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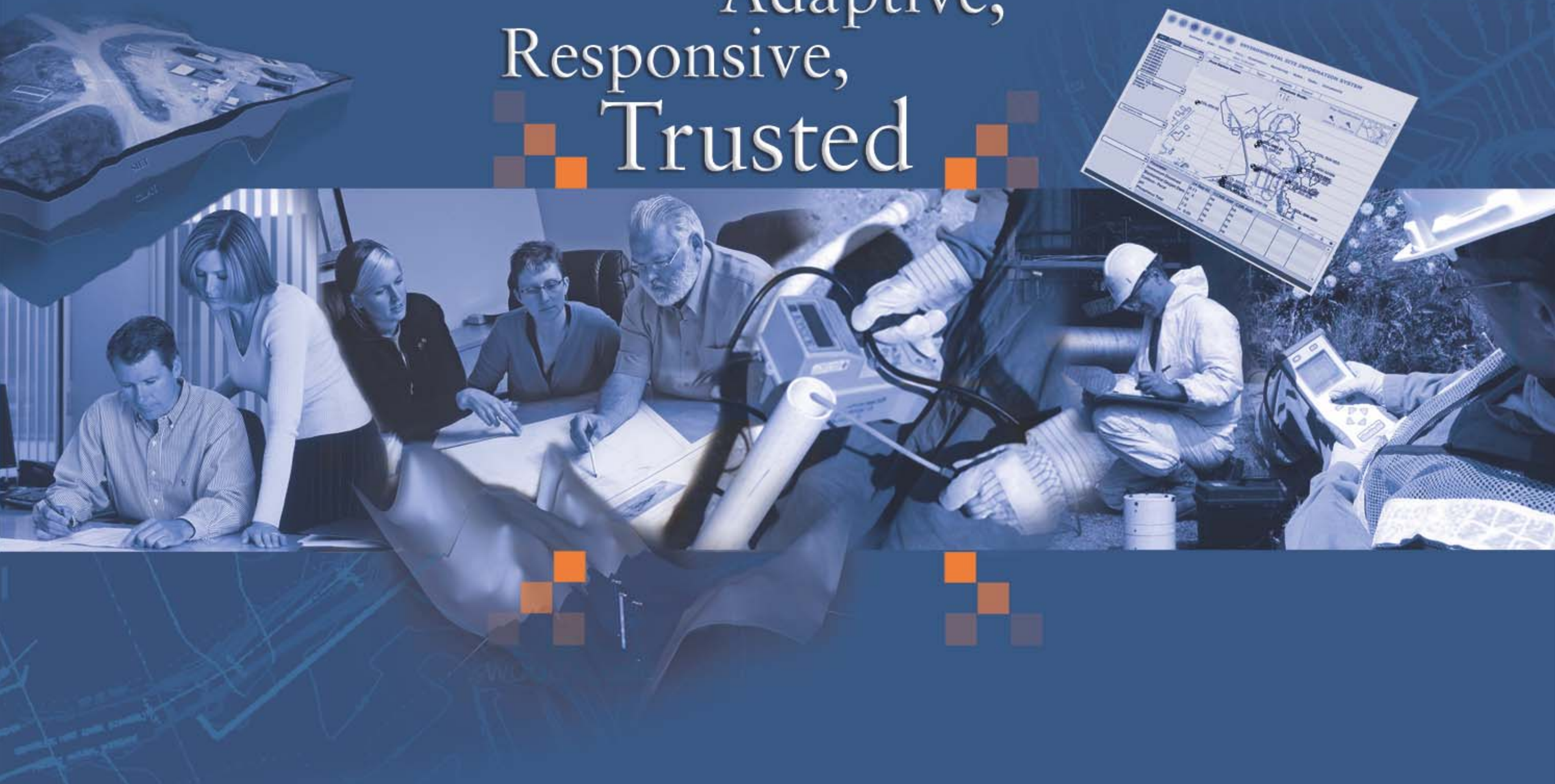

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The Practical Application of Unsaturated Soil Mechanics in Site Assessment and Remediation

by

Douglas A. Sweeney, M.Sc., P.Eng.

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Outline

- Why unsaturated soils approach
- What and how to obtain unsaturated soil parameters
- How to apply them in assessments
- How to apply them in remediation

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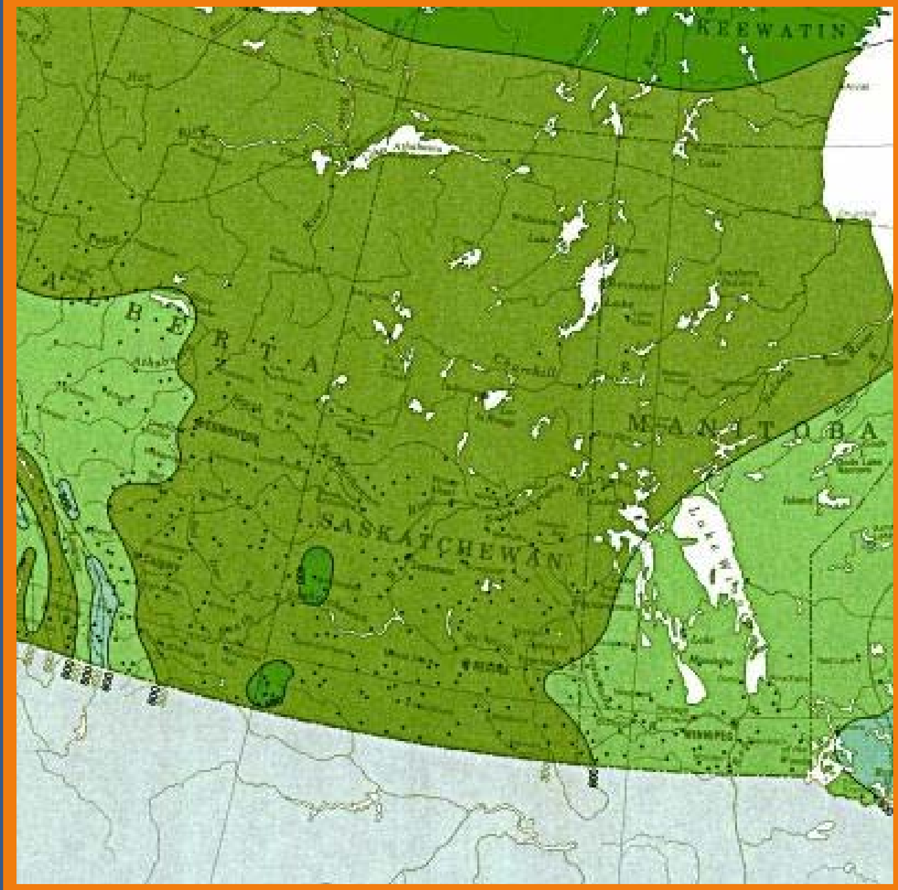
Why Use Unsaturated Soils Approach

- Most of Prairies is in a Semi arid climate (precip < evap). Average annual precip 477 mm average annual potential evap is 807 mm.
- Almost all sites have groundwater tables at some depth below the surface.
- Majority of our contaminant issues (LNAPL and Salts) are present in the unsaturated zone.



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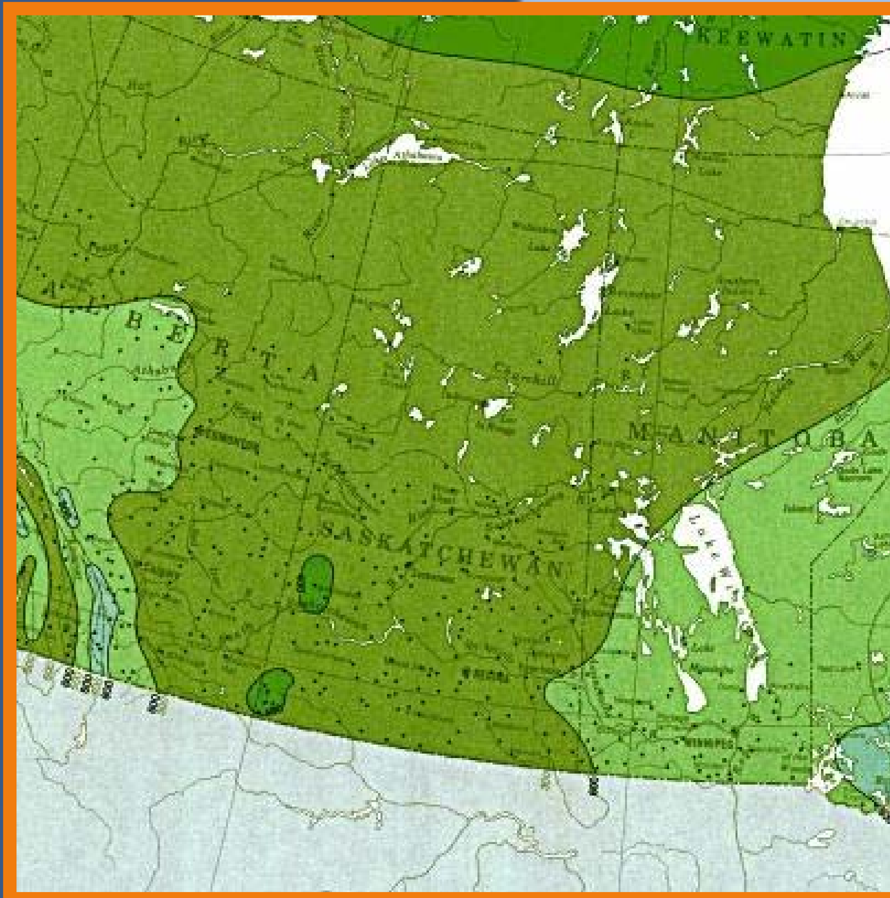
Why Use Unsaturated Soils Approach

- The science has been developed for practical applications using various tools (API - LNAPL Mobility, Vapour Inhalation and Risk Assessments with respect to Salts)
- Regulatory approaches are using the science (BC Screening Level Risk Assessments and CCME criteria)



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What is Unsaturated Soil Mechanics

- Karl Terzaghi – Father of Geotechnical Engineering as a science – two chapters in his 1943 book Theoretical Soil Mechanics dedicated to understanding unsaturated soils
- Dr. Delwyn Fredlund developed unsaturated soil mechanics as a science for geotechnical engineers to apply.
- Soil Mechanics for Unsaturated Soils – D.G. Fredlund and H Rahardjo 1993
- The agriculture related disciplines also developed theories on moisture movement in the unsaturated zone

Saturated versus Unsaturated flow

Ground Surface

Negative pore-water pressures (suction)

Water content varies

Hydraulic conductivity varies with water content

Groundwater flow v = k (suction) dh / dy

Positive pore-water pressure (peizometric head)

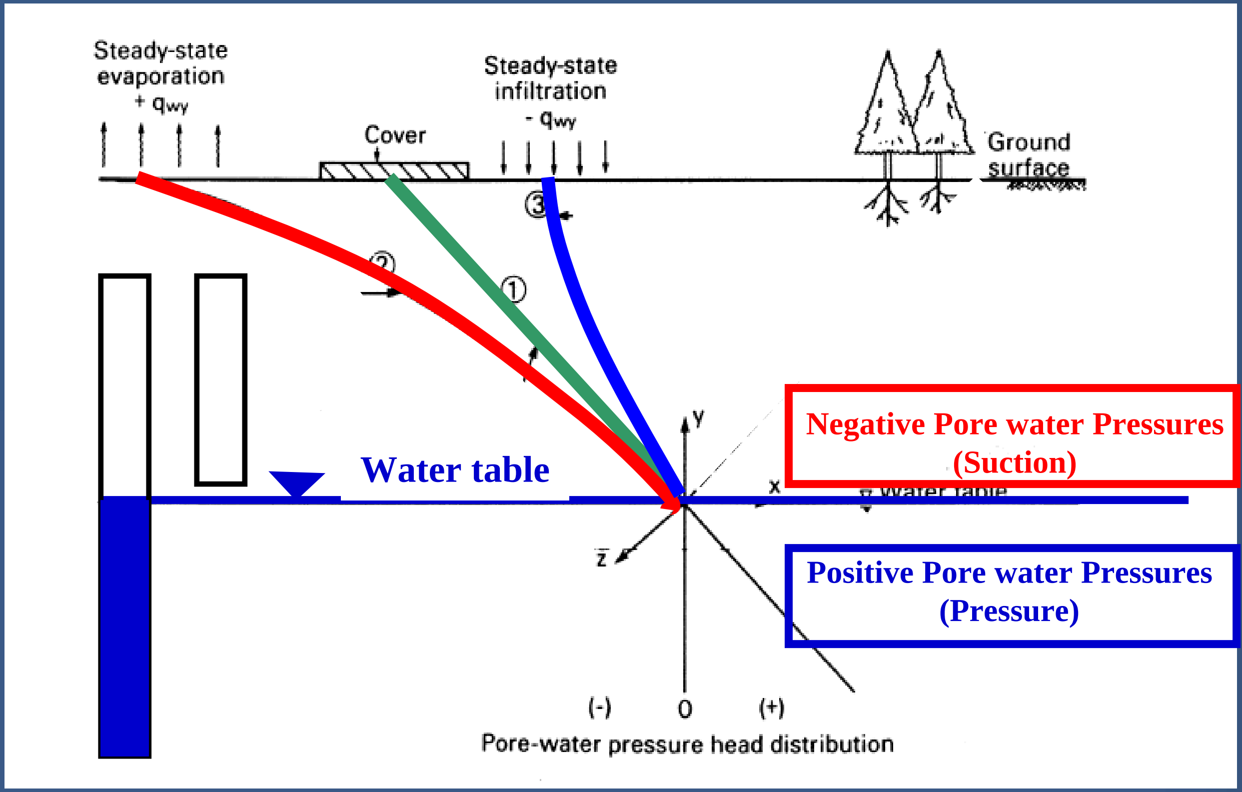
Water content = constant

Hydraulic conductivity = constant

Groundwater flow v = k (sat) dh / dy

Classical contaminant Hydrogeology

Saturated versus Unsaturated flow



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Saturated versus Unsaturated flow

Ground Surface

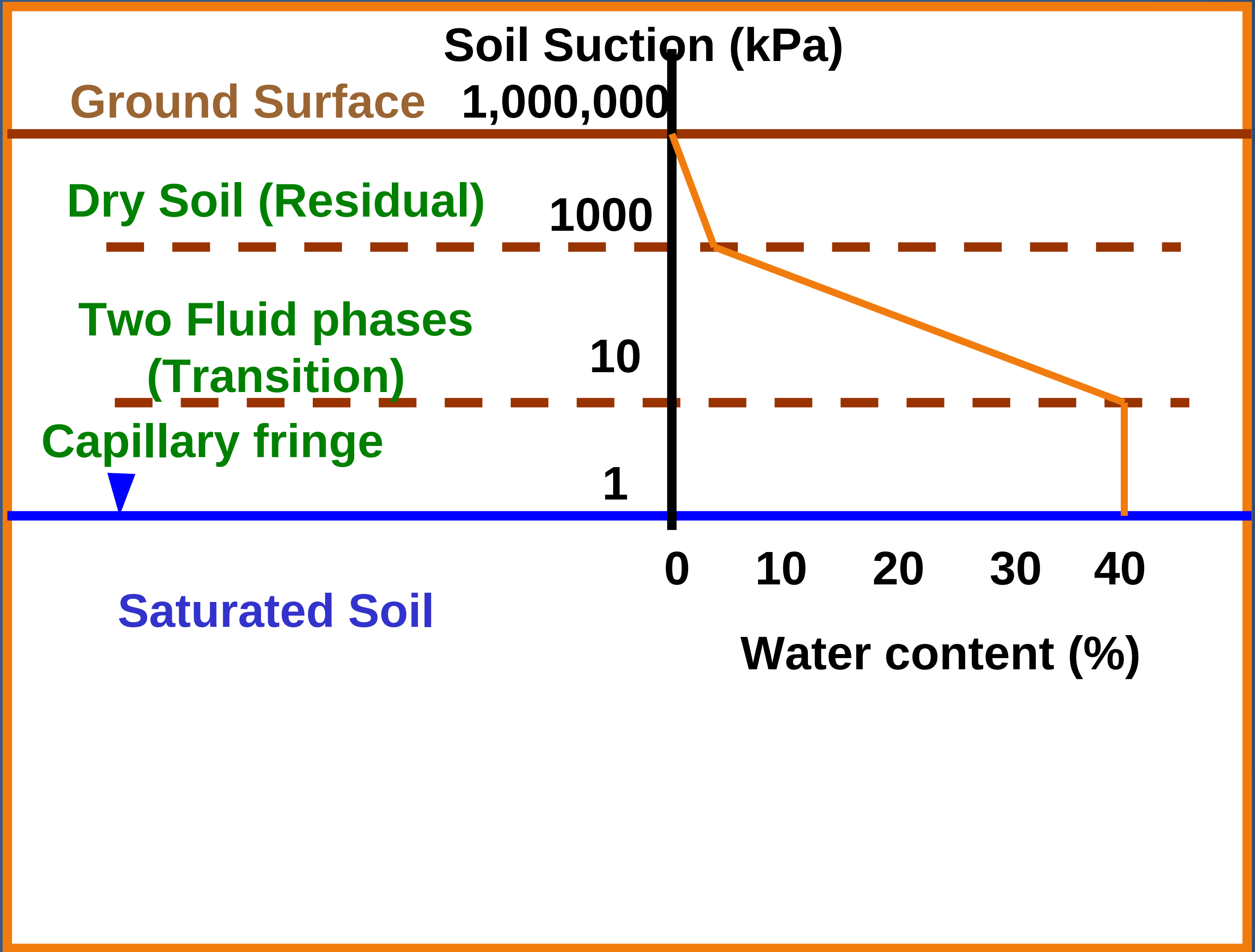
Dry Soil — Discontinuous water phase – air filling most voids

Two Fluid phases — continuous water phase – and air phase

Capillary fringe — Water filling most – discontinuous air phase

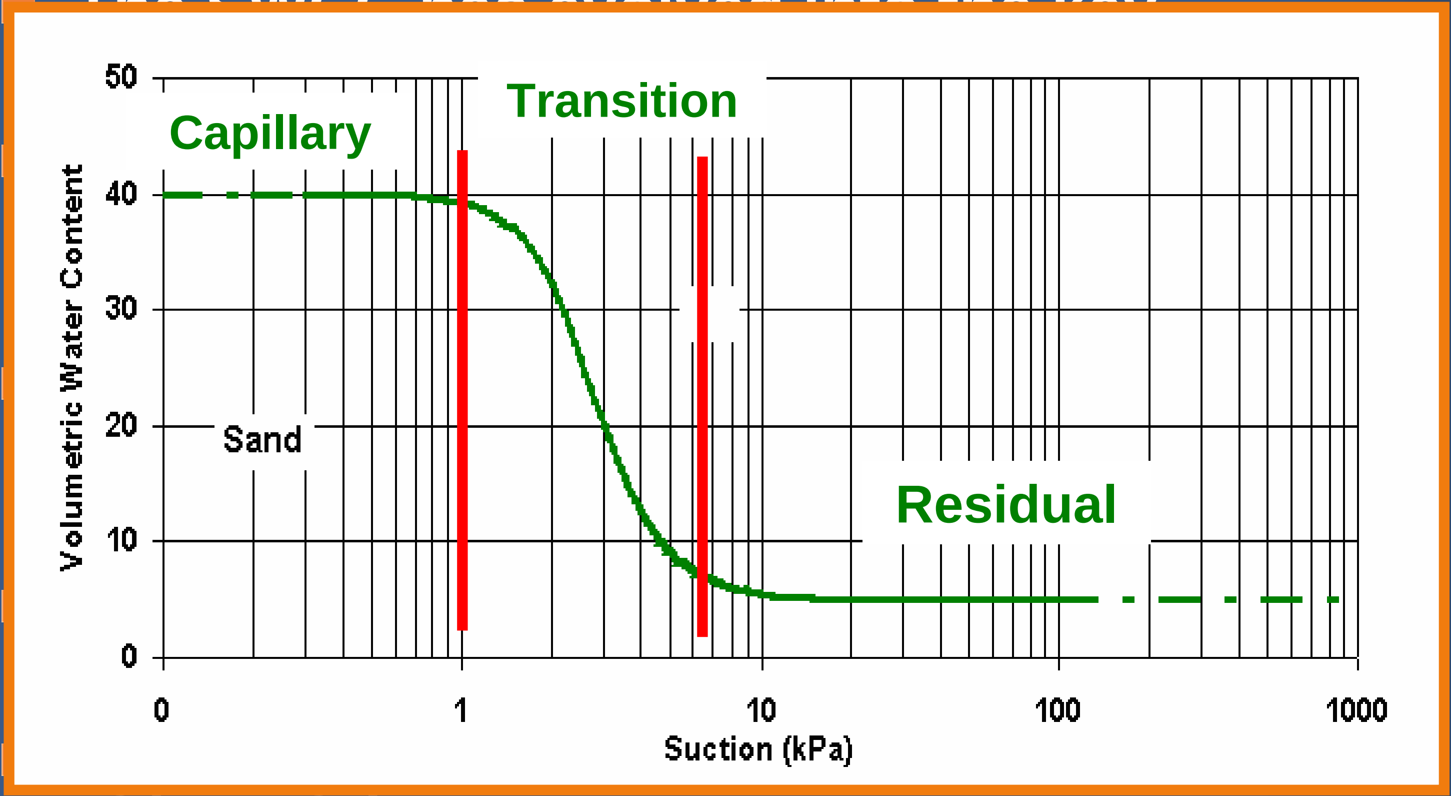
Saturated Soil — Water filling all voids – air in a dissolved state

Saturated versus Unsaturated flow



Soil Water Characteristic Curve (SWCC)

- The SWCC has evolved into the key



(volumetric) versus suction and typical working range is 1,500 kPa (matric suction)

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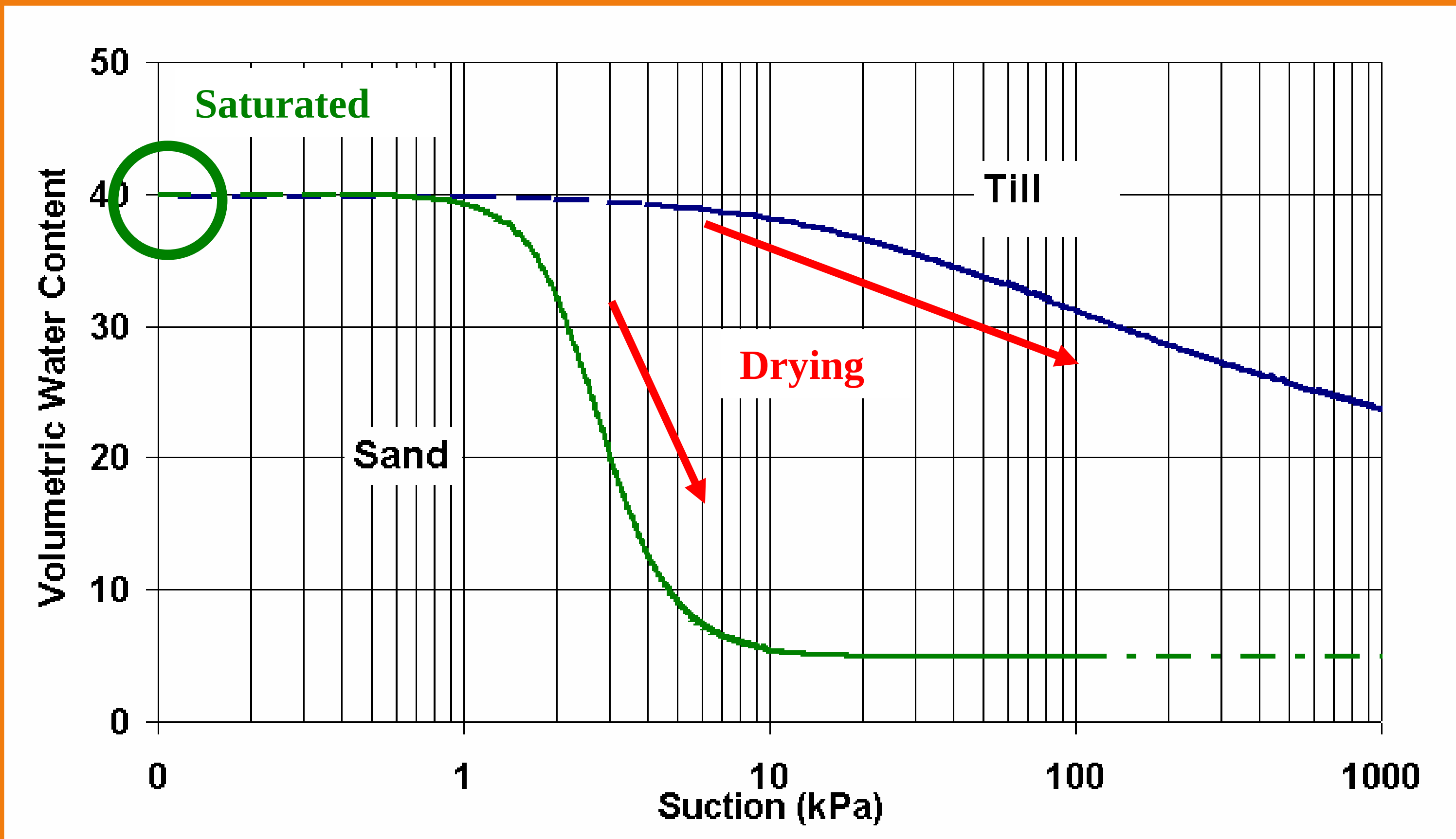
Coarse Grained and Fine Grained Soils



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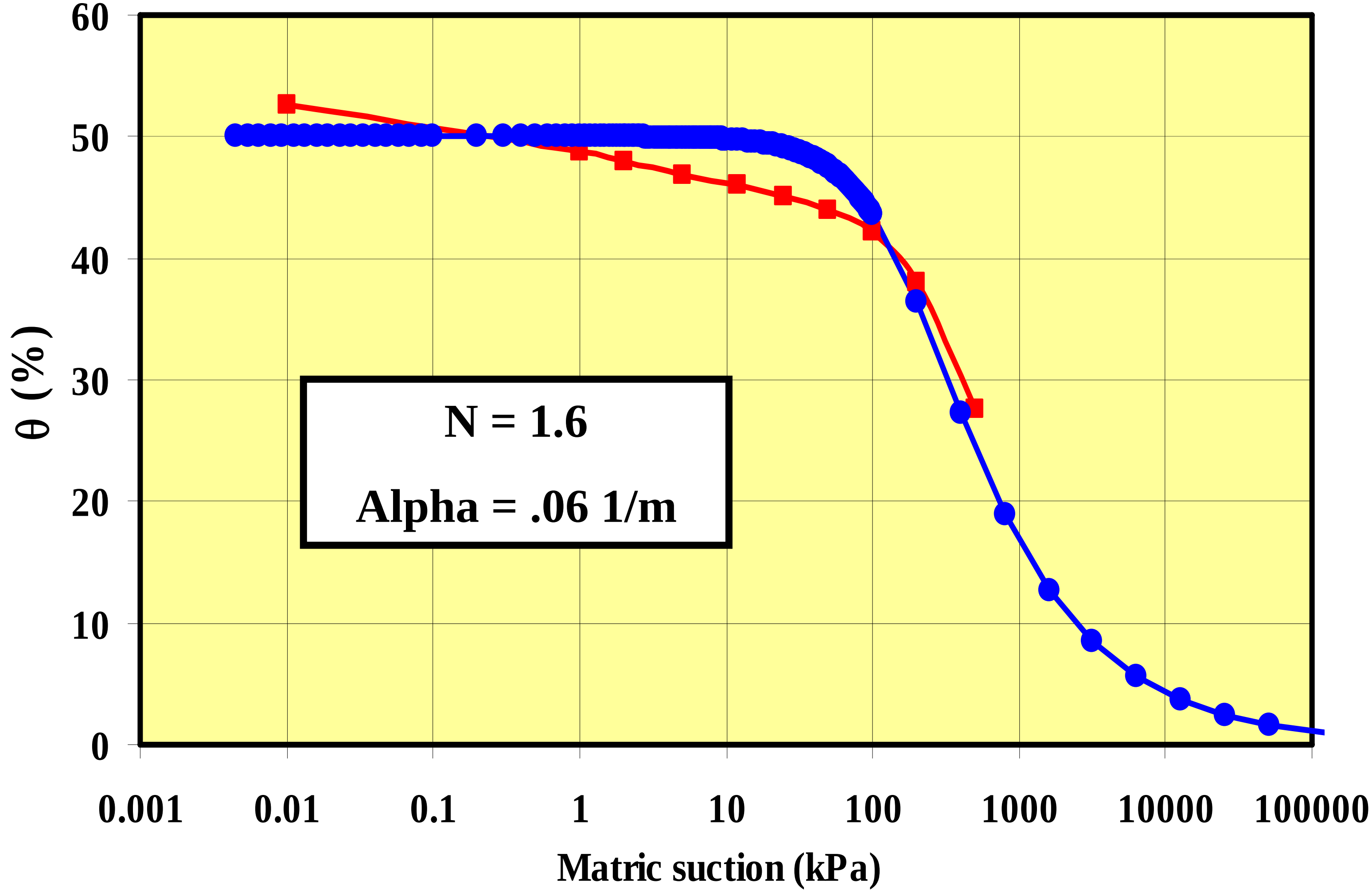
Soil-Water Characteristic Curve for Clayey Silt Matrix



Unsaturated Hydraulic Conductivity

- Several models (equations) have been developed to establish the unsaturated hydraulic conductivity from the SWCC
- The models are based on the SWCC parameters (van Genuchten or the Brooks Corey parameters) and the saturated hydraulic conductivity
- Most common empirical equations, Gardner (1958), Brook Corey (1964) and statistical functions Burdine (1953) and Mualem (1976)

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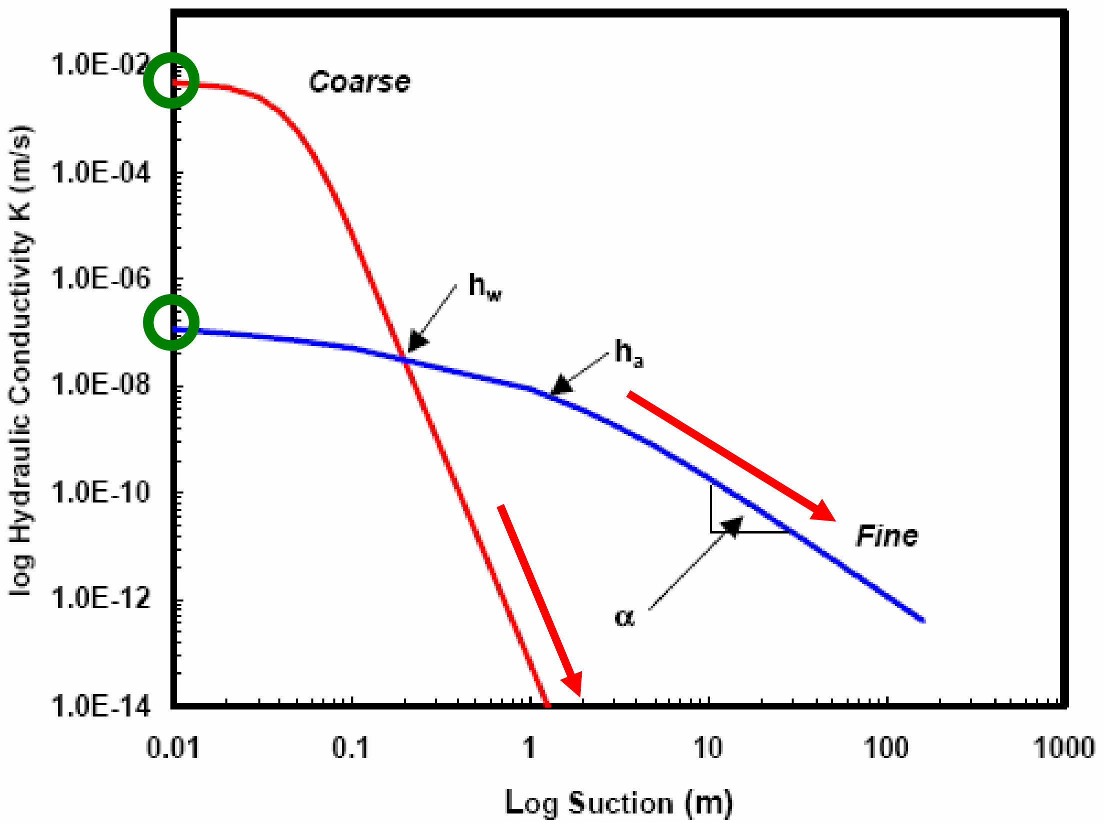
Unsaturated Hydraulic Conductivity



re 2.15 Hydraulic conductivity function for the coarse and fine textured materials used in the capillary barrier diversion length example.

Methods for determining the SWCC

- Predictions from grain size data – tend to be less accurate.
- Database search for typical SWCC – soils with similar grain size distribution and/or classification – agriculture related disciplines contain a large volume of SWCC, API data base – commercial service available in Saskatoon
- Laboratory Measurement of water content versus suction – tempe cell test or pressure plate. Two commercial labs in Saskatoon.

Other Data Requirements for Assessment and Remediation Using Unsaturated Soil Theory

- Moisture content profiles
- Grain size
- Bulk density
- Saturated hydraulic conductivity

The Key is a reasonable approximation of the SWCC

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Use of Unsaturated Soil Theory in Site Assessment

- Tier II evaluations (eg AENV) allow for parameter modification in the CCME Equations (vapour inhalation pathway and groundwater pathways)
- LNAPL volumes and LNAPL mobility

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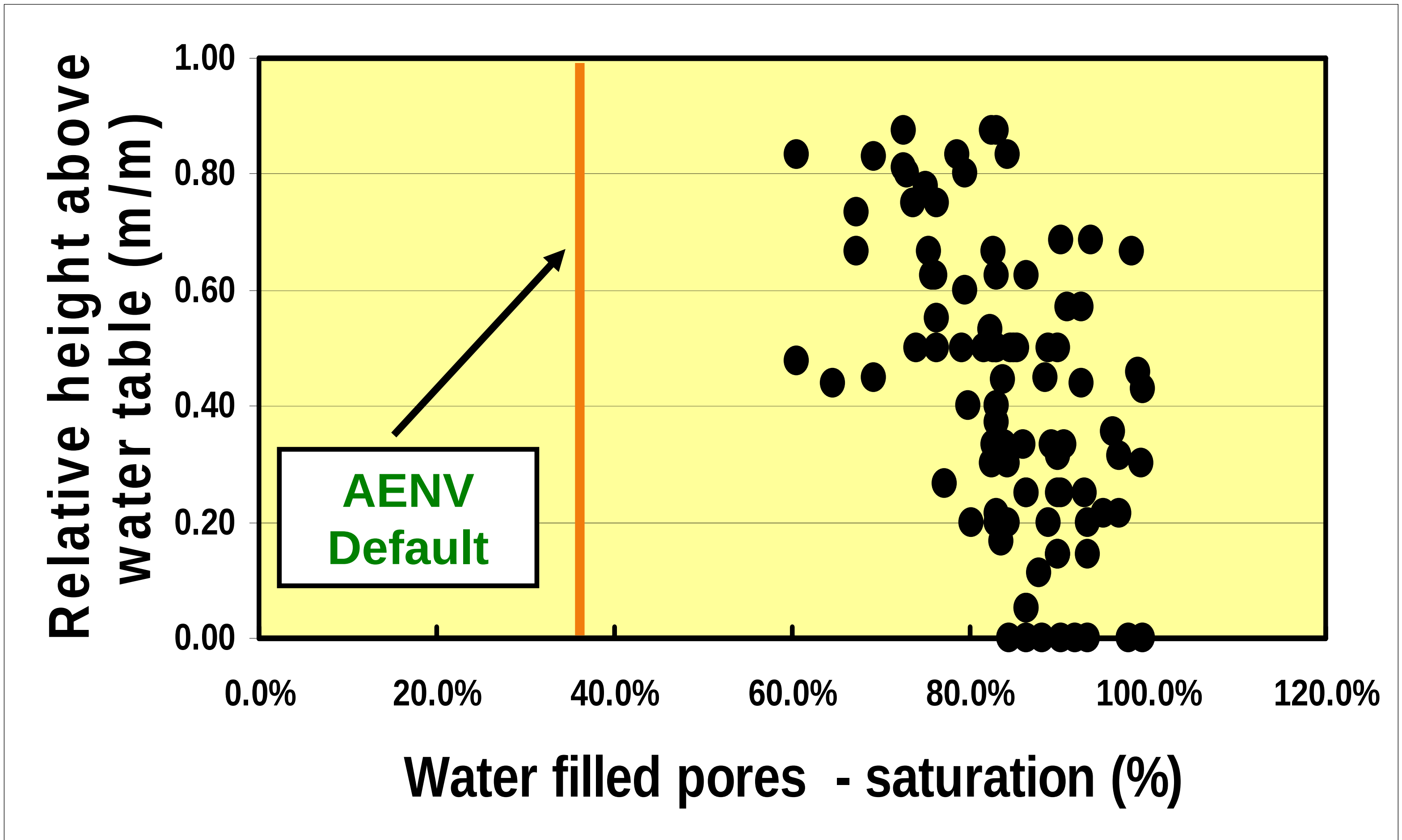
Indoor Inhalation Pathway

- Soil parameters maybe modified – dry bulk density, water content and porosities
- The Alberta Tier 1 default parameters based on fine grained water filled porosity of 0.168 (36% water) and an air filled porosity of 0.302 (64% air)
- Vapour inhalation parameter modification, especially for fine grained soils can potentially relax the benzene guideline value

Indoor Inhalation Pathway



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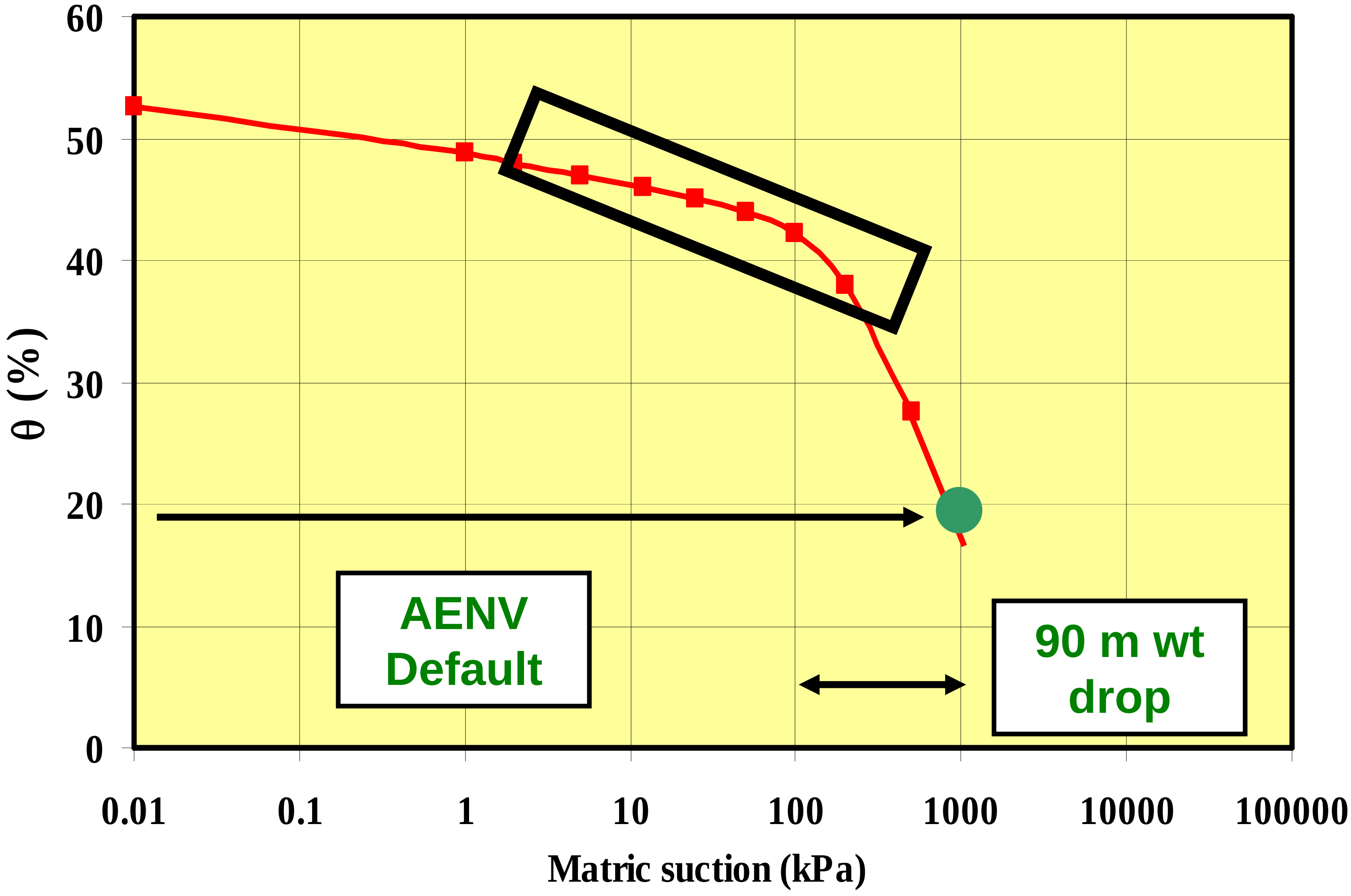

LNAPL Volumes and Mobility

- API has developed LNAPL volume and mobility tools
- The tools are based on LNAPL properties and soil properties – key soil property is the SWCC parameters (van Genuchten or the Brooks Corey parameters)
- The more accurate your SWCC curve the more accurate your volume estimates or mobility assessment
- TPH data from site is a simple method for LNAPL volume and mobility assessment verification and confirm your input parameters including the SWCC are reasonable

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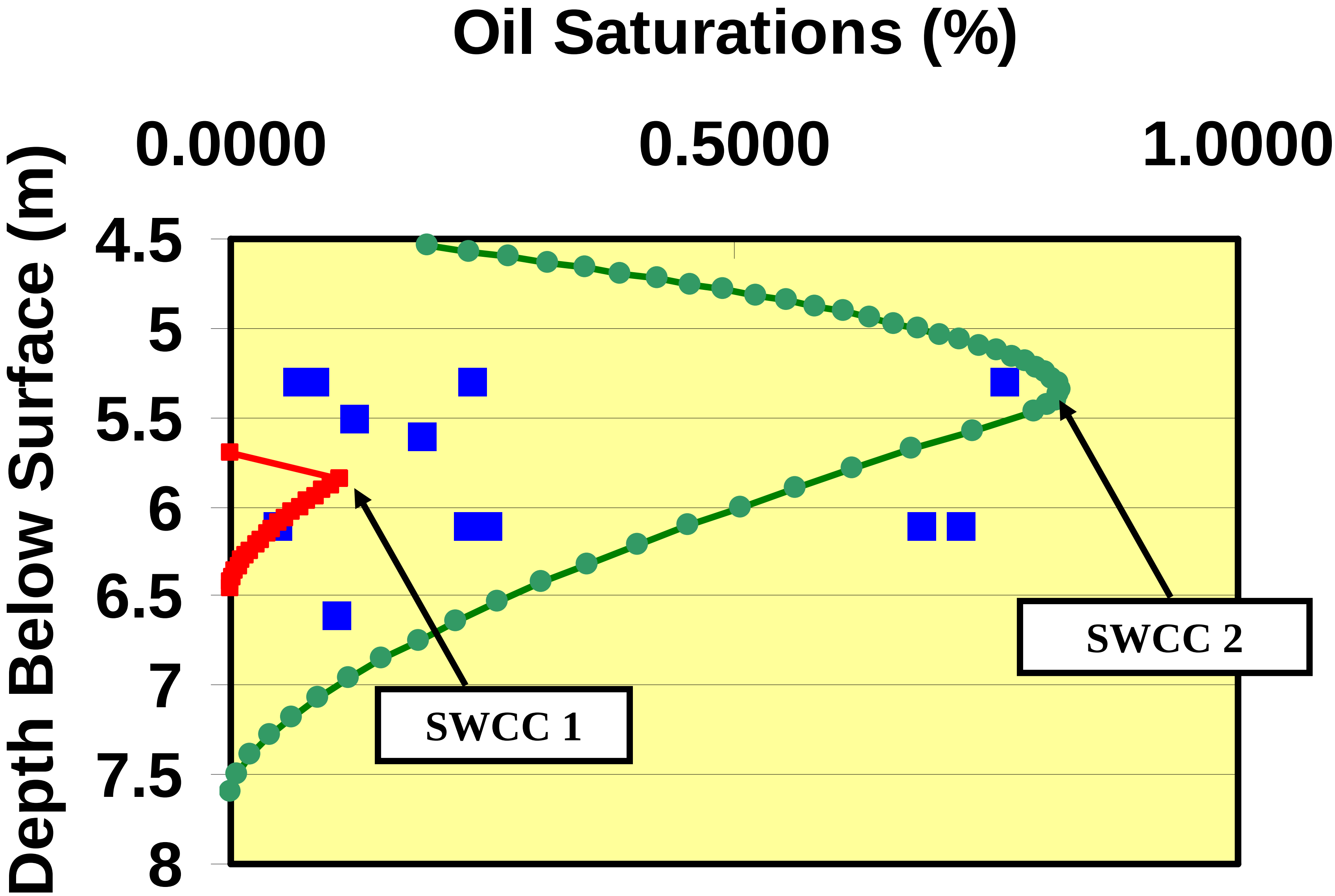
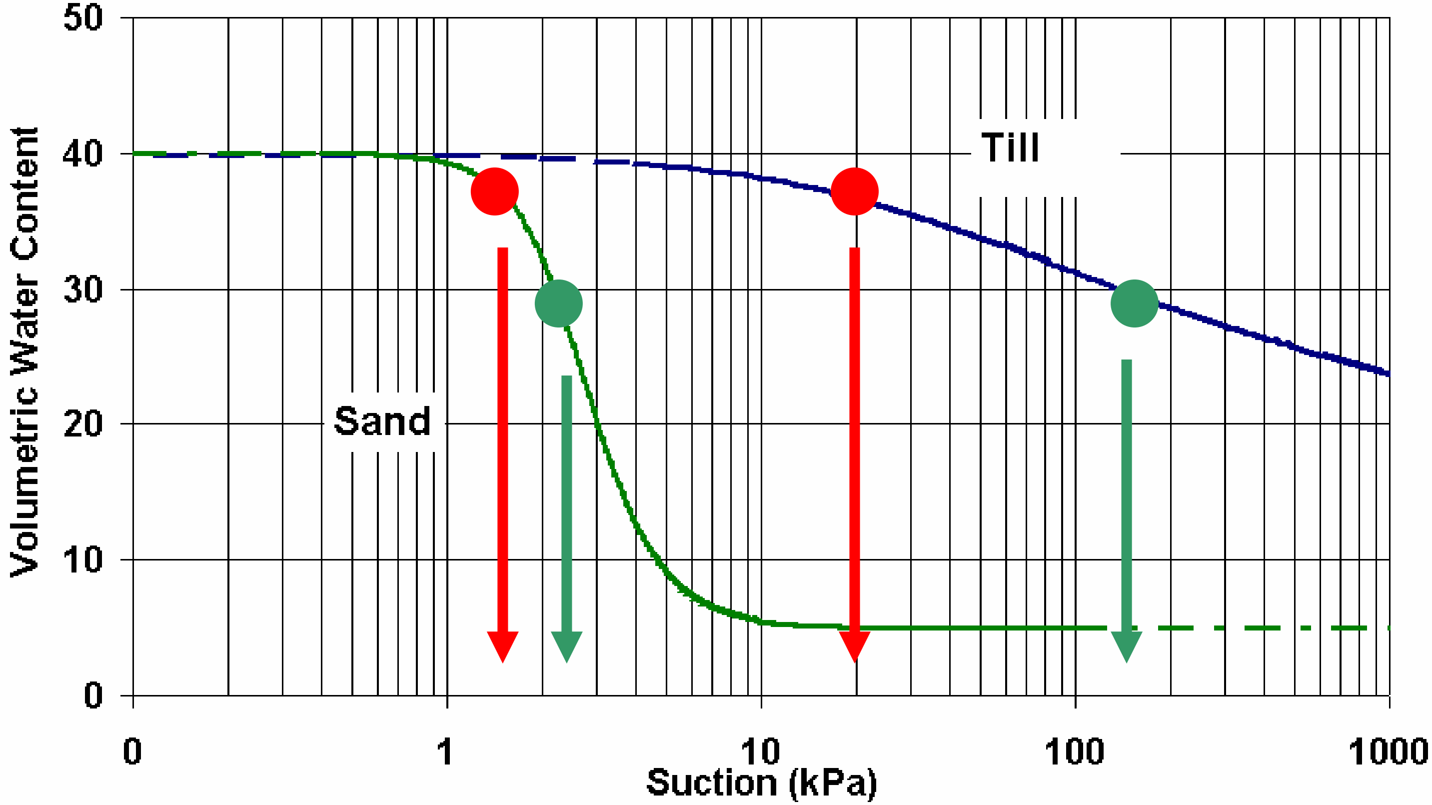


Oil Saturations (%)
0.0000
0.5000
1.0000
Depth Below Surface (m)
4.5
5
5.5
6
6.5
7
7.5
8
SWCC 1
SWCC 2

Use of Unsatured Soil Theory in Remediation

- Insitu remediation
- Risk Assessments for salt impacted sites require modelling of unsaturated flow.

Insitu Remediation



water column plus the air entry of the soil.

Salt Impacted Sites

- Migration of salts primarily controlled by surface flux conditions, precipitation and evapotranspiration
- Effective Risk Assessments or development of remediation options must consider moisture (contaminant) movement in the unsaturated zone.
- Several 1-D or 2-D models are available that can model flow in the unsaturated zone using SWCC, hydraulic conductivity, vegetation and climate data.

Summary

- Applying the science of unsaturated soil theory to our contaminant problems is becoming a requirement
- The tools and regulatory agencies are now using the science
- Key soil parameter is the SWCC curve
- Practical application of unsaturated hydrogeology to our contaminant problems is possible
- Better solutions start with better science.

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