Plot Scale
What this section will address

- Plot scale
- Hillslope scale
- Catchment scale
What are the first order controls on water movement vertically at the plot scale?

- Depth decline in drainable porosity
- Depth decline in hydraulic conductivity

How is it that preferential flow, while only a small part of the overall soil porosity, is responsible for most of the flow at or near saturation?
Some Soil Properties

- **Particle density**
  \[ \rho_b = \frac{M_s}{V_s} \]

- **Bulk density**
  \[ \rho_s = \frac{M_s}{V_t} \]

- **Porosity**
  \[ \phi = \frac{V_f}{V_t} \]

- **Void ratio**
  \[ \psi = \frac{V_s}{1 - \phi} \]

- **Water content (vol.)**
  \[ \theta = \frac{V_w}{V_t} \]

- **Water content (grav.)**
  \[ w = \frac{M_w}{M_s} \]

- **Degree of saturation**
  \[ s = \frac{V_w}{V_f} = \frac{\theta}{\phi} \]

I will assume you know this.
Plot scale: e.g. Inceptisols

- humid and subhumid regions that have altered horizons that have lost bases or iron and aluminum but retain some weatherable minerals.

http://www.statlab.iastate.edu/soils/photogal/orders/soiord.htm
Soil type and hydrological controls at the plot scale

- Soil surface sealing
- Top soil compaction
- Hydrophobicity
- Macroporosity
- Bedrock permeability
- Barriers to vertical flow
- Preferential lateral flowpaths
- Matrix permeability

Petra Fackel, used with permission

Peter Kienzler, ETH Zurich
These (matrix) changes with depth are first order controls on runoff generation at a point:

- Drainable porosity
- Bulk density
- Hydraulic conductivity
- Pore size distribution

Peter Kienzler, ETH Zurich
**Depth function – Soil moisture characteristic curve**

Data from WS10, HJA, Kevin McGuire

**Upper Slope (Pit 1)**

**Upper Slope (Pit 2)**
Decrease in storage with depth

Soil Water Content (m³/m³)

Pressure Head (m)
Drainable porosity

- Drainable porosity = saturated water content - water content at field capacity
- Change in drainable porosity will directly alter the depth function of drainable storage in the soil
- Relates to ground water table fluctuations

Data from WS10, HJA, Kevin McGuire
Soil data from grassland soils (Weiler, 2001), and from forest soils (Ranken and Harr, 1974; Rothacher et al., 1967)
….but, don’t forget textbook relations between hydraulic conductivity and matric potential (Bouma, 1977)
Cone with long shaft

Counting number of knocks for each depth interval

Changes show soil layer boundaries and bedrock boundary

Relate information to soil properties
The plot scale simplified

\[ n_d(z) = n_0 \exp \left( -\frac{z}{b} \right) \]

\[ K(z) = K_0 \left( 1 - \frac{z}{D} \right)^{m-1} \]

\[ q_{SSF}(t) = T(t) \beta w \]

*Weiler and McDonnell 2004 JoH*
If only it was so simple

While large pore space makes up only a small percent of the total porosity, they control almost all the flow at or near saturation.
It’s network-like \textit{and it’s} ubiquitous

A network of connected macropores and fissures that rapidly transmits water & solutes through the rootzone

\textit{Courtesy Brent Clothier}
If Darcy were alive today...

Merde!

\[ q = -K \cdot \frac{\Delta H}{\Delta z} \]
How infiltration REALLY works

A challenge for the traditional Darcy-Richards world

Dang

Markus Weiler (UBC)
An example

What is this showing?

Is the wetting front what you would expect?

Data by Jake Peters, USGS
Infiltration in macroporous soils

Macropore Flow Initiation
Water supply to the macropores

Interaction
Water transfer between macropores and the surrounding soil matrix
Take a virtual field trip that deals with vertical preferential flow at

http://www.cof.orst.edu/cof/fe/watershd/fe537/FE605-VFT_jc.htm
Classification of macropores

- **Size Classes**

- **Types of Macropores**
  - Pores formed by soil fauna
  - Pores formed by plant roots
  - Cracks and fissures
  - Natural soil pipes

- **Poiseuille’s Law (laminar flow!)**:

\[
Q = \frac{\pi r^4}{8 \eta} \frac{\Delta p}{L}
\]

Great review by Beven and Germann, 1982 WRR
Chip Ross Park
If we were to dig a pit

Remember back to the changes with depth that we discussed earlier…

How might the pref. flow conspire with depth changes in DP, Ks, BD?

Photo: Markus Weiler UBC
In other words

High rainfall intensity  Dry soil

Dye pattern

Water content change

1.0 Depth (m)

M. Weiler UBC
Where the land is of a stiff clayey nature, there are considerable difficulties in adapting it for irrigation. In undrained clay land, under ordinary circumstances, cracks one and two inches wide and five feet deep are sometimes met with, and it has been found that these are intensified in drained land, with the result that direct passage of sewage and surface water into them has occurred on sewage farms of this nature, so that the effluent is not purified as intended. It is thus very unsuitable for irrigation, unless the surface is specially prepared, as mentioned under the head of broad irrigation, and other treatment should be resorted to.

1898 - Some 104 years ago

Courtesy Brent Clothier
Observations

Soil water content measurement

Vertical dye pattern

Flow process

High rainfall intensity
Dry soil

Weiler, UBC
Observations

Matric potential measurement

Duration of sprinkling experiment

Vertical dye pattern

Flow process

Subsurface initiation (saturated matrix)

Low interaction (saturated matrix)

Weiler, UBC
Kitihara-san’s Lab at FFPRI in Japan

\[ Q = \frac{\pi R^4 \Delta p}{8 \eta L} \]
Plot scale—a common finding

High rainfall intensity
Dry soil

Legend:
- unstained
- stones
- macropores
- Stained areas with:
  - low concentration
  - medium concentration
  - high concentration

Weiler, UBC)

Oregon State University
Can also be highly seasonal

Moisture content (%)

Satellite

Dry

Wet

Roger Grayson, pers. Comm.
Preferential flow is everywhere!