

HWRS 561b: Physical Hydrogeology II

Pore-scale fluids distribution

Agenda:

1. Air-water interface
2. Capillarity

Air-water system in capillary tubes

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Bo Guo
Spring 2026

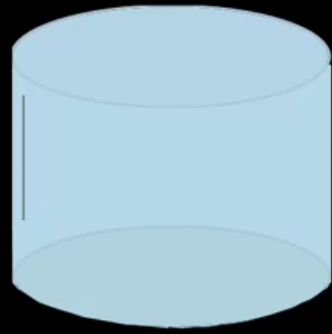


1. Why does the water try to hold together?
2. Why does the water not wet the surface?

Air-water system in capillary tubes

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**SURFACE
TENSION**



Link to the video: <https://youtu.be/zMzqiAuOSz0>

Air-water system in capillary tubes

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- Two and three phase systems: water, oil, air
- *Interfacial tension (cohesive forces between fluid molecules)*

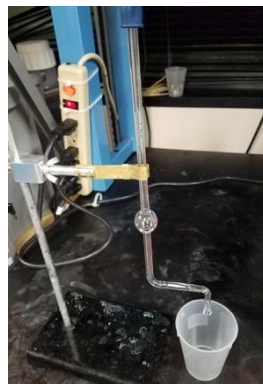


Typical values of surface tension:

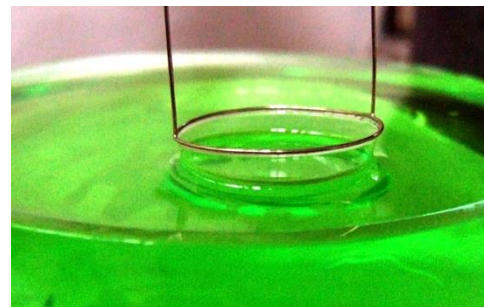
air-water	0.072 N/m
oil-water	0.20 N/m
oil-water w/ soap	0.0001 N/m

How to measure interfacial tension?

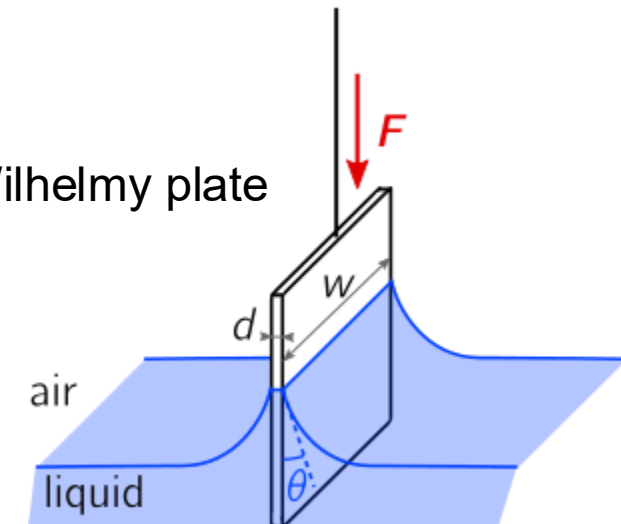
Drop weight
method



ring method

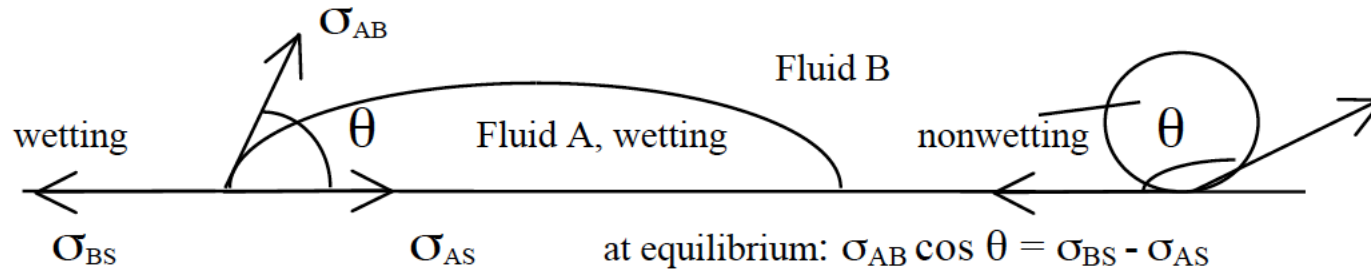


Wilhelmy plate



Air-water system in capillary tubes

- *Wettability (adhesive forces between the fluid and solid surface)*



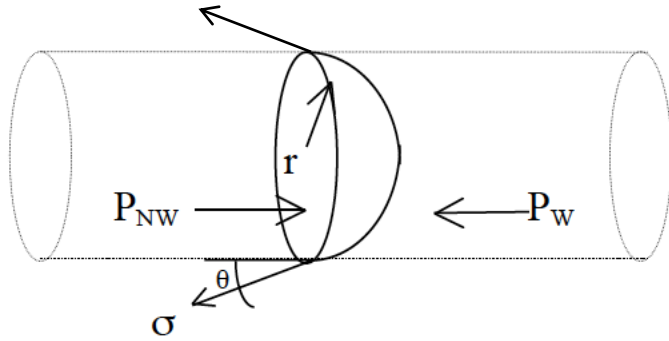
$\theta < 90^\circ$: fluid A is wetting with respect to fluid B on the solid S
 $\theta > 90^\circ$: fluid A is nonwetting with respect to fluid B on the solid S

Wettability is a function of the fluid properties, soil properties, and history of contact. For most soils, the relative wettabilities are: water > oil > air

Recommended video for the concepts of *viscosity, cohesive and adhesive forces, surface tension, and capillary action* https://www.youtube.com/watch?v=P_jQ1B9UwpU

Air-water system in capillary tubes

Capillary pressure (difference between the nonwetting and wetting phase pressures)



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Capillary pressure, Young-Laplace Equation

Pressure jump across a
fluid-fluid interface



Pressure jump across a fluid-fluid interface is
determined by interfacial tension + geometry
of the interface (radii of the curvature)



Art of porous media flow

Optional, but strongly encouraged, Mini-project

Take a photo or a video (< 2 min) in your day-to-day life that you think best illustrates some cool phenomena of porous media flow.

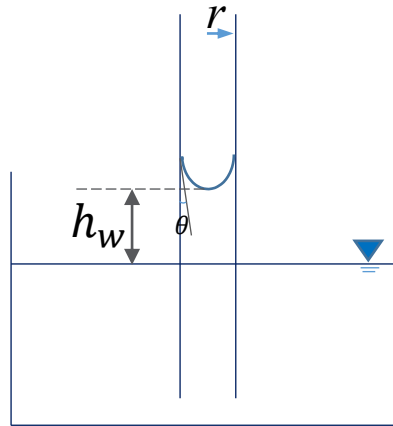
I will create a dropbox on D2L for you to upload the photo or video (due **April 26**).

Depending on the quality of your picture or video, you can receive up to 5 bonus points in your final grade (out of 100 points).

Air-water system in capillary tubes

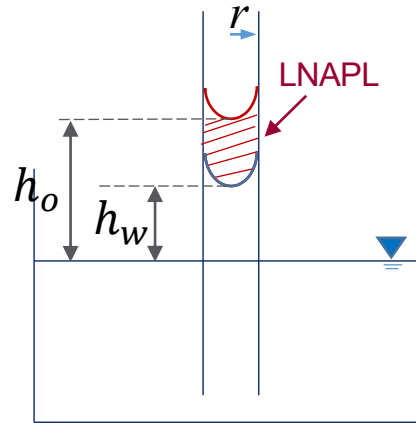
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Capillary rise in a Capillary tube



Air-water system in capillary tubes

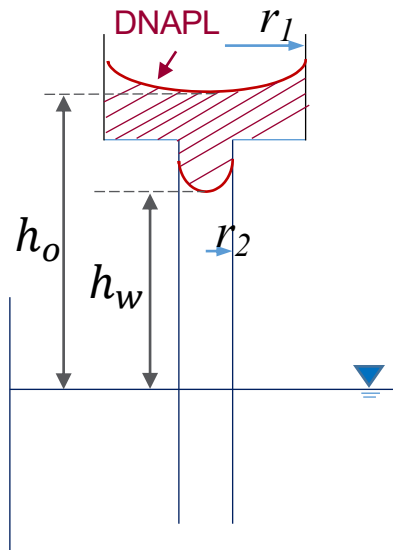
Capillary rise in a Capillary tube in the presence of an LNAPL (Assuming zero contacts)



Air-water system in capillary tubes

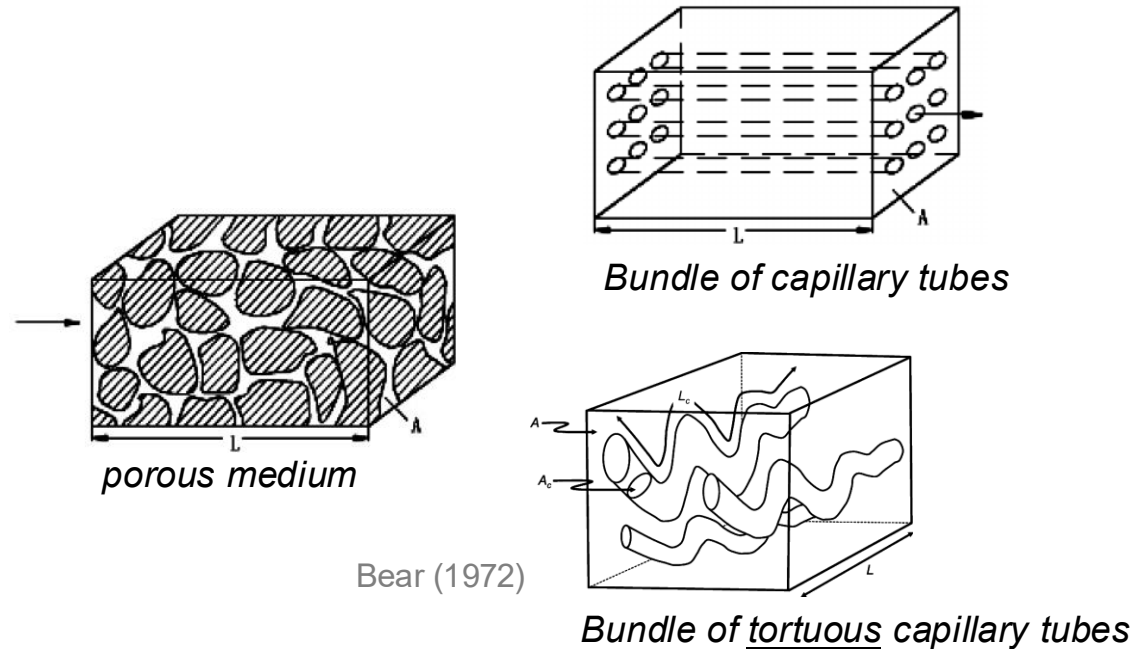
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Invasion of a nonwetting fluid into a pore (Assuming zero contacts)



Air-water system in capillary tubes

Model of a porous medium as a Bundle of Capillary Tubes



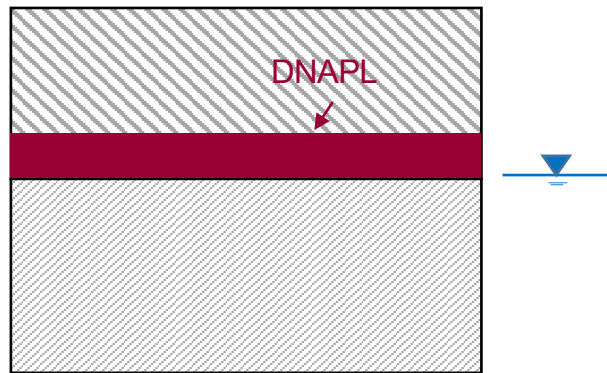
❖ Very simplified model, but its application has tremendously improved our understanding of fluid flow and transport phenomena in porous media.

Some examples:

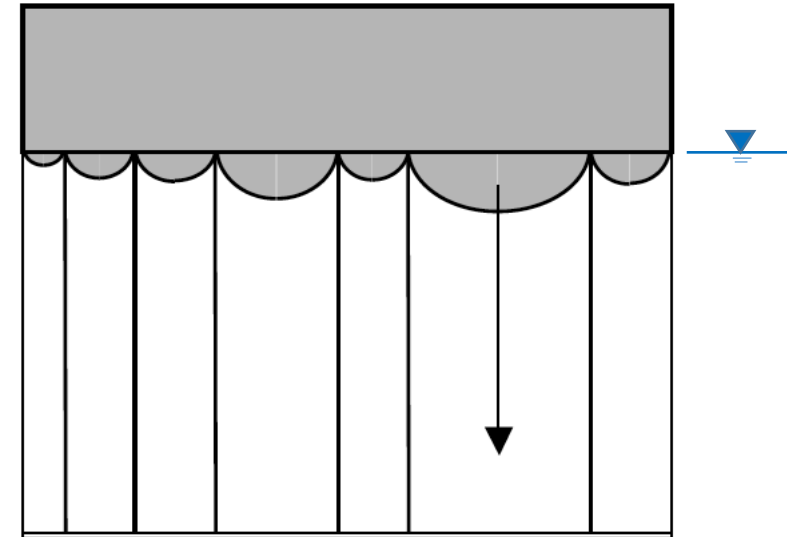
- Permeability (already discussed)
- Dispersion (already discussed)
- Fluid invasion
- Capillary transition zone
- Soil water characteristic curve
- Relative permeability

Air-water system in capillary tubes

Invasion of a nonwetting fluid into an aquifer



Representing the aquifer as a bundle of capillary tubes



1. Which is easier for DNAPL to invade?

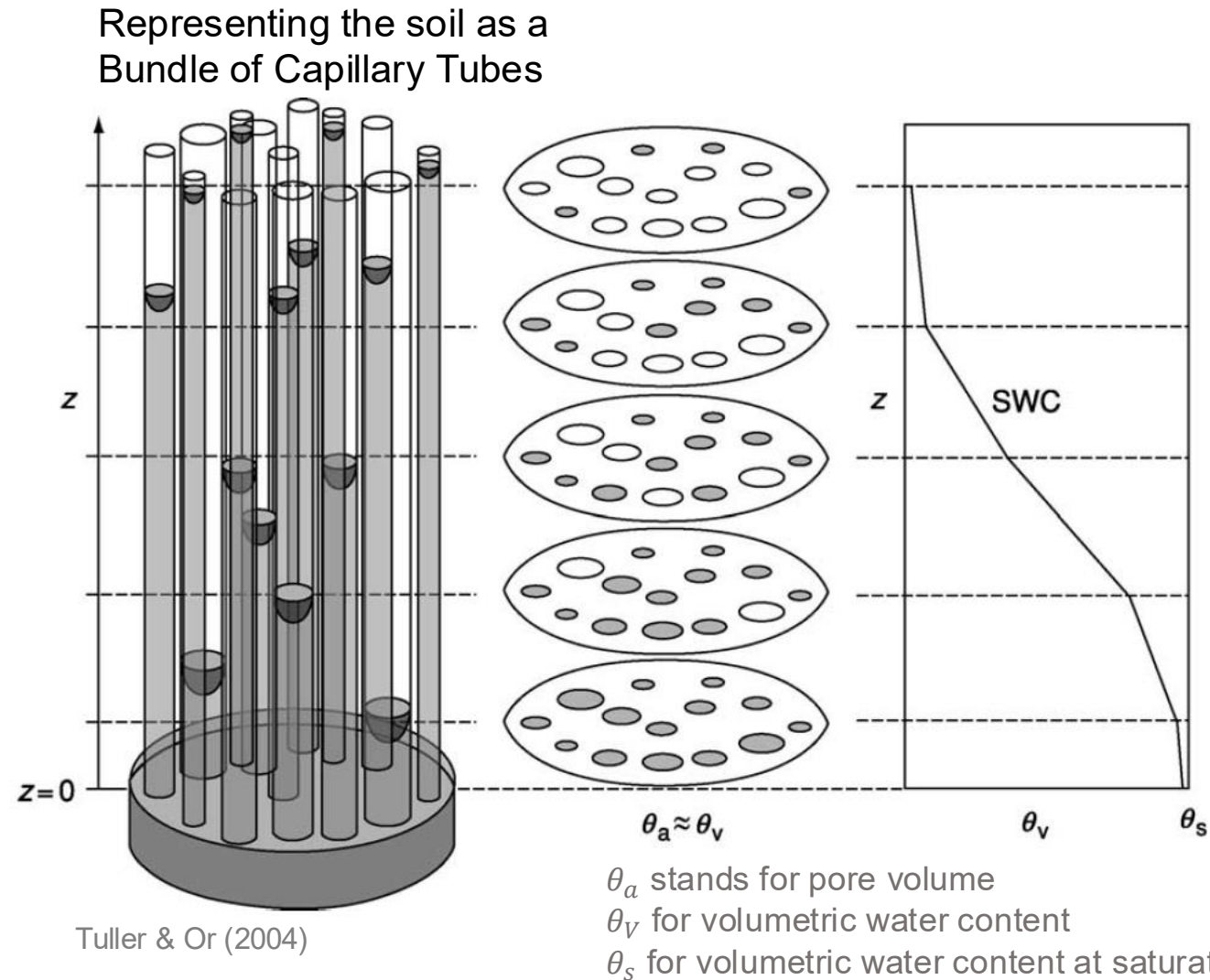
Coarse sand or fine-grained medium?

2. For some reason, if DNAPL modifies the wettability of the porous medium grain surfaces, e.g., the contact angle of water increases from 0° to something between 0° and 90° .

What may happen to the DNAPL?

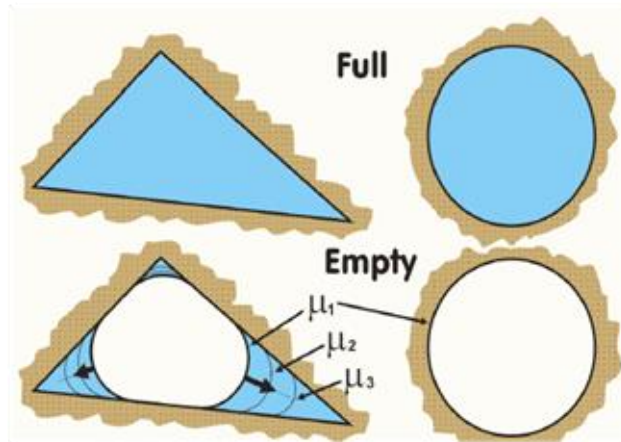
Air-water system in capillary tubes

Water retention (or capillary transition zone) in the vadose zone



Air-water system in capillary tubes

Bundle of triangular capillary tubes vs. bundle of cylindrical capillary tubes



Tuller, Or, Dudley (1999)

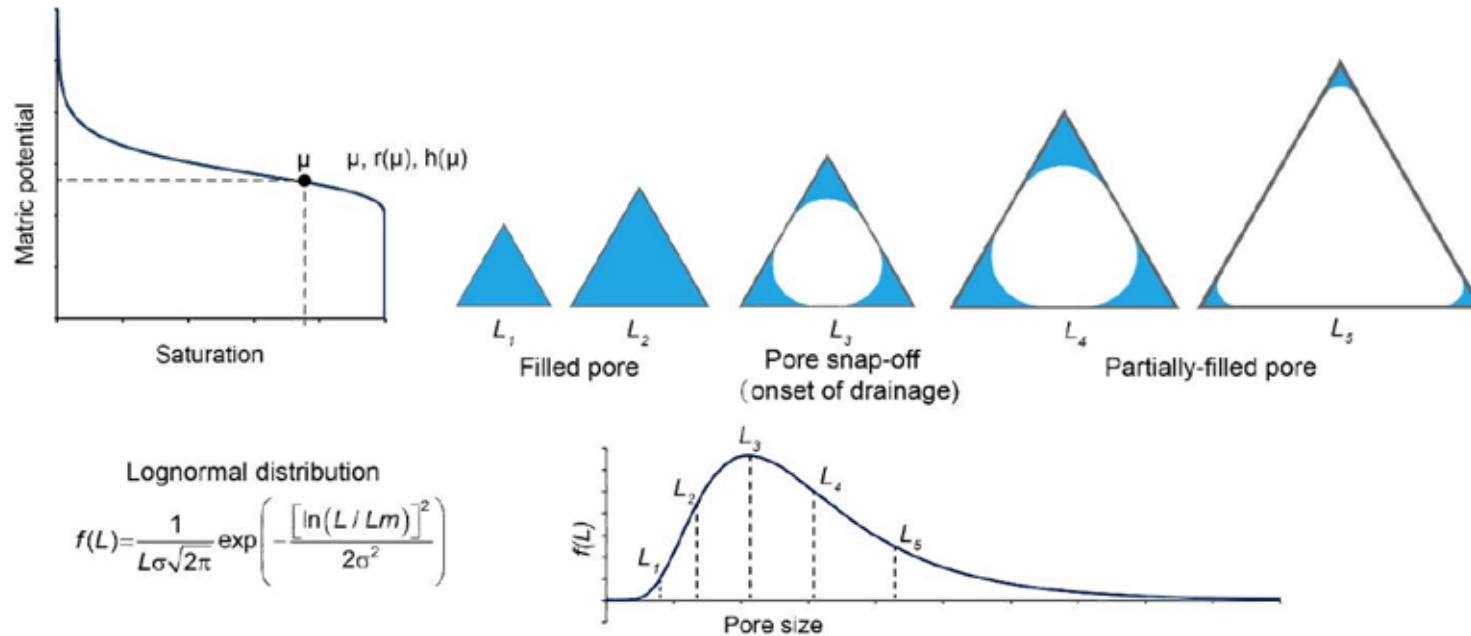
Bundle of triangular capillary tubes model have several advantages:

1. Can represent thin films and corner fluid
2. Saturation-dependent capillary pressure within a single-pore
3. More realistic representation of pore geometry
4. ...

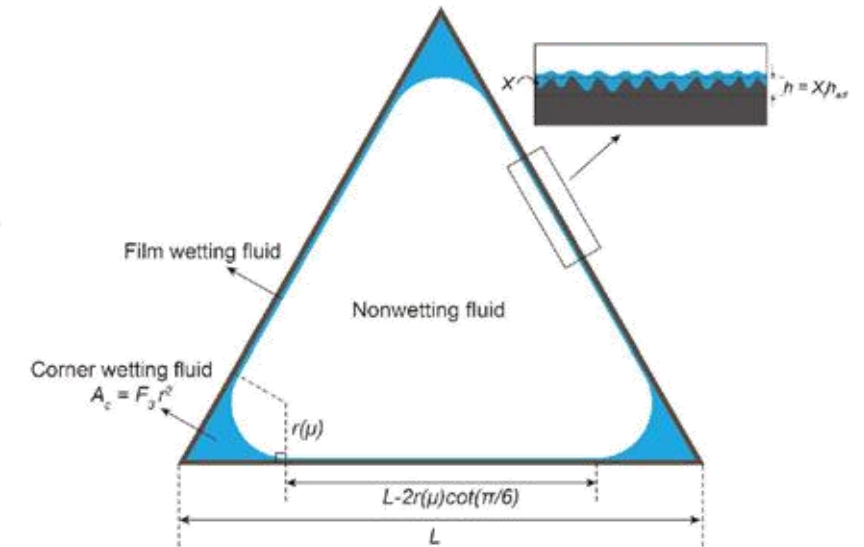
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An example study using the bundle of triangular capillary tubes model to examine the impact of surface roughness on fluid-fluid interfacial areas $A_{aw} = A_{aw}(S_w)$



Simulating the soil-water characteristics



Representing the surface roughness and films