C.2. Constructed Pile Experiment

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Waste Rock Hydrology Research Program

Constructed Pile Experiment

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Constructed Pile Overview

Pile Construction
- Design Issues

Instrumentation
- Moisture content
- Matric suction

Results To Date
- Natural conditions Sept. 98 – Aug. 99
- Artificial rainfall events Aug 99 – Oct 99
- Tracer test

Chemistry
- Internal
- Outflow

Results Not Shown

Summary

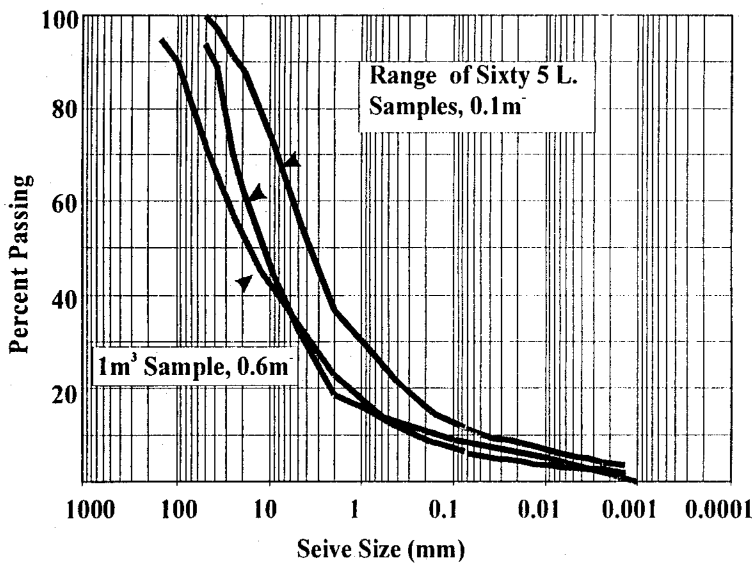
Waste Rock Characteristics

Source Material

- Mined in fall: 1996
- Pile constructed: summer 1998
- Average total sulphur (0.2-0.5%)
- NP:AP Ratios from 13.2 to 0.1, Average 2.0

Grain Sizes:

- 20%-30% Sand
- 10% Silts and Clay
- Boulders to 1.5 m



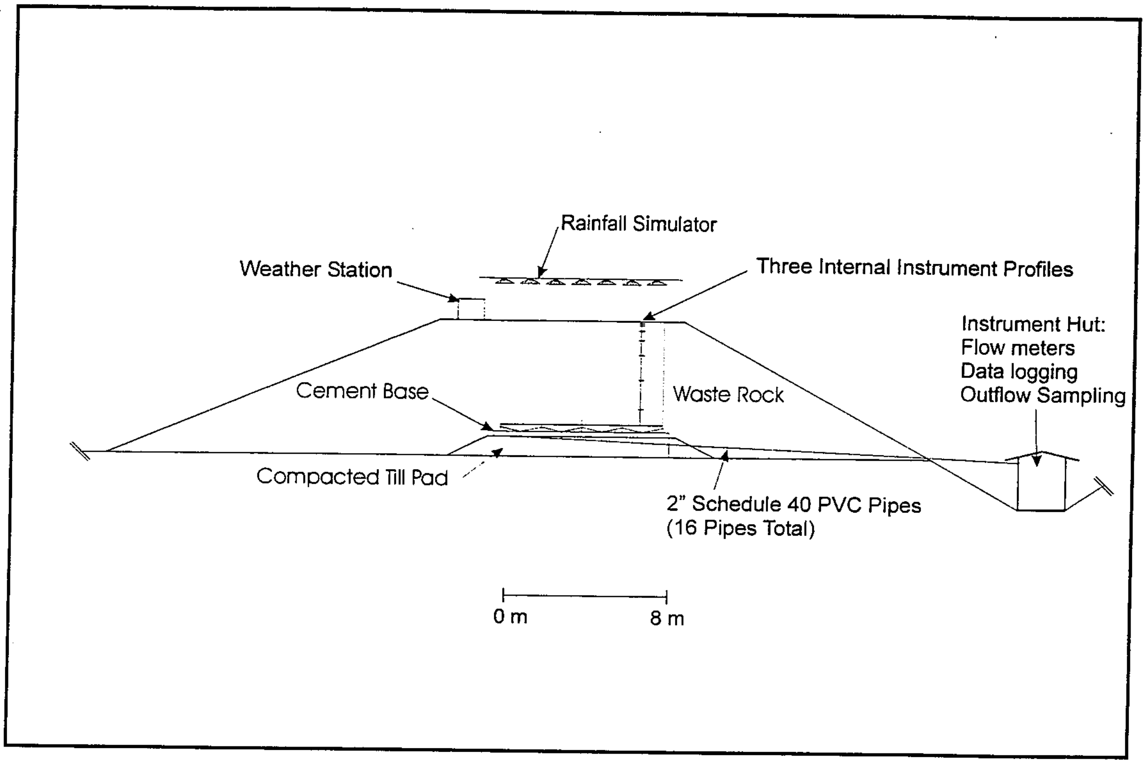
Pile Construction

Design Must Include

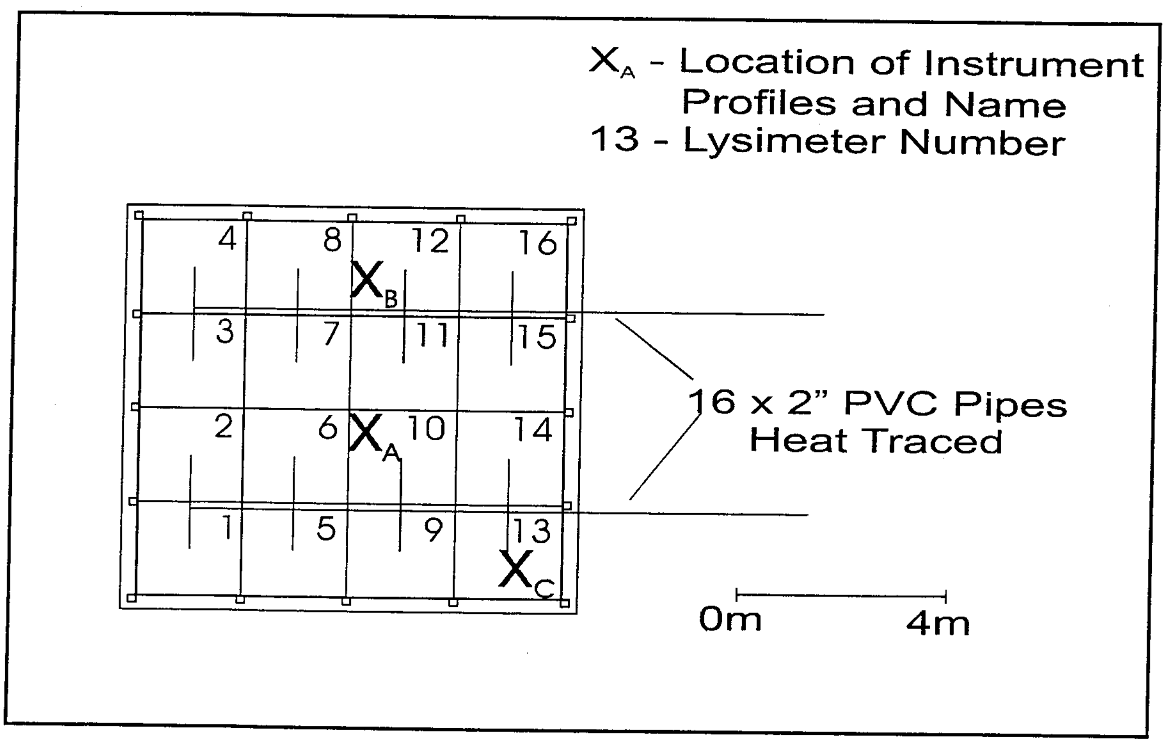
- Capillary-dominated matrix flow
- Non-capillary flow
- Spatial variability and scale
- Real and artificial rainfall
- Tracer testing
- Realistic internal pile structure
- Realistic surface condition
- Year-round operation
- Unattended

Practical

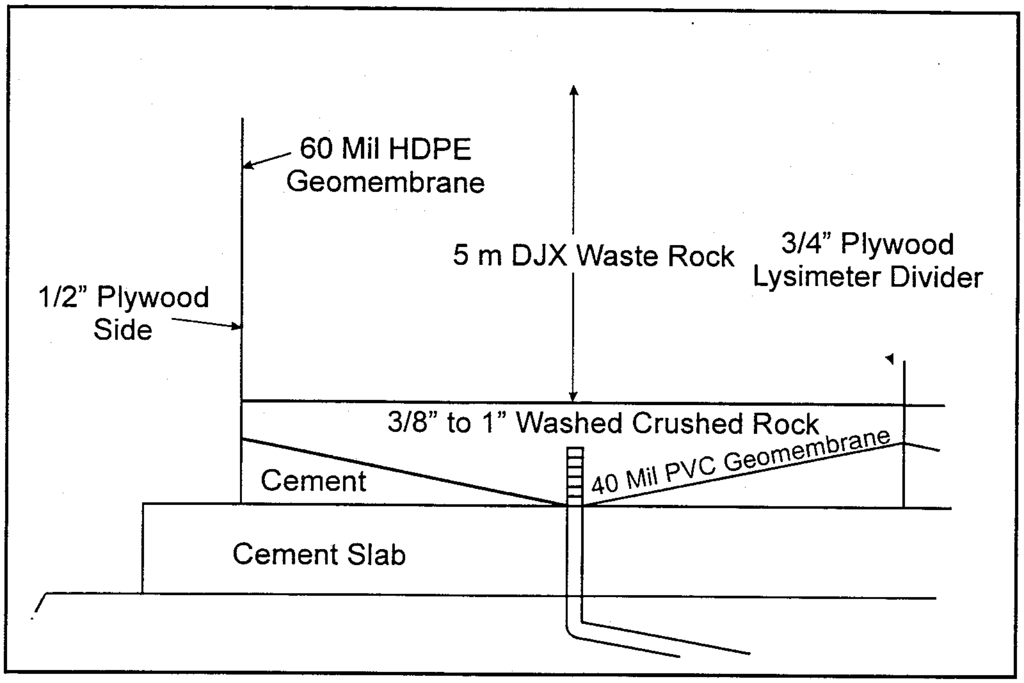
- Size and cost
- Material available
- Possible construction methods



Simplified Cross-Section of Constructed Pile



Lysimeter Grid Details



Lysimeter Base: Detailed Cross-Section

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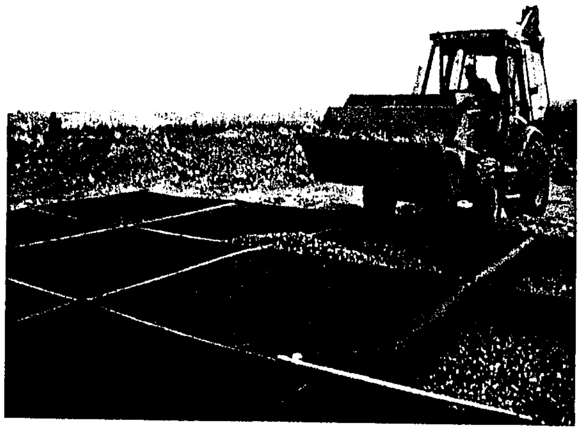
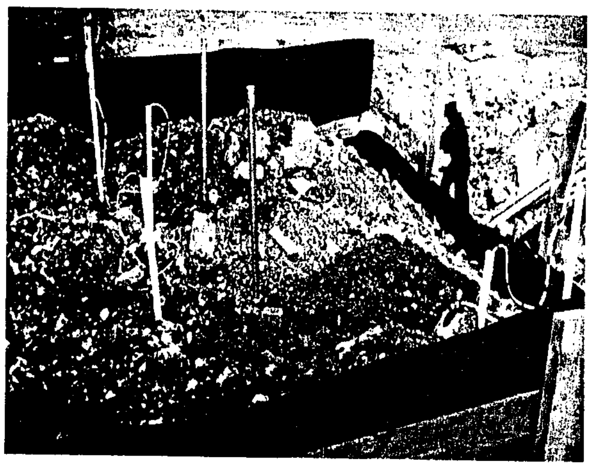


Lysimeter Base

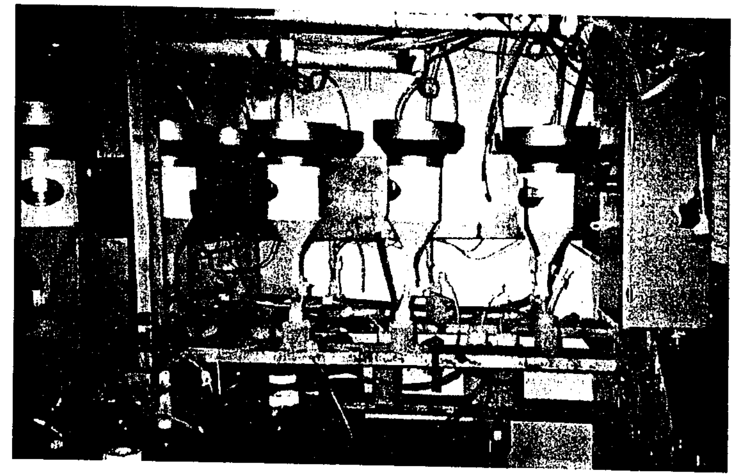


Sides and Internal Instruments

Internal Pile Structure

Pile Top Surface

Pile Side View and Instrumentation Hut



Flow Metering and Sample Collection System

Pile Instrumentation

Surface
Weather Station: Rainfall and Evaporation
- Calculated evaporation matched to field mini-lysimeters

Internal
3 Profiles of sensors at depths:
10, 20, 50, 100, 175, 300, 450 cm

Temperature
- Commercial thermistors

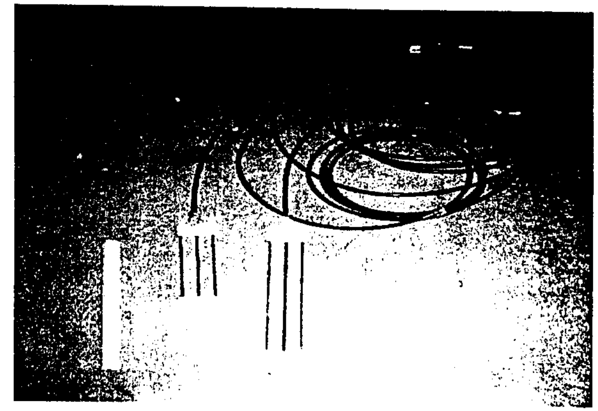
Matrix Water Chemistry
- Suction lysimeters

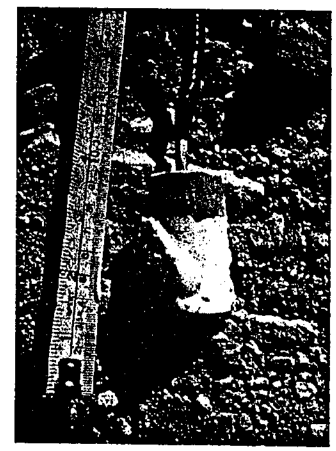
Gas Composition
- Small diameter tubing

Flow Rate
- Tipping-bucket rain gauges

Outflow Chemistry
- Water sampling system allowing on-line compositing

Moisture Content
Uncoated and Coated TDR Probes





Matric Suction
Thermal Dissipation Sensors and Tensiometers

Moisture Content By Time Domain Reflectrometry (1)

Velocity of a voltage pulse down a waveguide (probe) is determined by the dielectric of the material around the probe:

- Send square-wave voltage pulse down the cable to the probe.
- Find voltage reflection caused by change from shielded cable to exposed probe.
- Find reflection from the end of the probe.
- Determine velocity and hence bulk dielectric.

Theory

Use a mixng law of dielectric components determine moisture content.

Dielectrics:	1	Kair
	2-4	Kmineral soil
	80	Kwater

$$\sqrt{Kwetsoil} = \sqrt{Kdrysoil} + \theta\left(\sqrt{Kwater} - 1\right)$$

Advantages

- Automated
- Real time data
- “Universal” empirical calibration equation: the Topp equation

Moisture Content By Time Domain Reflectrometry (2)

Problems

- Long cables lead to signal smearing.
- Signal loss due to highly conductive soil water solutions.
- Simplifying assumptions of usual calibration are not true.
- Calibration varies with:

  a)Grain size of the material placed around the probe: clay and gravel

  b)Bulk conductivity of soil

  c)Frequency spectra of TDR pulse

  d)Temperature

Moisture Content By Time Domain Reflectrometry (3)

Solutions

Remote Diode Shorting

- Uses active electronic components within the probe to create short-circuits at either end of the probe.

Coated Probes

- Center conductor of probe coated with a resistive heat shrink to eliminate conductive signal losses.

Complex Calibration

- Each probe must be individually calibrated to determine the non-linear correction factors for that probe.
- Must use field setup of actual cable lengths, connectors and multiplexers to ensure consistent frequency components.
- Have an independent measurement of soil water conductance.
- Do a calibration for different soil water conductances.
- Install side by side coated and uncoated probes.

Matric Suction (1)

Thermal Dissipation Sensors
Principle

- Heat pulse is generated within a film canister sized, ceramic probe.
- The rate of heat dissipation away from the probe body core is proportional to the moisture content of the probe.
- Moisture content of the probe is related to the external matric suction.

Advantages

- Automated
- Operates year round
- No maintenance

Disadvantages.

- Probe responses are affected by hysteresis: different responses when wetting or drying.
- Requires specialized equipment for calibration and 2 months.
- Temperature dependent.
- Sensors very difficult to operate 0-15 kPa.
- Pre-calibrated sensors not commercially available.

Matric Suction (2)

Tensiometers
Water filled ceramic cup in contact with soil.
Water pressure measured by gauge or transducer.

Advantages
- Direct measurement of matric suction.
- Cheap pressure transducers can automate measurement.
- Can double as suction samplers.

Disadvantages

- Require near-daily maintenance.
- Only useful at shallow depths.
- Only operate when air temperature > 0.
- May need reinstallation every spring.

Conclusion

Need both tensiometers and thermal dissipation sensors for a reliable measurement.

Results Summary: Natural Conditions Sept 98 – July 99

Construction
- No rainfall for 2 months.
- Temperatures in mid twenties to mid thirties.
- Dry layers created in the pile.

Rainfall and Outflow

- First outflow 5 to 30 days after first rainfall.
- 110 mm rainfall, 7000 litres of precipitation, 200 litres of outflow.
- 30-40,000 litres of “resident” water within pile.

Moisture content and matric suction

- Moisture content increases show the movement of wetting fronts.
- Matric suction drops from 100’s to <10 kPa.

Summary

- Wetting up period for an experiment can be long.
- Spatially variable flow.

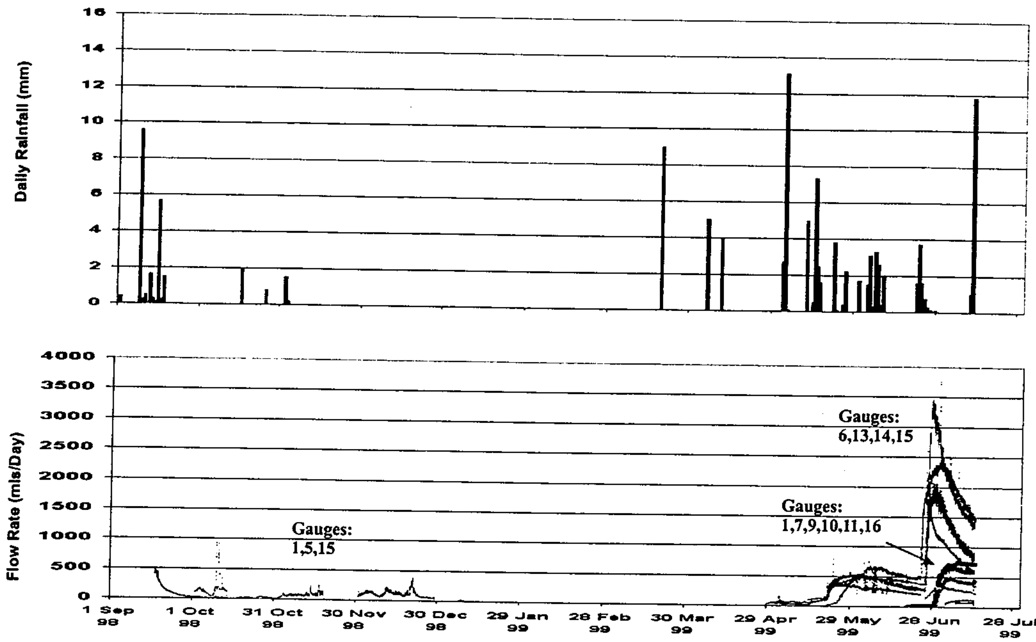
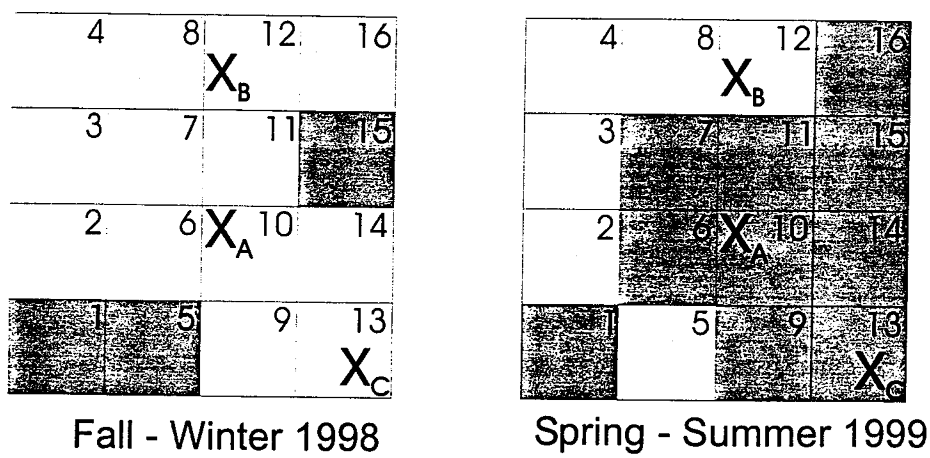


Figure 4: Daily rainfall volume and outflow rate summary



Spatial Distribution of Pile Outflow

Results Summary:
Artificial Rainfall Aug 99 – Oct 99

- 1999 was a drier then average summer .
- Determine the response to controlled rainfall.
- Tracer test with a conservative tracer (LiCl).
- Rainfall rates and amounts bounded by site rainfall statistics.
- Winter erases effects of one season to next.

Tracer Test

- September 24
- 2000 mg/L Chloride as LiCl

Summary

- Spatially variable at scale <2m., 2m+
- Spatially and chemically distinct flow pathways exist.

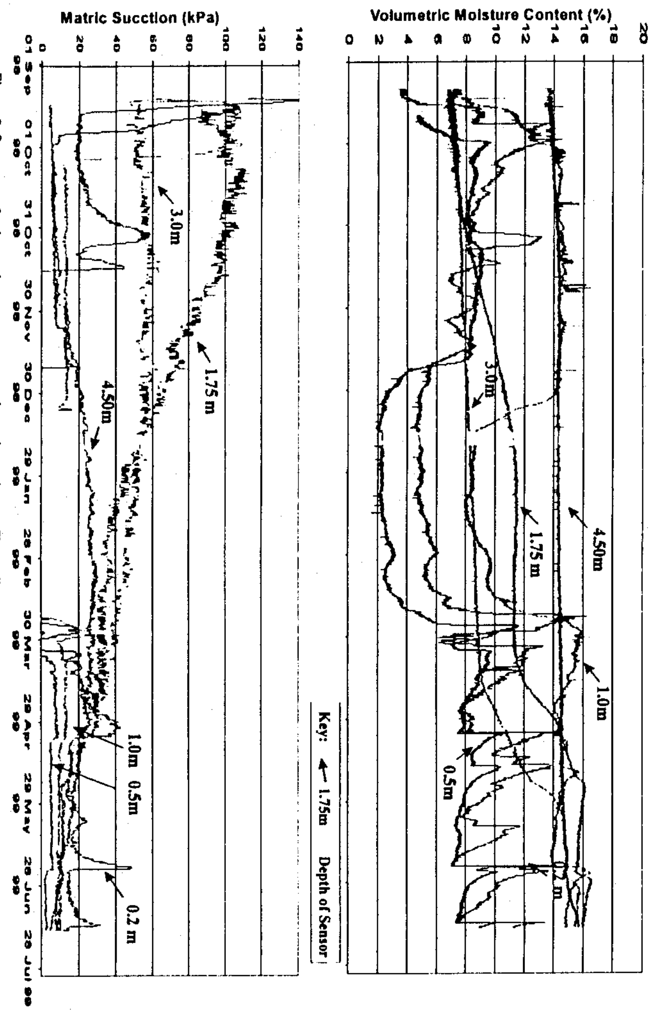
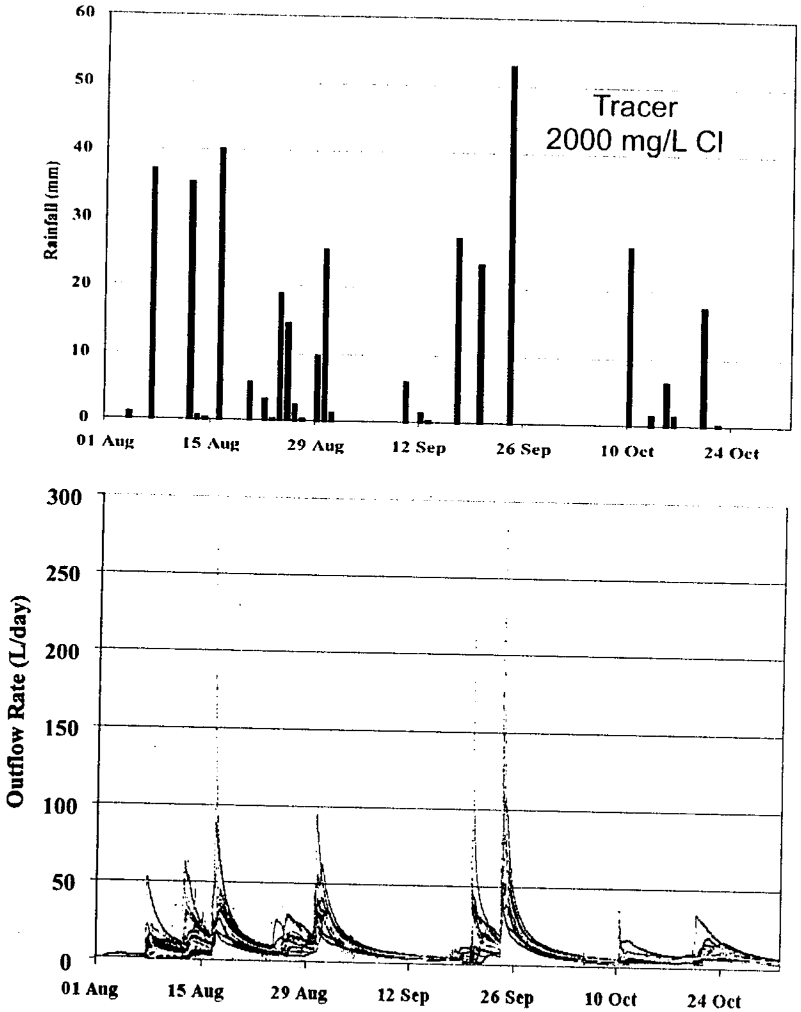
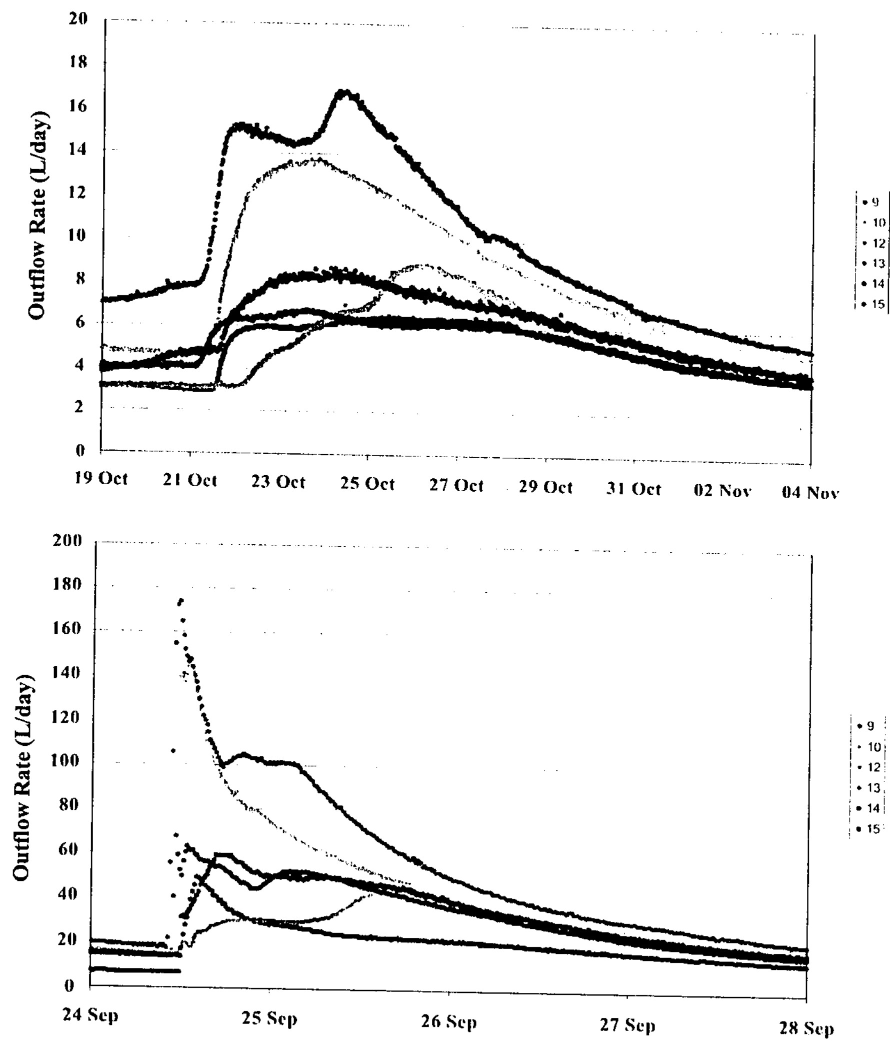


Figure 5: Summary of volumetric water content and matric suction profile at pile center

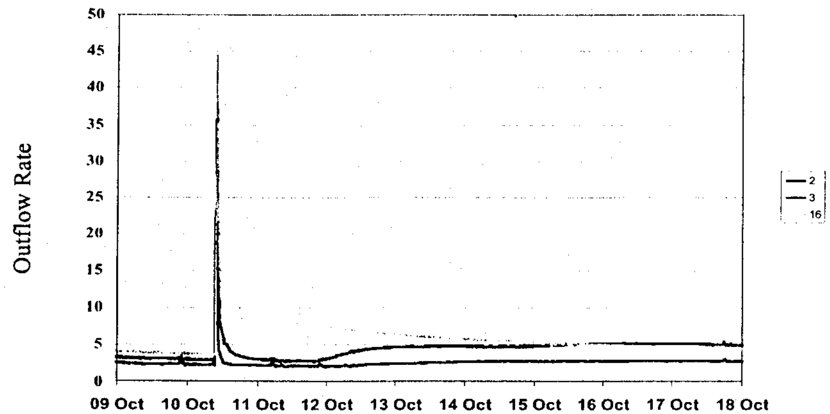
Rainfall and Outflow Summary August to October, 1999

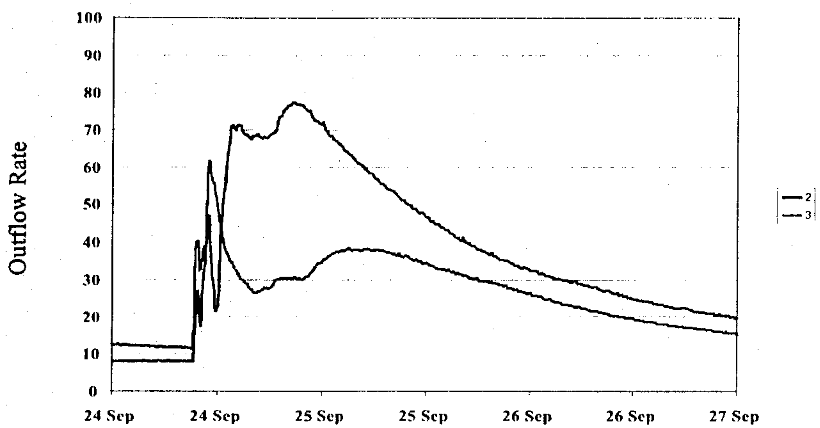


Outflow Rates Sept 24 and Oct 20 Rainfall Events: Examples of Spatial Variations of Flow

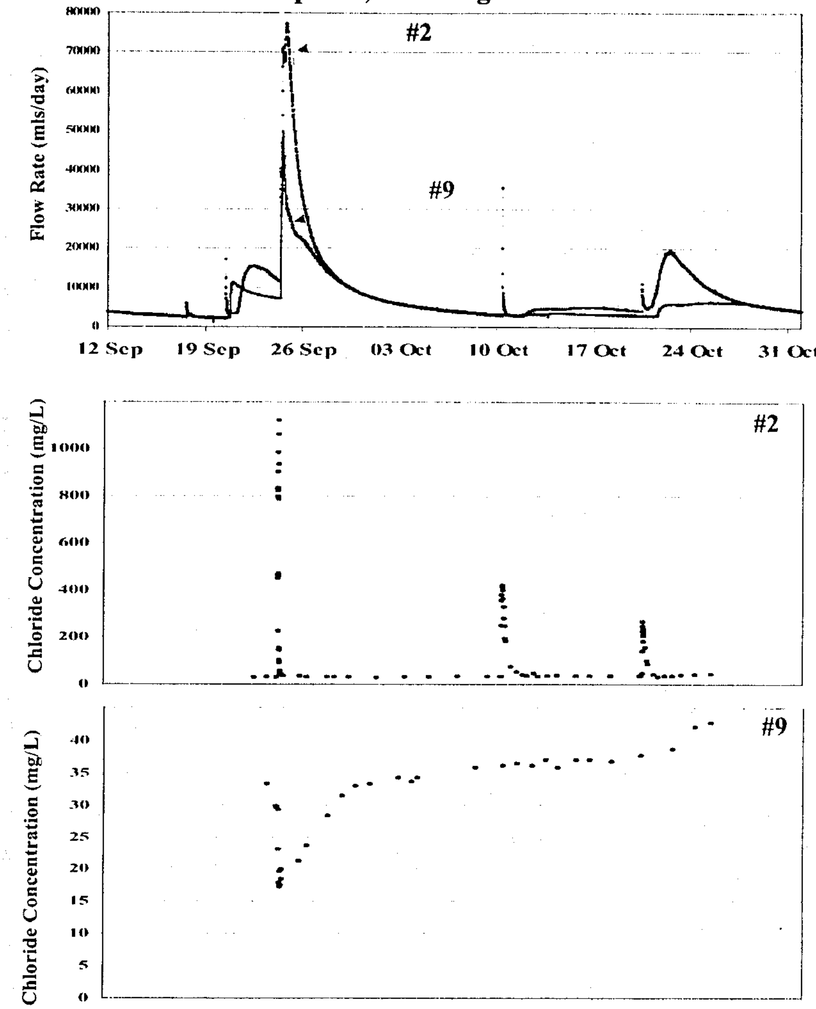


Outflow Rates Sept 24 and Oct 10 Rainfall Events :



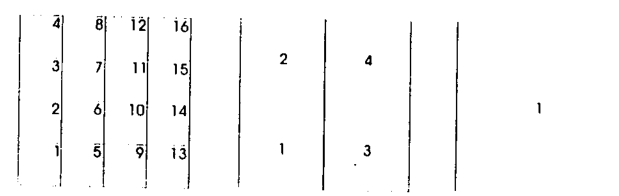


Preliminary Tracer Test Results: Sept. 24, 2000 mg/L Cl as LiCl



Results Pending

- Evaporation
- Neutron probe data
- Soil water characteristic curves
- Hydraulic conductivity curves
- Gas pressures
- Gas chemistry and isotopic ratios
- Additional kinetic testing varying grain size and moisture content
- Mineralogical study of waste rock
- Weathering properties
- Detailed water chemistry
- Examine scaling of both flow and chemistry



- Laboratory column experiment (1m x 2 m)

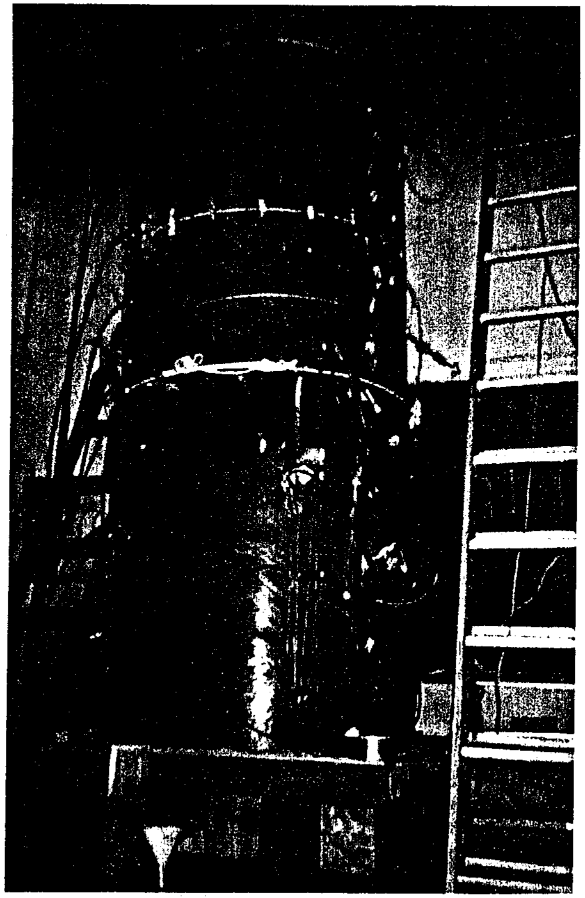
Internal

pH	Cond. (uS/cm)	Depth (cm)
3.4 - 4.3	2000-4000	20
3.0 - 3.4	5000-9000	175
3.2 - 3.5	8000-18000	450

Outflow

Date	pH	Conductivity (uS/cm)
Sept 98	3.9 to 7.7	
Aug 99	3.3 to 4.2	9 to 17,000
Sept 99	3.5 to 3.9	10 to 15,000
Oct 99	3.5 to 3.7	10 to 12,000

Summary of Pile Chemistry



Laboratory Column Experiment

Summary to Date

- Building an experiment such as this requires a great deal of planning.
- To determine evaporation, it is better to locate the experiment such that the top surface is flush with the top surface, and downwind of, an existing pile.
- Moisture content by TDR appears to be the most clear indicator of flow conditions in the matrix. Coated and uncoated probes should be installed side by side.
- Initial outflow from the an experimental pile is slow. Necessary construction practices will make prediction of the timing of initial outflow from a real pile difficult.
- Flow is spatially variable on the scale of <2 metres.
- Physically and chemically distinct fast flowpaths for new water do exist.
- Old water can be remobilized from near surface to depth.
- A large proportion of outflow response appears to be old water expelled by a pressure wave.