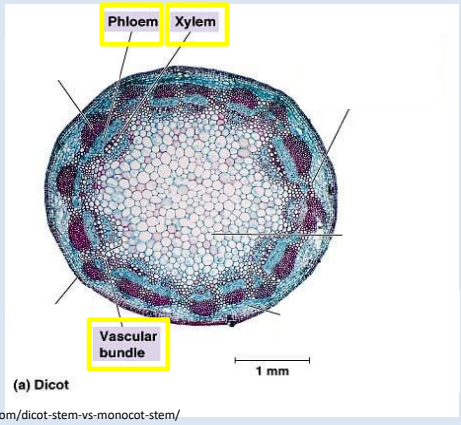
https://www.slideserve.com/nivedtha/greek-angeion-case-sperma-seed



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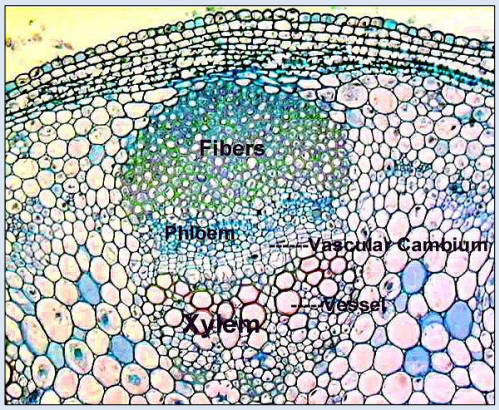
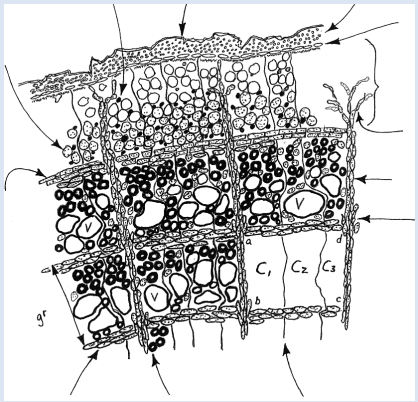
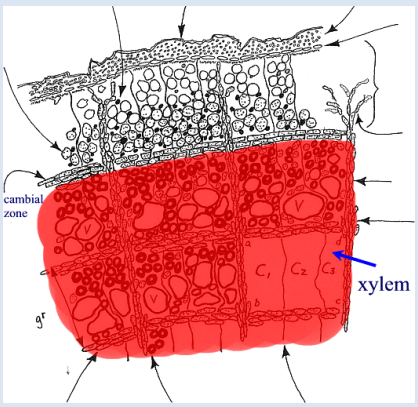


https://lima.osu.edu/academics/departments/biology/plant-anatomy/stems.html



Illustrations, PowerPoints or photos by Edward F. Gilman, Professor, Environmental Horticulture Department, IFAS, University of Florida



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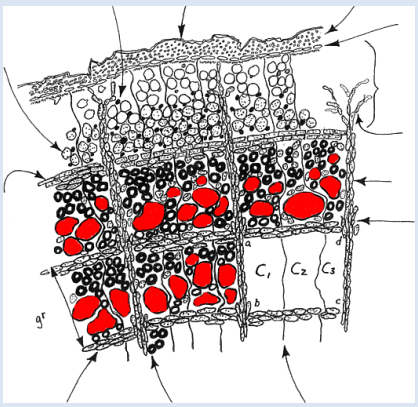

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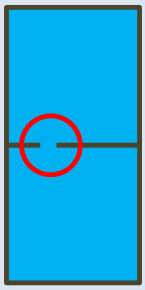
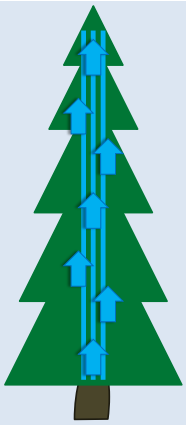
Xylem Vessel Elements

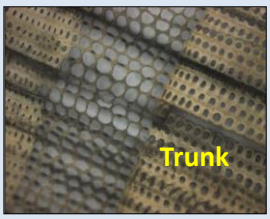
- Can be up to 10 ft long!!!
- Have pores 2 – 5 µm (0.000007 – 0.0002 inch)

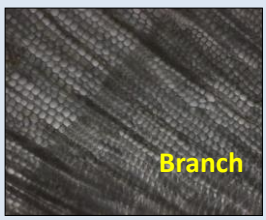




The water molecules in a tree are in solid, unbroken, columns in the xylem

What's happening?

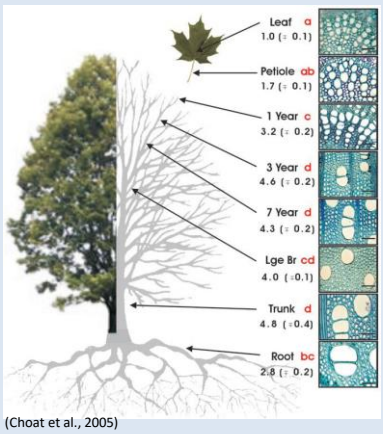




Resistance to water flow through the xylem

Slash Pine

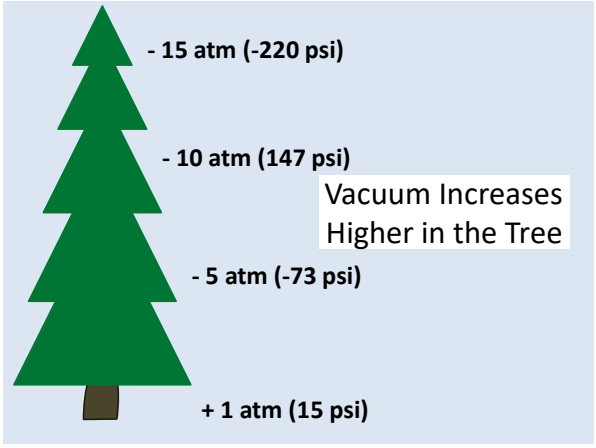
Slide curtesy of Tim Martin



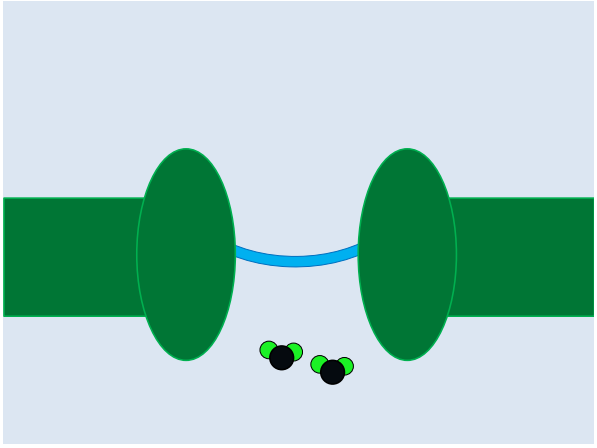
Air seeding threshold (MPa) in Sugar Maple.

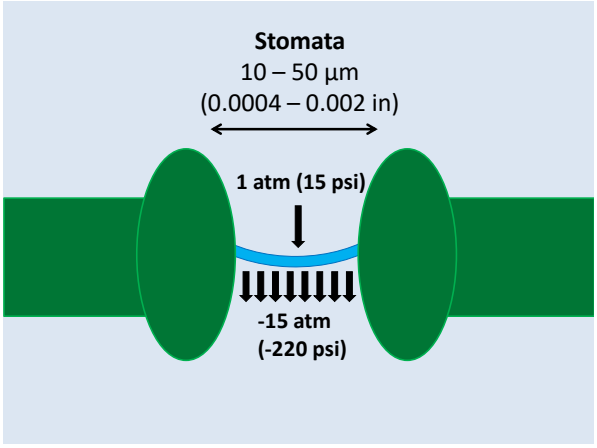
Negative pressure (tension) required to draw a bubble through an inter-vessel pore

(Choat et al., 2005)


- 15 atm (-220 psi)
- 10 atm (147 psi)
Vacuum Increases
Higher in the Tree
- 5 atm (-73 psi)
+ 1 atm (15 psi)


Let's look at what's happening
in the leaves




Stomata
10 – 50 µm
(0.0004 – 0.002 in)
1 atm (15 psi)
-15 atm
(-220 psi)

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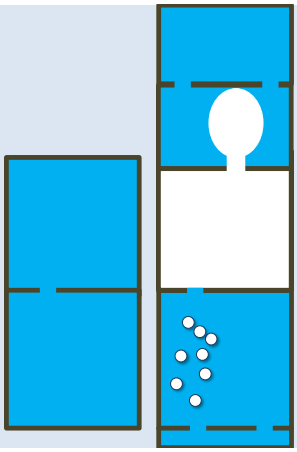
When there is a break in the water column a cavitation occurs

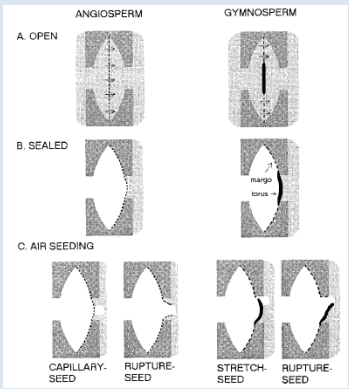
Wider and longer vessel have higher chances of embolism

Freeze-thaw cycles



Air Seeding

Air bubble is pulled through the pit because of the different pressure between an air-filled vessels and vessels under tension



(Sperry *et al.* 1996)

Acoustics of Cavitation

Ultrasound acoustic emission sensor that attaches to the xylem to record cavitation

- Ultrasonic acoustics emissions of cavitation in arborvitae recorded 0.1 – 1 megahertz
- Can last 20-200 microseconds
- Noise attracts insects

Jackson and Grace, 1996. Tyree and Dixon 1983. Plant Physiology, Vol. 72, Issue 4. August 1983

Secondary Problems

- Some pest insects are attracted to drought-stressed trees
- Concentrated nutrients can favor insect development
- In conifers, drought results in less resin production, a primary defense mechanism

Photo courtesy of the National Park Service

Secondary Insect Pests

- Bark beetles
  - Dutch elm disease vectors
  - Oak wilt vector
- Two-lined chestnut borer
- Bronze birch borer
- Ambrosia beetles
- Two-spotted spider mite

Pitch tubes produced by Southern pine beetles. Photo: Erich G. Vallery, USDA Forest Service - SRS-4552, Bugwood.org

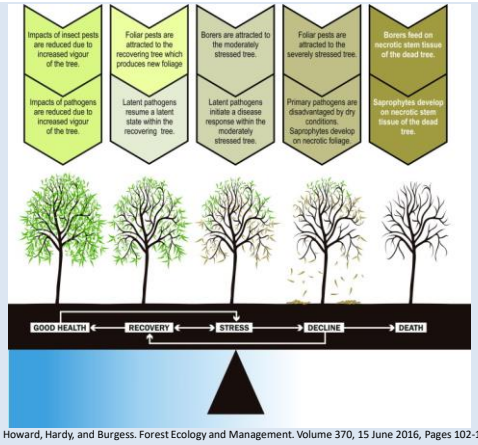
Drought stress and Disease

- Canker fungi
  - *Fusarium*
  - *Botryosphaeria*
  - *Diplodia*
- Stem and heart rots
  - *Ganoderma*
  - *Armillaria*
- Root rots
  - *Phytophthora*
  - *Pythium*

Biscogniauxia (*Hypoxylon*) canker on oak
Photo credit: Les Fortenberry

Drought and Chemical Defense

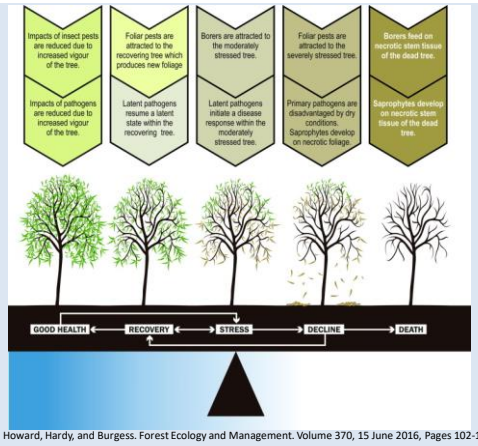
- Drought stress results in less secondary metabolites or defensive compounds
- Defense chemicals are not as strong and more easily broken down by insect pests
- Defense chemicals are not able to stop fungal infections
- Increases susceptibility to attack



Whyte, Howard, Hardy, and Burgess. Forest Ecology and Management. Volume 370, 15 June 2016, Pages 102-113

Mild-Moderate Drought

- Leaves can recover by re-leafing-out
- Low levels of cavitation
- Some plants can recover/refill after cavitation, but it is very rare
- Even recovered plants are a high probability of dying
  - Out competed for resources
  - Attract insect pests and pathogens



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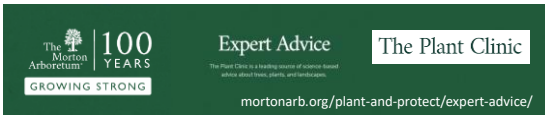
Sever Prolonged Drought

- Cavitation occurs extensively
- Plant are then in their survival mode
- There are thresholds where trees will never recover
  - 50% in conifers
  - 90% in angiosperms

Summary

- Drought stress is a primary stressor that can start the decline spiral
- Maintaining a solid water column by watering can prevent secondary problems
- It takes years for trees to recover from drought stress, prevention is the best medicine



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Thank You!

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Thank You!