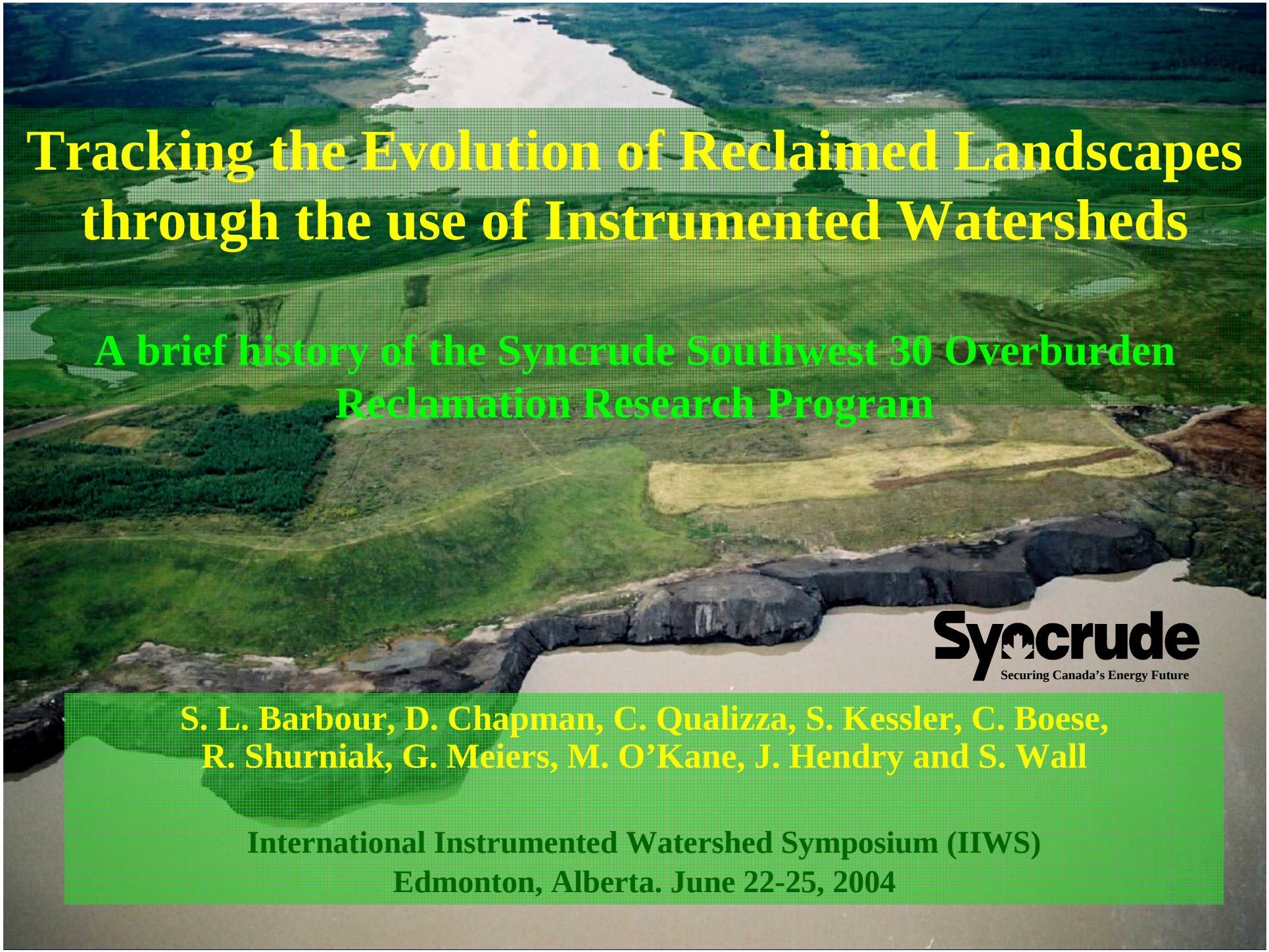


Tracking the Evolution of Reclaimed Landscapes through the use of Instrumented Watersheds

A brief history of the Syncrude Southwest 30 Overburden Reclamation Research Program

Syncrude
Securing Canada's Energy Future

S. L. Barbour, D. Chapman, C. Qualizza, S. Kessler, C. Boese, R. Shurniak, G. Meiers, M. O'Kane, J. Hendry and S. Wall

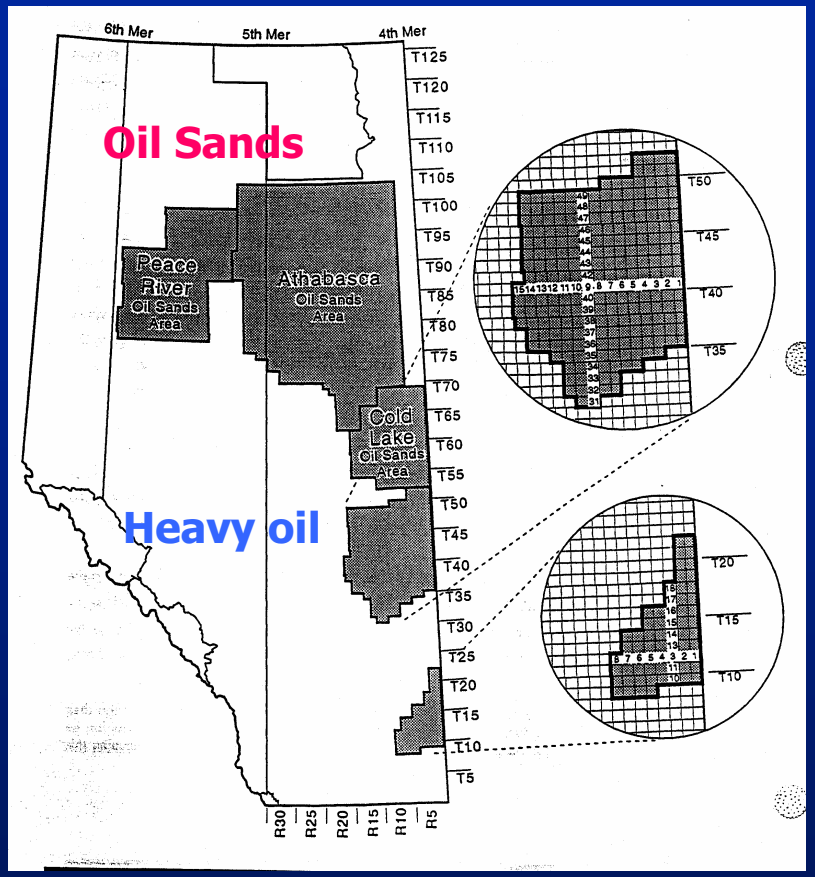
International Instrumented Watershed Symposium (IIWS)
Edmonton, Alberta. June 22-25, 2004

Presentation Outline

- **Introduction (Clara)**
  - **Syncrude and the Mildred Lake Mine**
  - **Reclamation Challenge**
  - **Corporate Reclamation Strategy**
- **Review of Research Program (Lee)**
  - **Objectives**
  - **Instrumentation**
  - **Data Management**
  - **Presentation of Typical Results**
  - **Key Analyses and Interpretations**
  - **Conclusions and Recommendations**

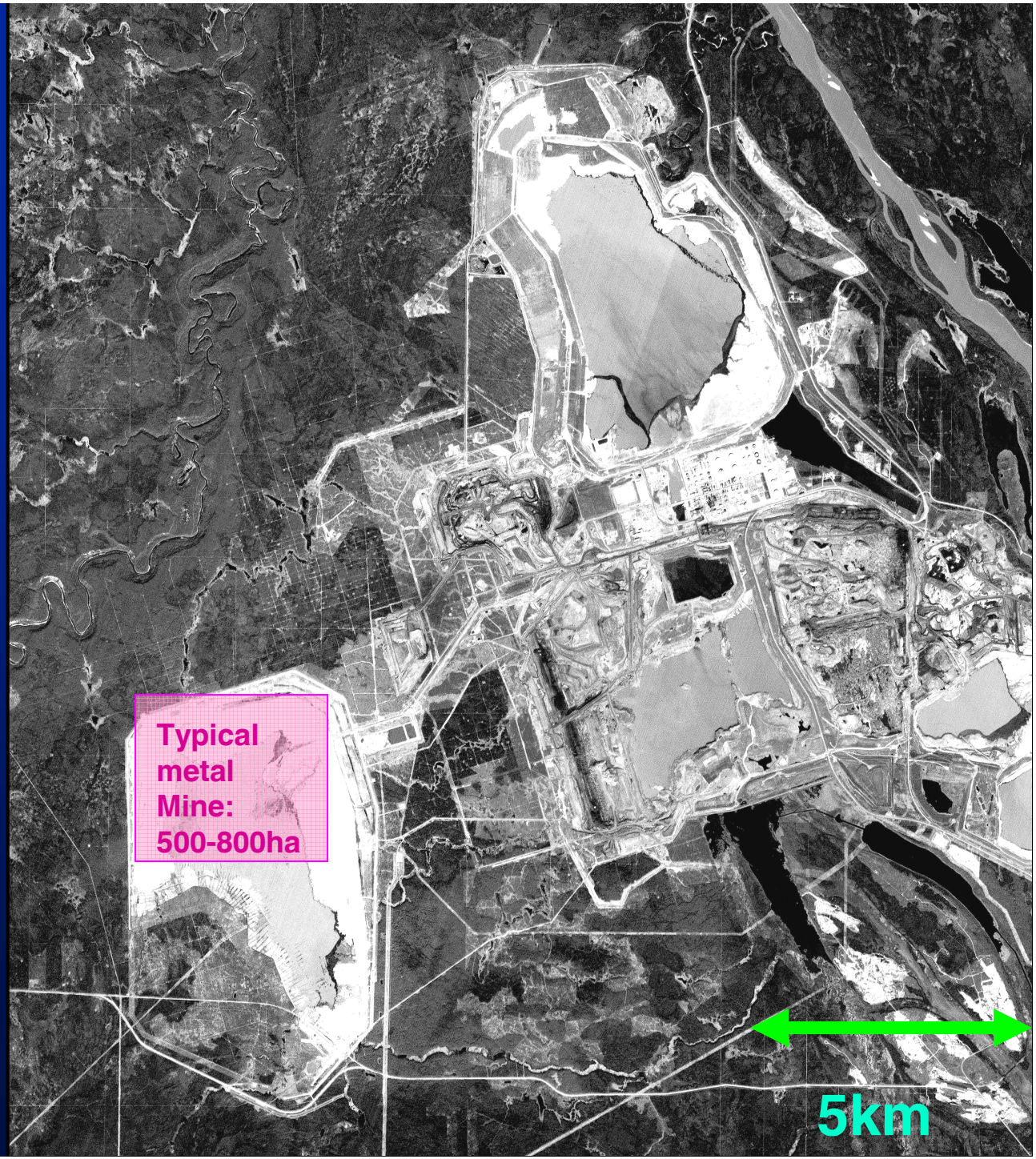
Oil Sands

- Oil Sand regions
  - 4 in Alberta:
    - » Athabasca, Wabasca, Cold Lake, Peace River
  - Largest petroleum resource in the world
  - Deposits contain
    - » 1.7 – 2.5 trillion barrels of bitumen
    - » 300 billion recoverable with current technology
  - 30% of Canada's oil production, within next 10 years, 50%



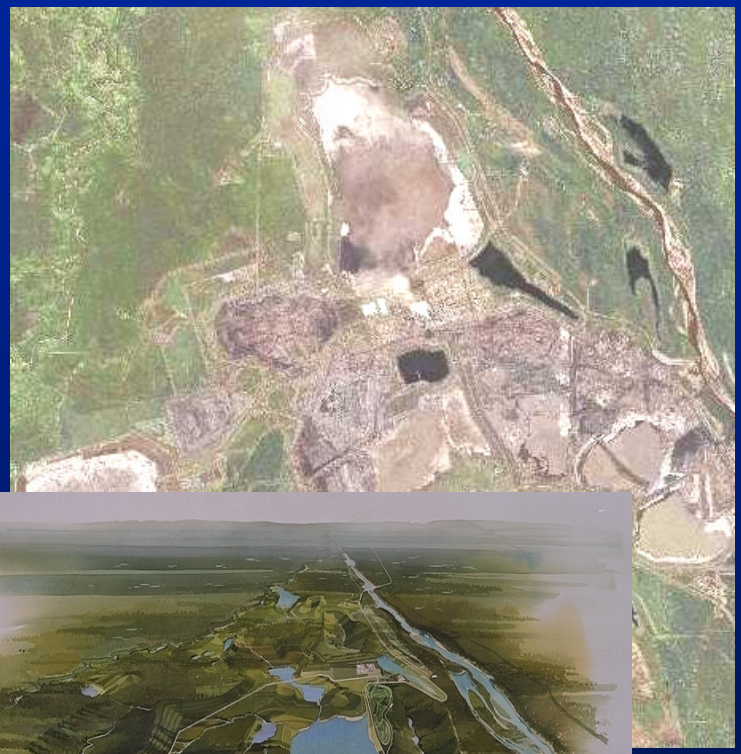
Syncrude's Base Mine

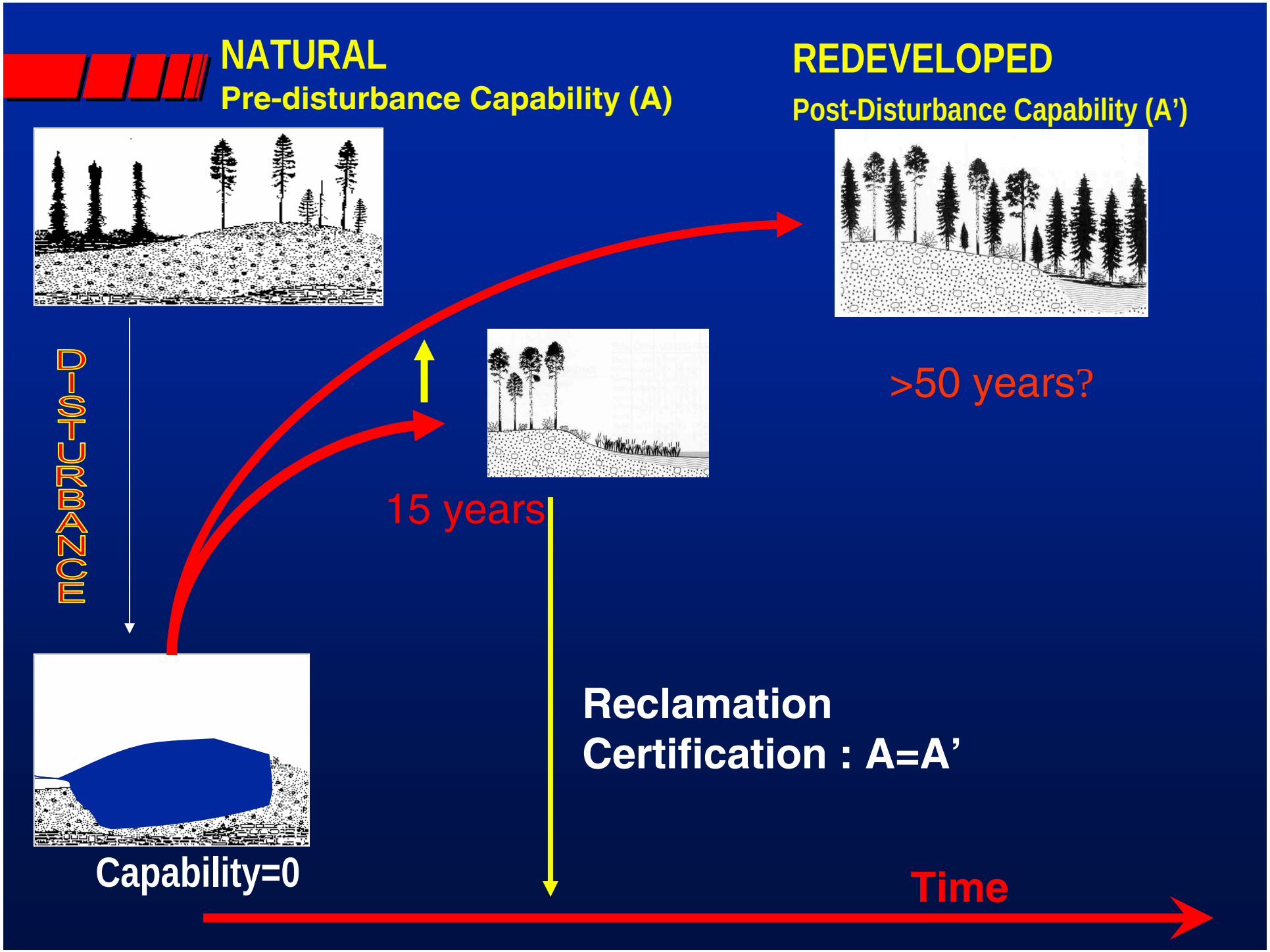
- Resource Access will require disturbance of 21,000 ha
- Other regional operators similar



Duty to Conserve and Reclaim

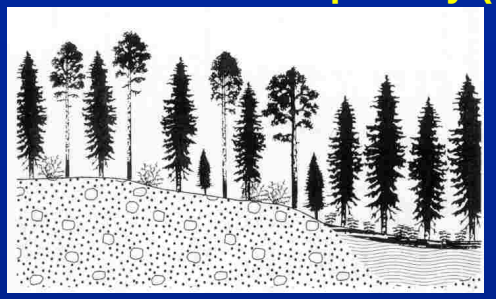
- **Alberta's Environmental Protection and Enhancement Act (EPEA)**
  - **Part 5 Section 122(1)**
  - **An operator must: conserve & reclaim specified land**
    - » **Unless exempted by the regulations, obtain a reclamation certificate in respect of the conservation and reclamation**



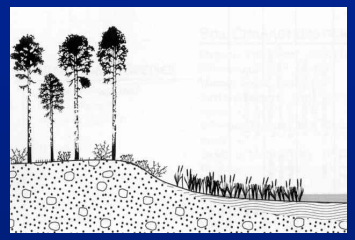

NATURAL
Pre-disturbance Capability (A)
REDEVELOPED
Post-Disturbance Capability (A')
DISTURBANCE
>50 years?
15 years
Reclamation
Certification : A=A'
Capability=0
Time

NATURAL
Pre-disturbance Capability (A)

REDEVELOPED
Post-Disturbance Capability (A')

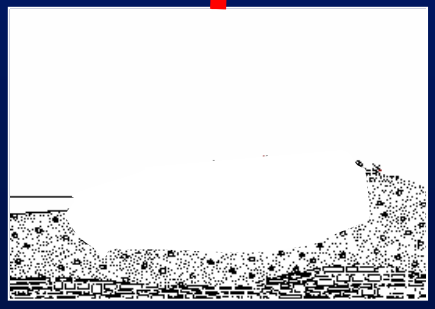


>50 years?



15 years

DISTURBANCE



Capability=0

Reclamation R& D :

1. **Defining the trajectory**
2. **Optimizing reclamation techniques**

Time

Landforms

Revegetation

Soil Placement

Reclamation R& D :

1. **Defining the trajectory**
2. **Optimizing reclamation techniques**

→ **Reduced liability**

Reclamation R&D Research Approach

- **In order to make statements about** ecosystem trends **in response to design or management we need:**

1. **Time**
2. **A landscape**
3. **A multi disciplinary team**

Interactions at **the landscape level** control if the reconstructed ecosystem will be

Why a watershed?

- The major **building block** of our landscapes
- Majority of **questions** asked about **landscape performance** can be addressed at the watershed scale
- Encompasses the range of target **ecosites** we desire for the particular parent material
- Allows for “real” measurement of **balances** and **patterns**
- Demands thought about **interactions**
- It is **manageable**

TEAM

- **Scientists and engineers working together**
- **Define how manipulations of**
  - **Landform construction**
  - **Soil placement**
  - **Revegetation**
- **Interact to control the successful evolution of the final landscape**

The Instrumented Watersheds: Meeting Places

- Encompassing ecological and human dynamics that
  - accelerate arrival at optimal reconstruction practice
  - certification

1st Watershed:
Saline Sodic Overburden

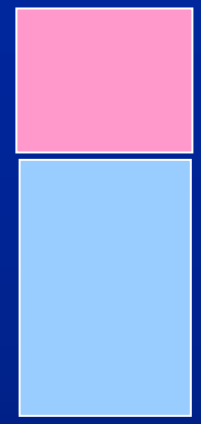
- **Cretaceous marine shale**
  - **Swelling clays**
  - **High salt content**
  - **Sodium rich**
- **Severely limited plant growth**
- **Highly erosive**
- **Will occupy 80 km^2 of final landscape‘**

Ya So

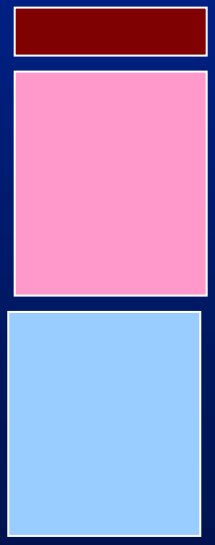
- **Next 10 years:**
  - **14 million cubic meters of soil**
- **Today:**
  - **~ 1.5 million cubic meters**

The question

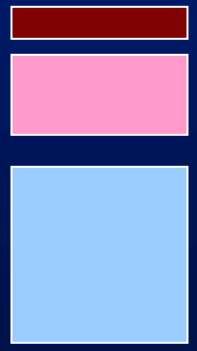
- **What is the correct soil profile ….**
  - **To establish a productive boreal forest ecosystem**
    - » **functioning uplands AND wetlands**
    - » **minimizing salt leaching/erosion**



50 cm Unlayered?



1 m layered



35 cm Layered?

The TEAM

- **University of Saskatchewan**
  - **Civil Engineering and Geological Engineering**
  - **Soil Science**
  - **Geology**
  - **Geography**
- **Linkages to to University of Alberta:**
  - **Hydrology/Hydrogeology**
  - **Terrestrial ecology**
  - **Biogeochemistry**

Original Research Program

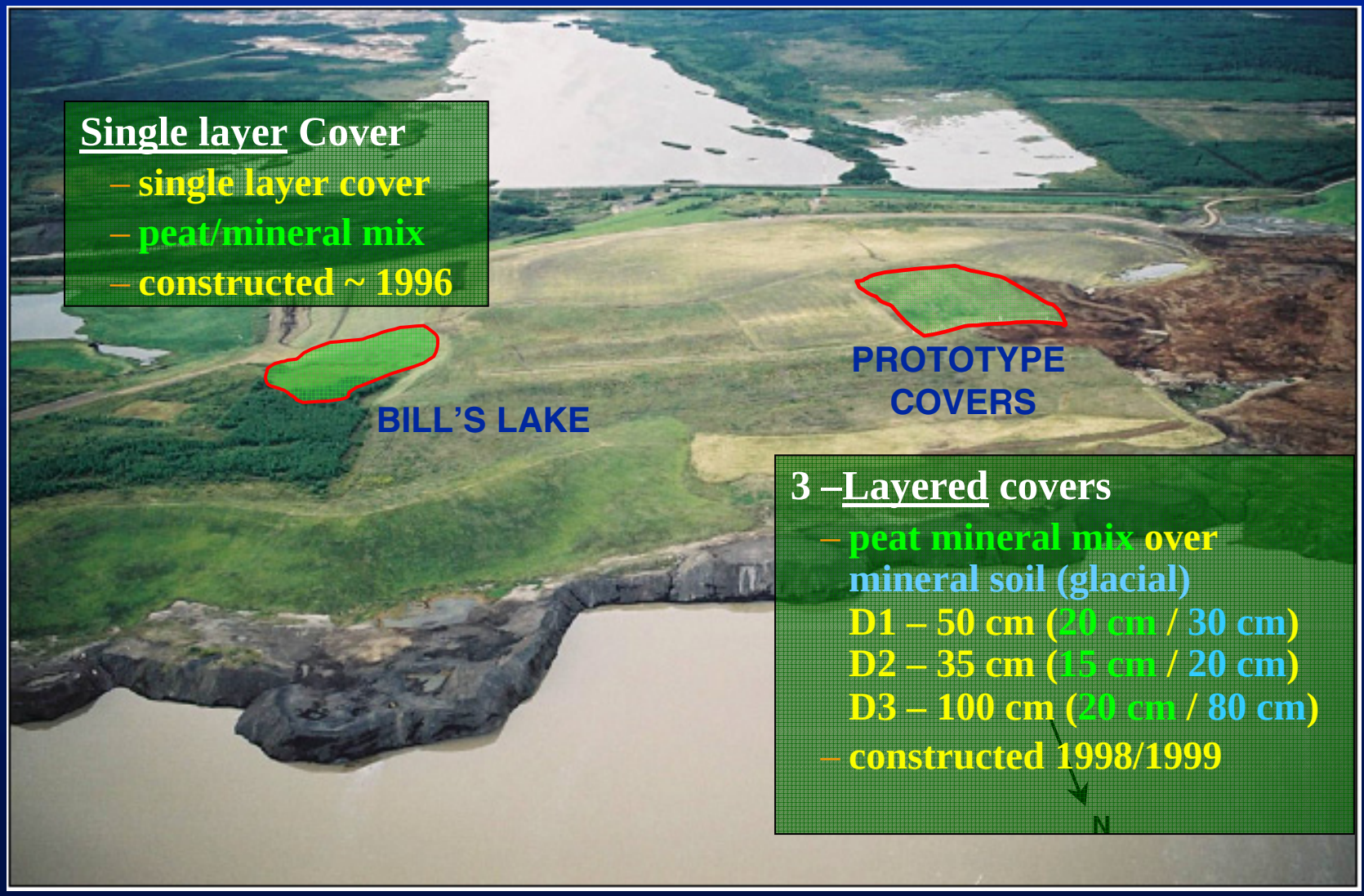
"Characterization and Prediction of the Performance of Virgin, Reclaimed Watersheds on Sodic Waste from Oil Sands Mining"

- **Objectives**
  - **Evaluate long-term performance**
    - » **alternate soil cover designs**
    - » **minimum cover thickness**
      - **sustainability - 'Land Capability' ranking**
  - **Monitor watershed performance**
    - » **hydrologic / hydrogeologic evolution**
    - » **monitor wetland development and salt transport**
  - **Evaluate hydrologic models**
  - **Characterize weathering of sodic overburden**
    - » **physical stability and hydraulic behavior**
- **Overall objective:**
  MECHANISMS (moisture & salt transport)

  Monitoring --- Modelling --- Management

Field Site and Instrumentation

- **Southwest 30 Overburden Hill**



Field Monitoring:

- Soil
  - Soil Monitoring Stations
    - water content – FDR
    - suction – TCS (CS, U of S)
    - Temperature
    - Tensiometer check of TCS
  - Neutron probes
  - Insitu K
    - Guelph Permeameter
  - Interflow (volumes/chemistry)
    - Interflow collection system
    - Saturated Wedge monitoring
  - Runoff:
    - snow survey
    - Weirs
  - Sampling
    - Soil w.c., density, chemistry
- Vegetation
  - LAI / Root Growth
  - Photosynthetic efficiency
  - Biomass
  - Diversity indices
- Climate and Hydrology
  - Climate:
    - Rh, wind speed, precipitation, net radiation, temperature
  - Evaporation:
    - Bowen Ratio, Pan evaporation
  - Snow Survey
    - Snow depth and SWE
  - Surface Ponds
    - Leakage - seepage meters
    - Staff gauges
    - EC/chemistry
- Hydrogeology:
  - Deep Piezometers
- Geochemistry
  - Gas profiles / fluxes
  - Oxidation rates/reactions
- Geophysics:
  - EM31, EM38, ERT

Soil Monitoring

N →

Runoff Weir

Reclamation Material

Instrumentation Station

Neutron Access Tube

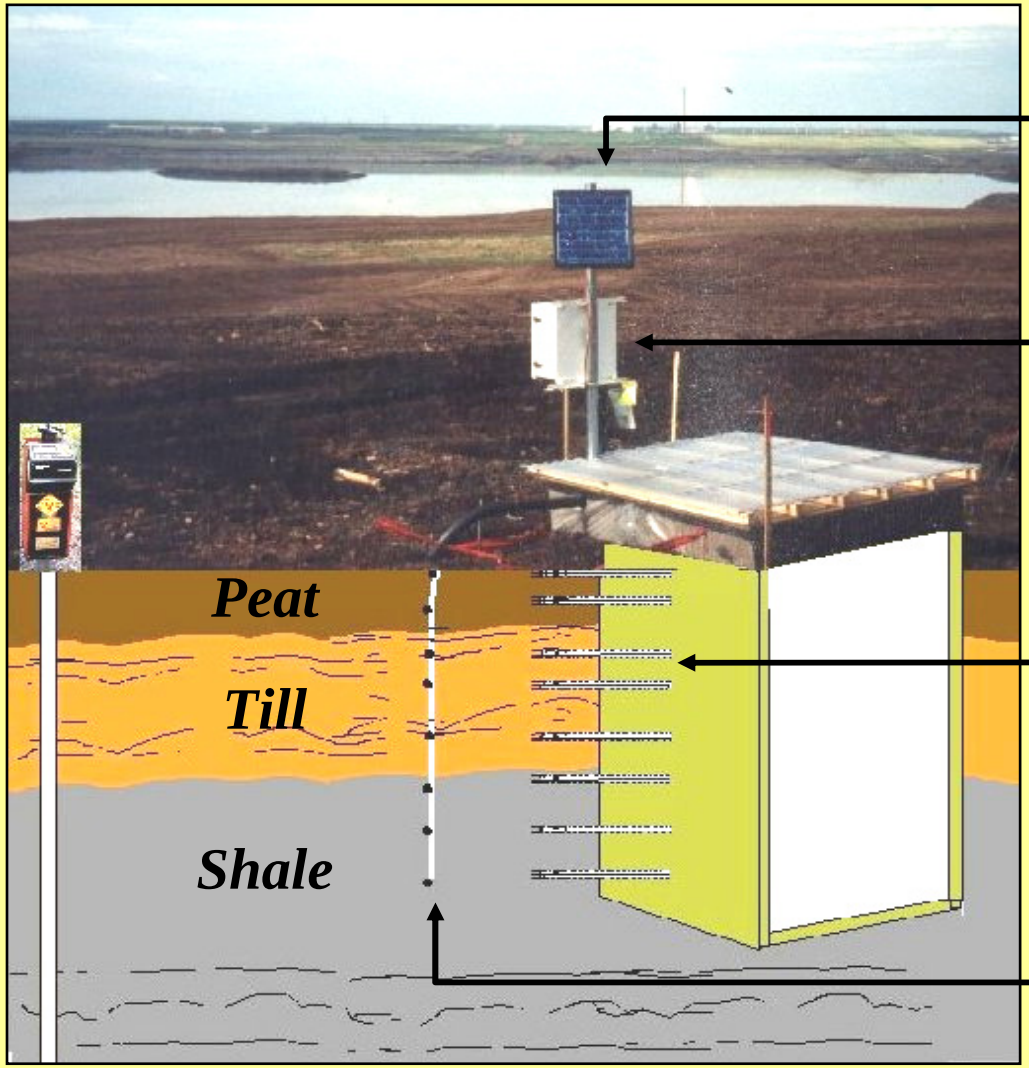
Drainage Ditch

Interflow Collection

And saturated wedge monitoring

Saline Sodic Overburden

Soil Monitoring Station



Neutron Probe & Access Tube

Solar Powered D.A. System

Soil Suction & Water Content Sensors

Temp. Sensor

Interflow Collection System:

Data Management

- **Data Collection / DA Systems**
  - **Weekly download in summer, monthly rest of the year**
  - **Data integrity**
    - **all data reviewed for sensor failure prior to adding to the database**
- **Maintenance/Calibration**
  - **Bowen ratio**
    - **Summer operation only**
    - **Bi-weekly maintenance of air temperature/vapour pressure sensors**
    - **Continuing problems with thermocouples breaking**
    - **Occasional lost data due to shut down**
  - **Tipping Bucket**
    - **Addition of snowfall adapter/windshield in fall 2000 enable winter use**
    - **Still require snow survey to ensure freshet volumes**
  - **FDR – water content monitoring**
    - **Laboratory calibrated with site soils but …**
    - **Further work to deal with elevated salt levels (shale & lower cover soils)**
  - **Frozen Ground Limitations**
    - **FDR and TCS sensors inoperative below O^{o} C**
  - **Continuity of personnel**
    - **Annul or biannual graduate student turnover**
    - **1998-2002 University of Saskatchewan**
    - **2002-presented Contracted to O'Kane Consultants**

Essential Questions

- ‘Fluxes’ controlling vegetation sustainability
  - Water and Salt
  - Energy
  - Nutrients
- ‘Flux’ Mechanisms – Transient Phenomena
  - Flow and Storage / Dynamic in Nature
- ‘Flux’ Variability
  - Localized performance
    - » Yet integrated over landscape
  - Dimensional Variability
    - » Influence of aspect, slope, cover geometry, etc.
  - Temporal Variability
    - » Influence of climatic variability on ‘risk’ of failure
- Provides a Filter for Key Research Findings
  - Water and Salt ‘Fluxes’ (balances)
  - Mechanisms and Magnitudes
  - Temporal and Spatial Evolution

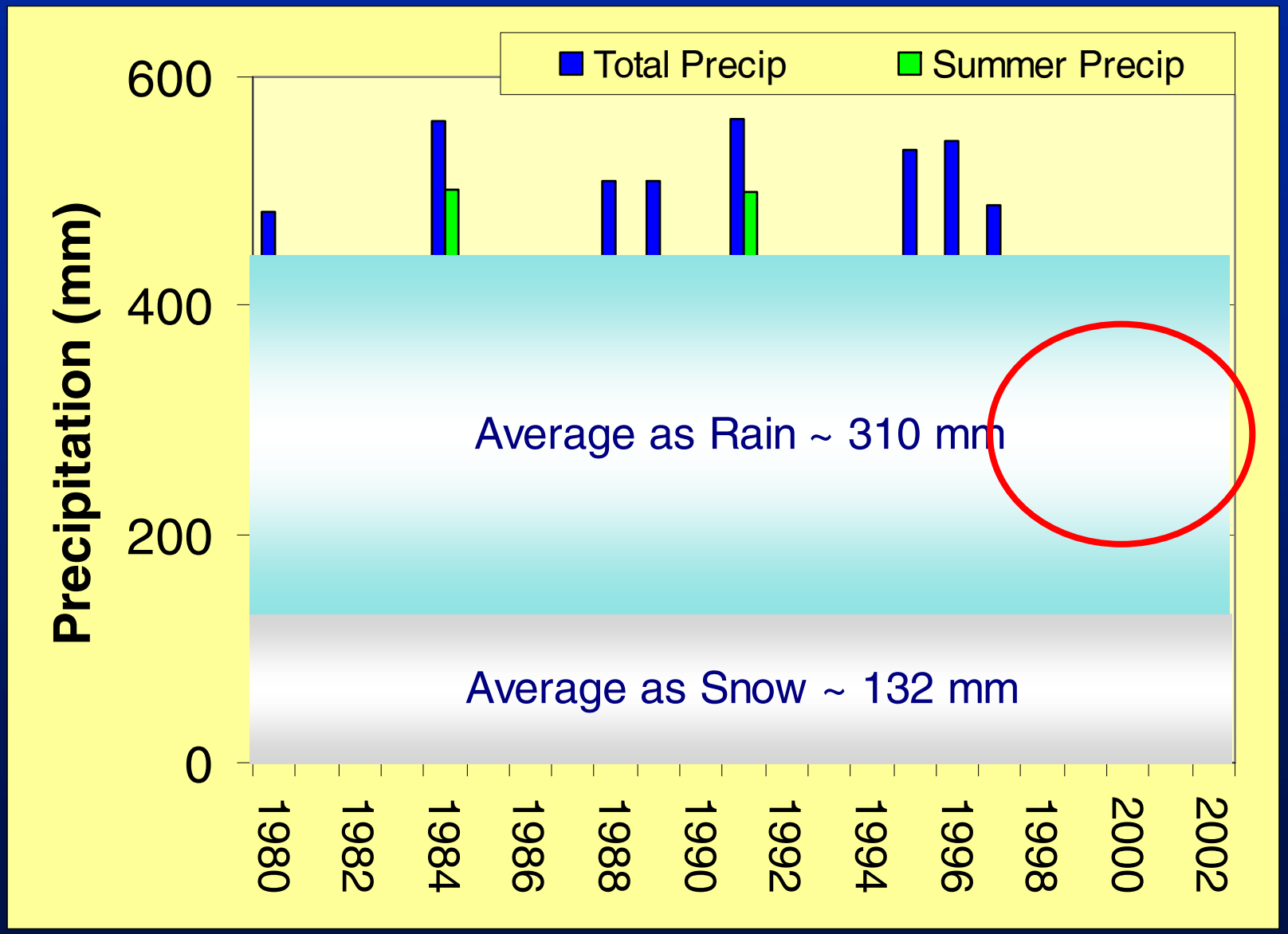
Presentation of Results

‘Snapshot’ of a Dynamic System

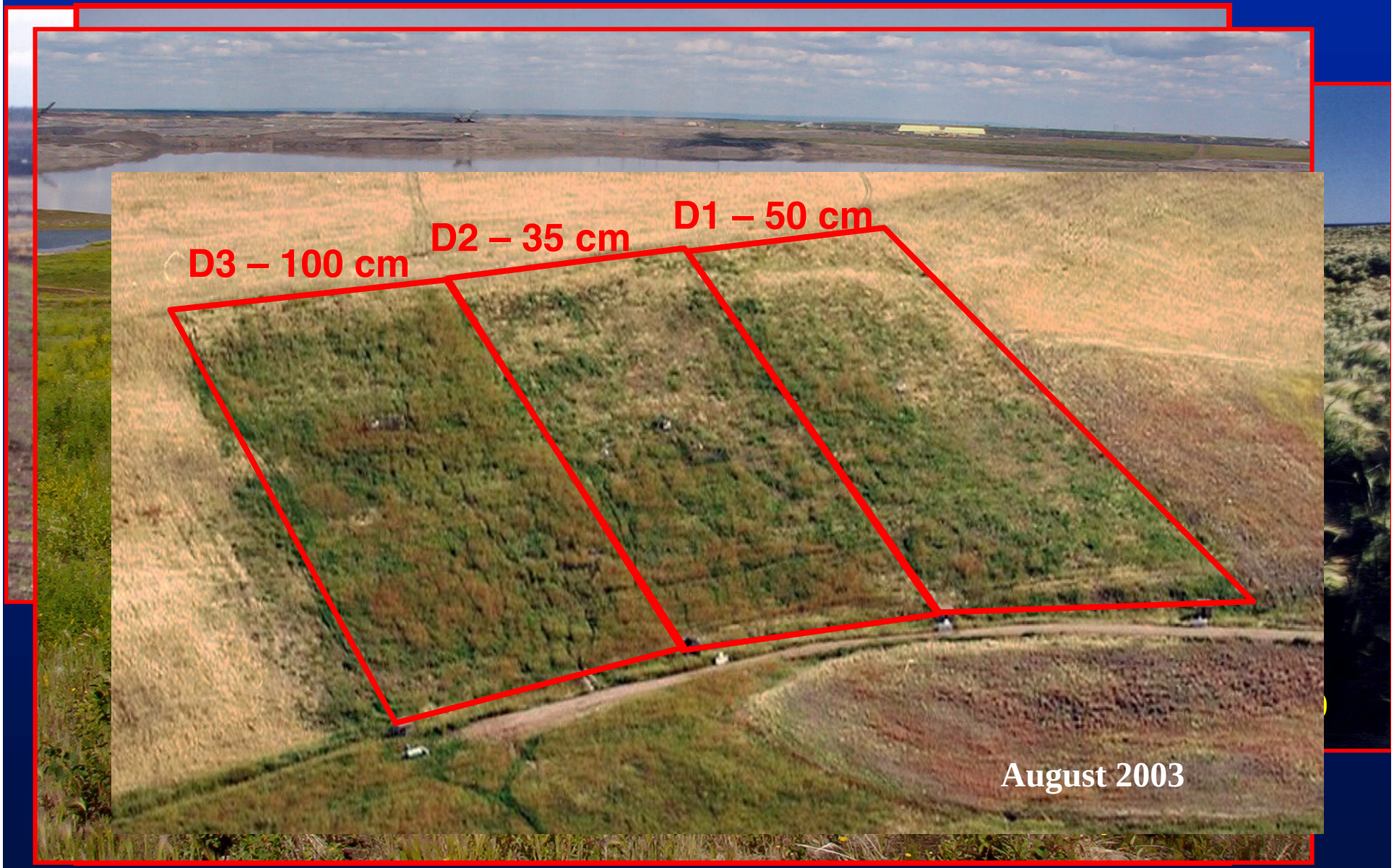
- Climate
  - Historical
  - Variable
- Vegetation
  - Qualitative
  - Quantitative
- Salt
  - Storage
    - » Shale Chemistry
    - » Salt Ingress
  - Flow
    - » Interflow Chemistry

- Water
  - Storage
    - » Water Content
    - » Water Volumes
    - » Suction
  - Flow
    - » Runoff
    - » Interflow
    - » Hydraulic Conductivity

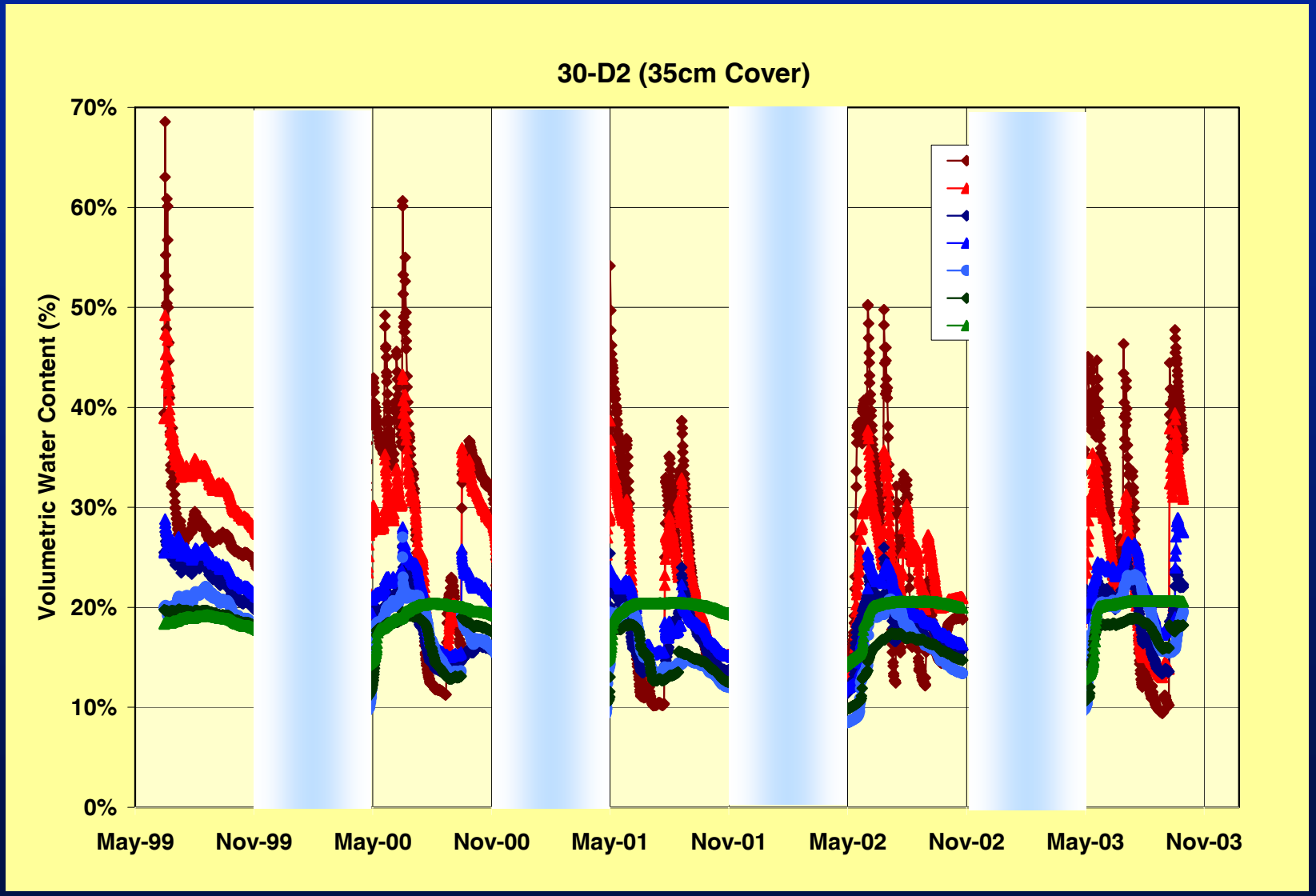
Historical Climate



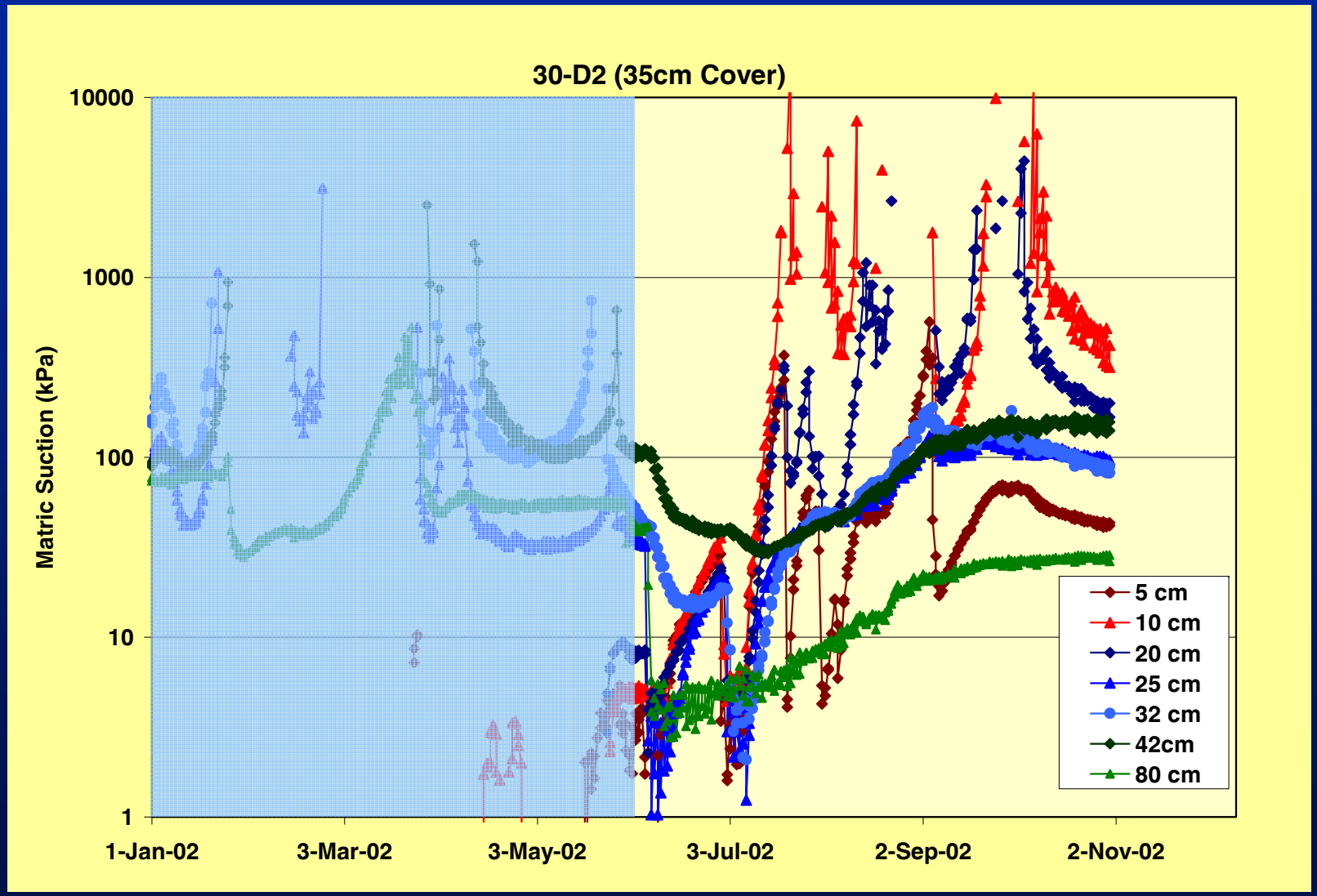
Vegetation - Prototype Covers



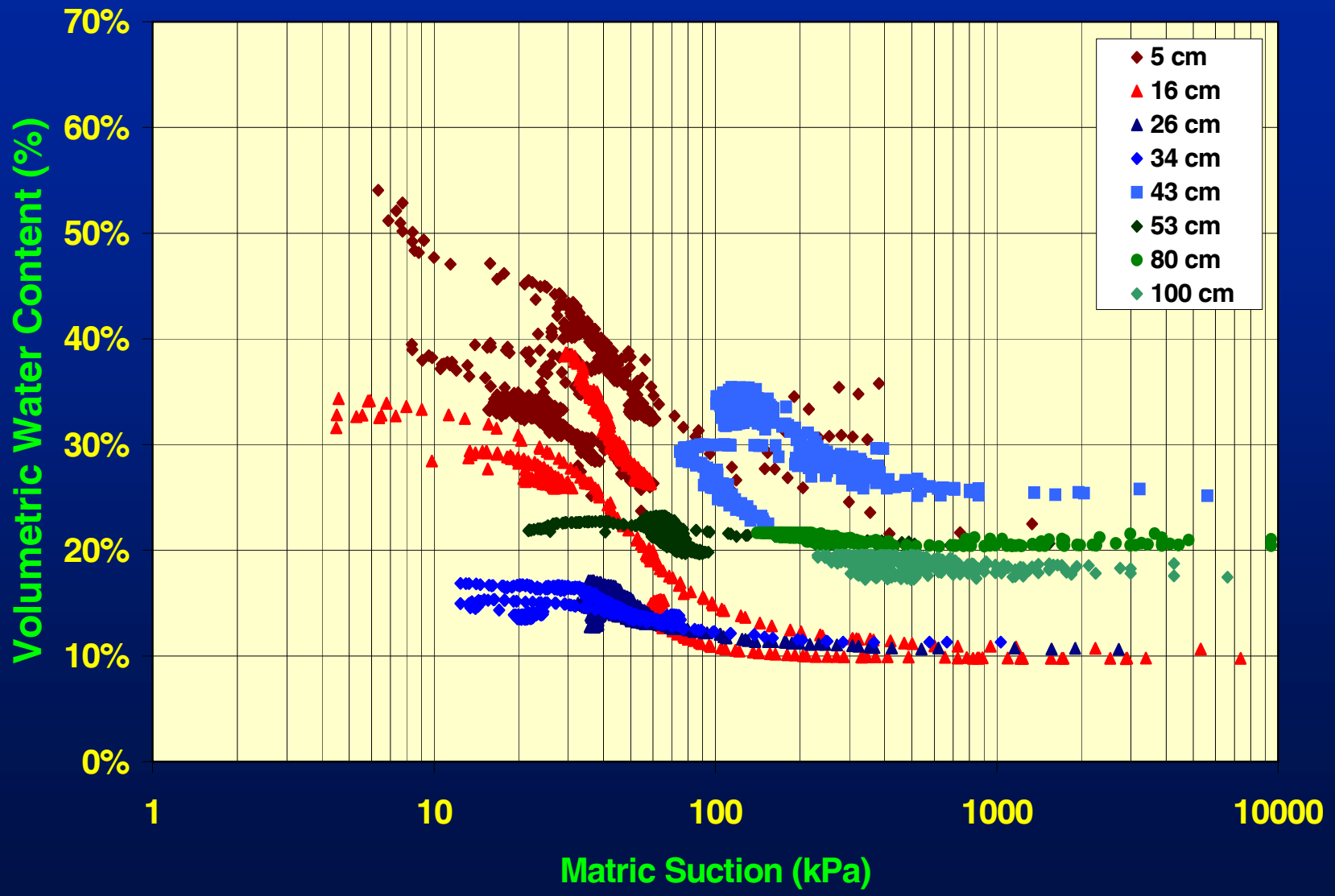
D2 – 35 cm Water Content



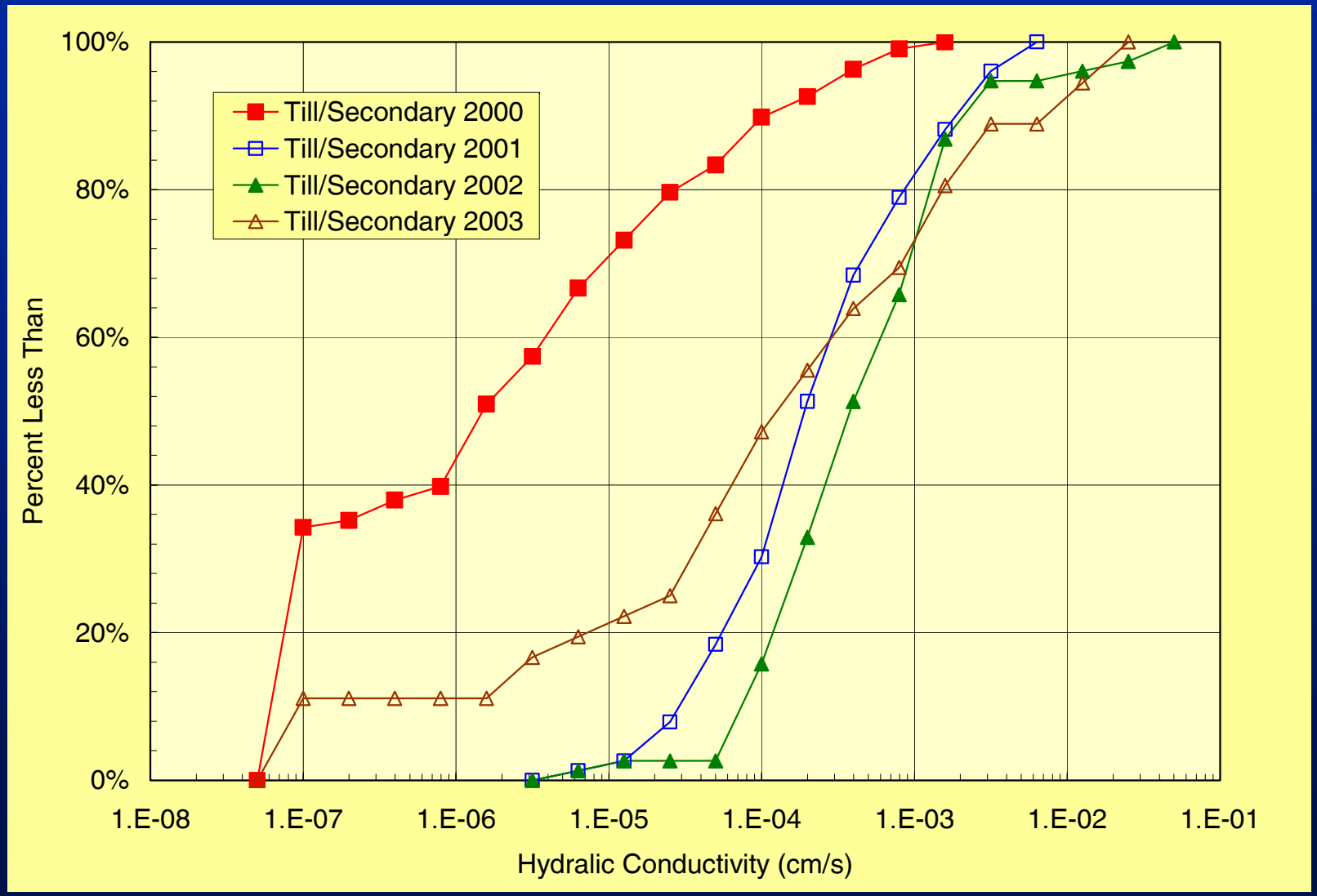
D2 – 35 cm Suction



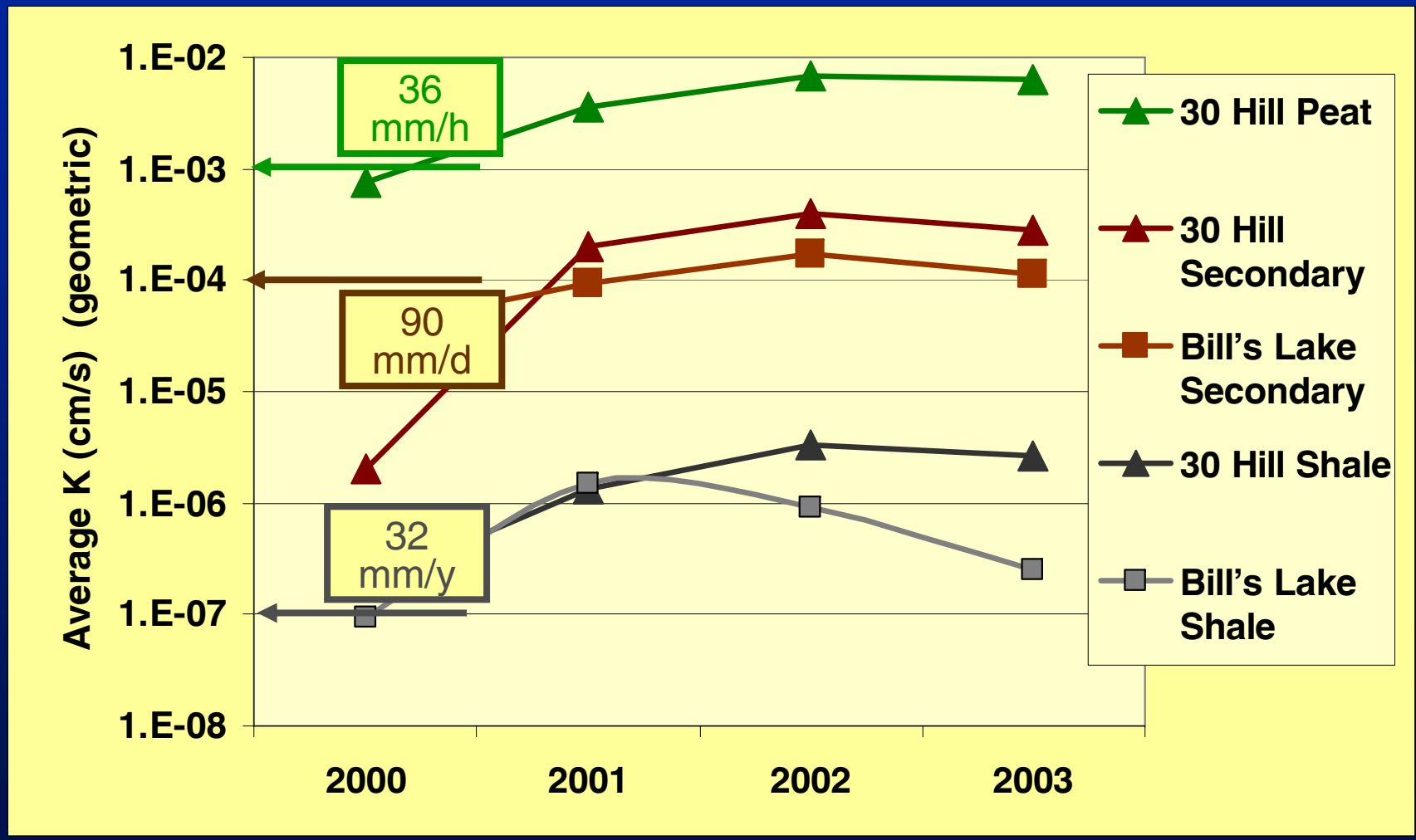
SWCC – 50 cm Cover 99 - 01



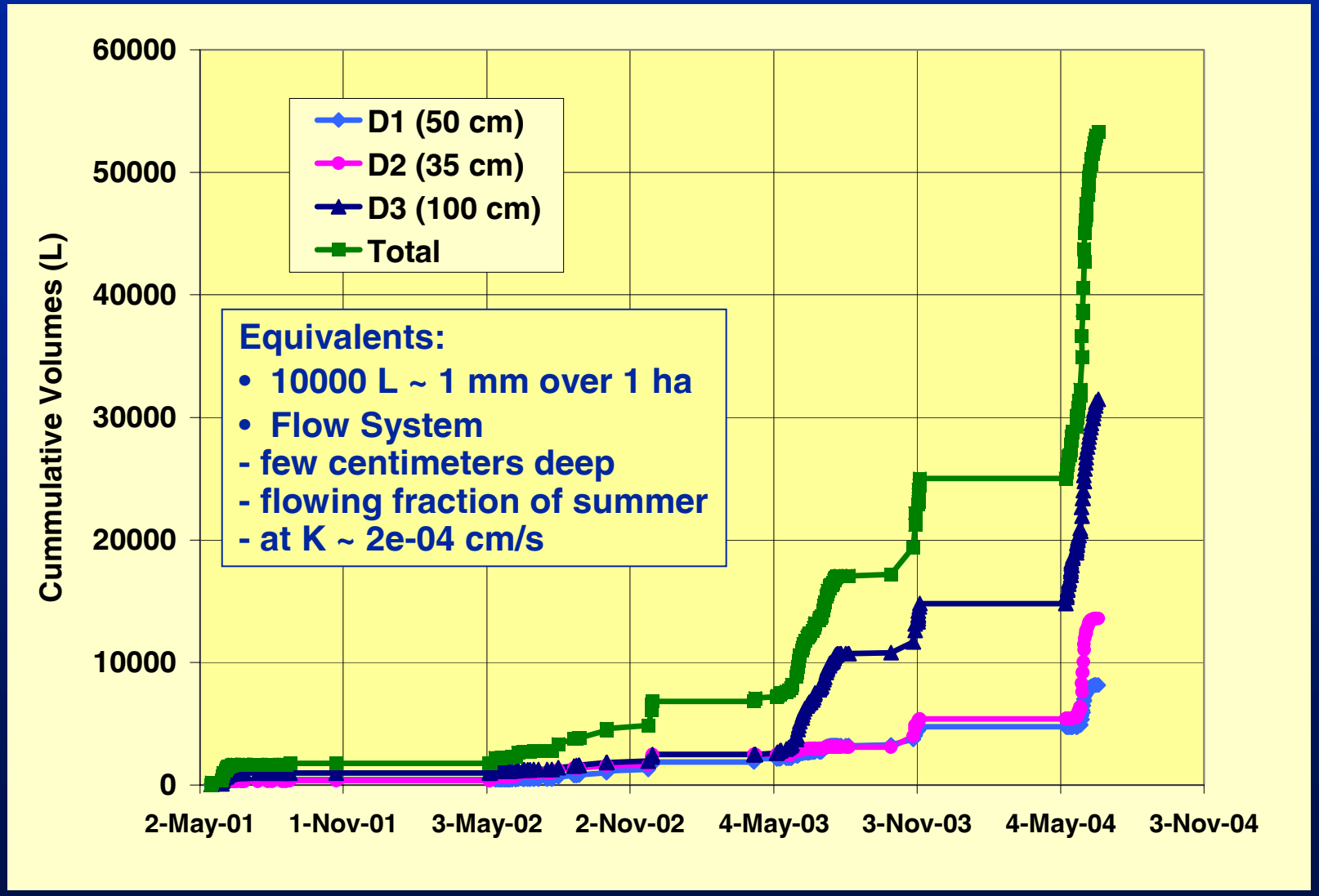
Secondary Hydraulic Conductivity



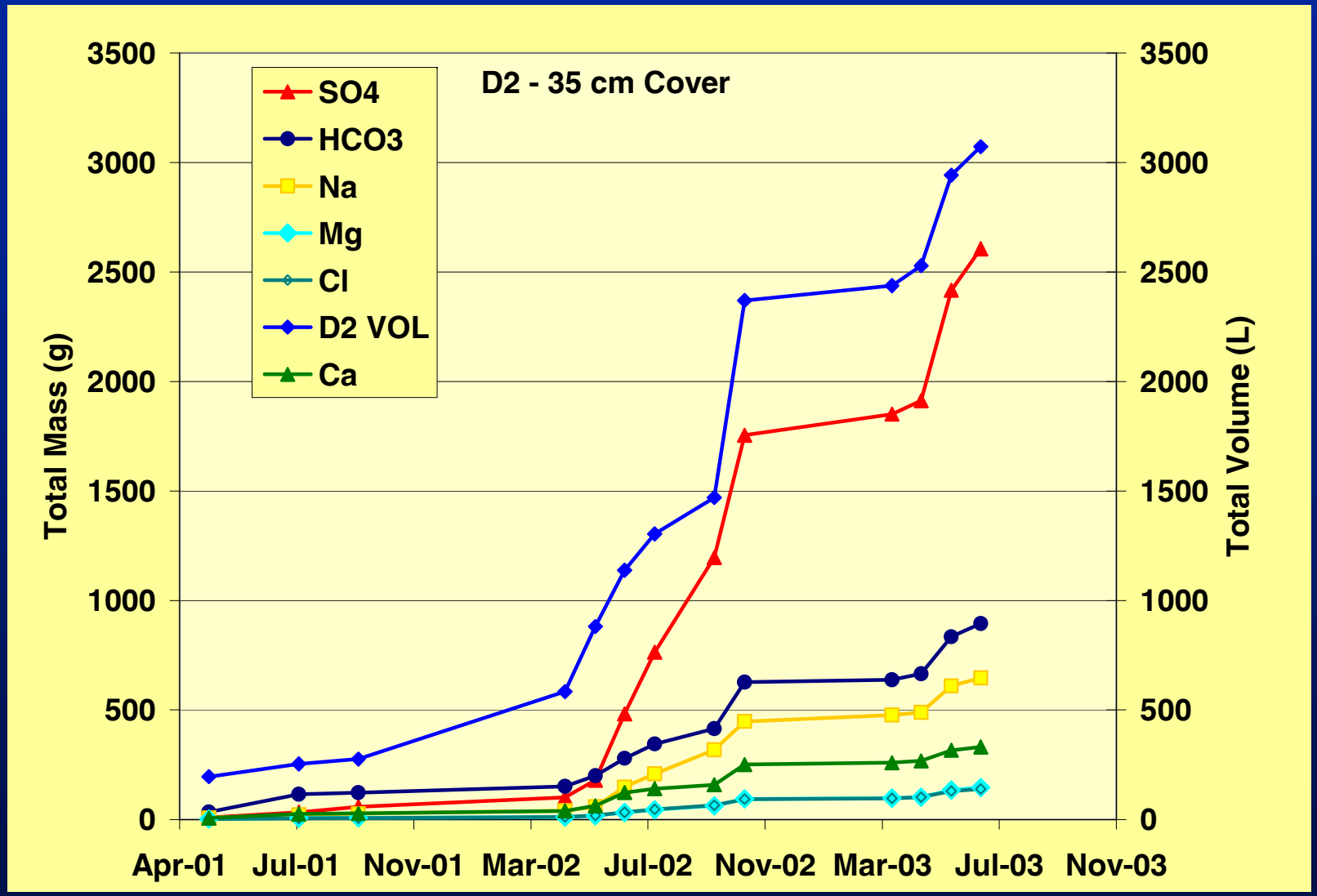
Hydraulic Conductivity of Cover Soils



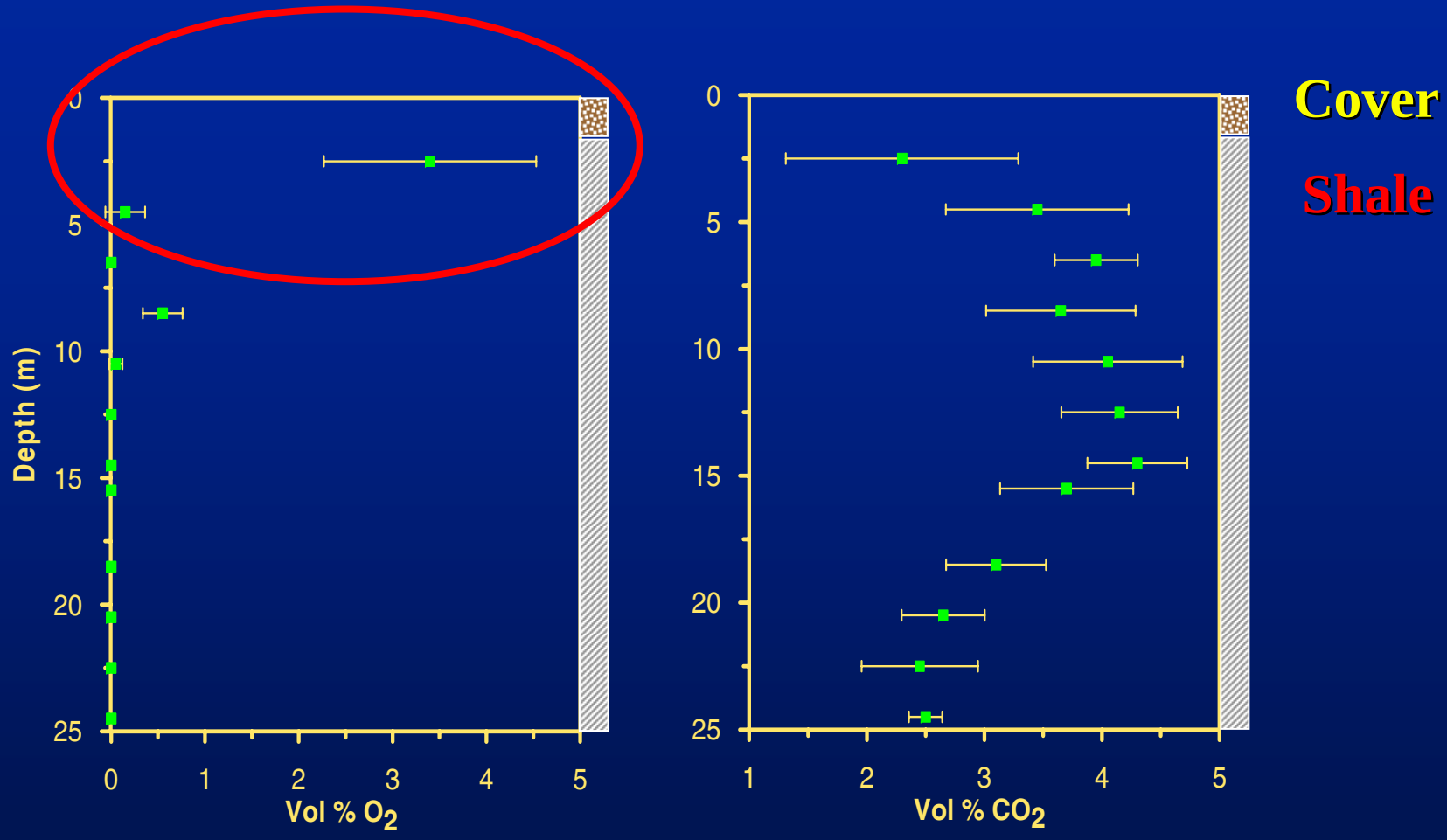
Cummulative Interflow Volumes



Interflow 'Loading' Rates

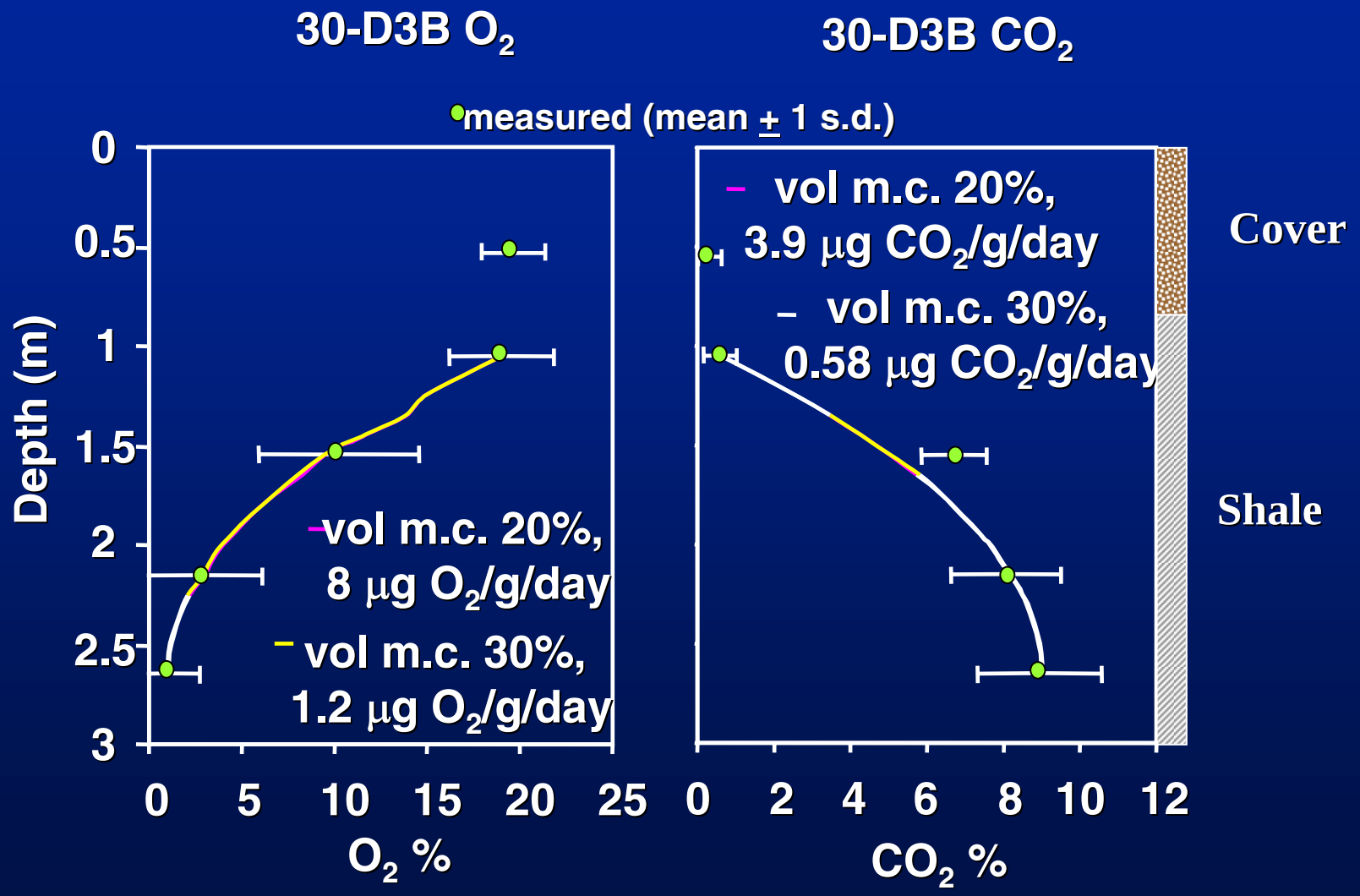


O_2 and CO_2 concentrations

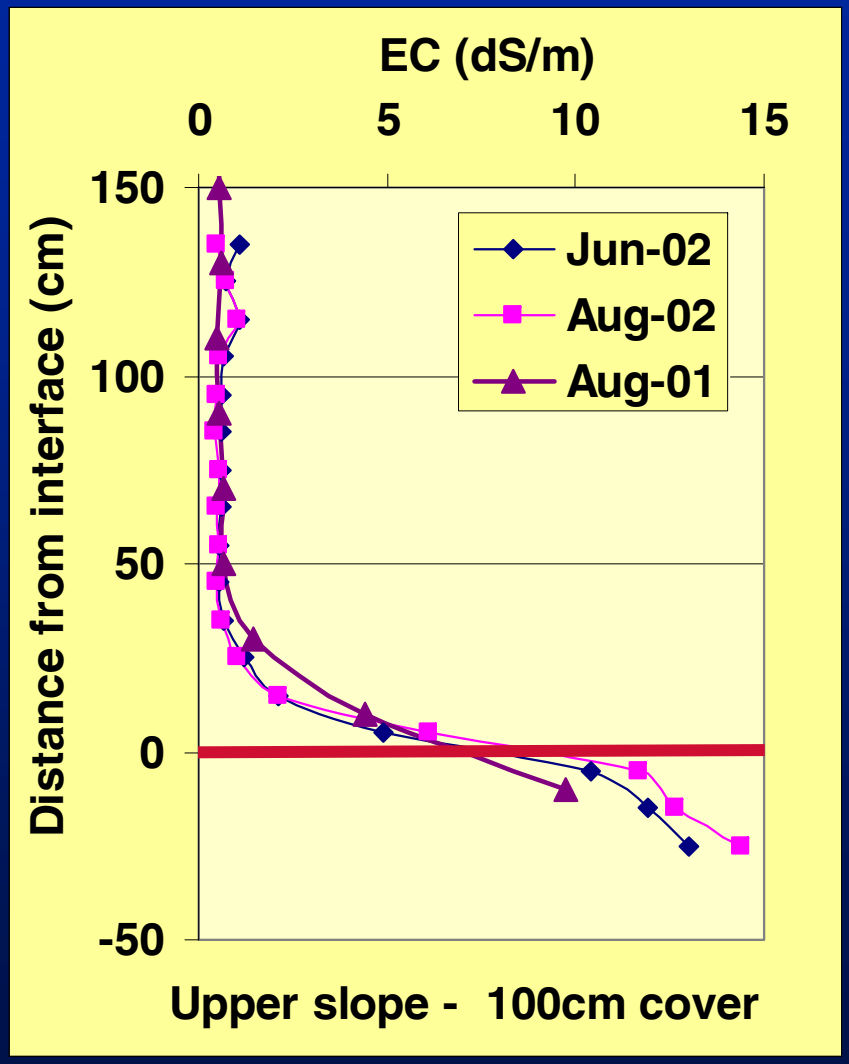


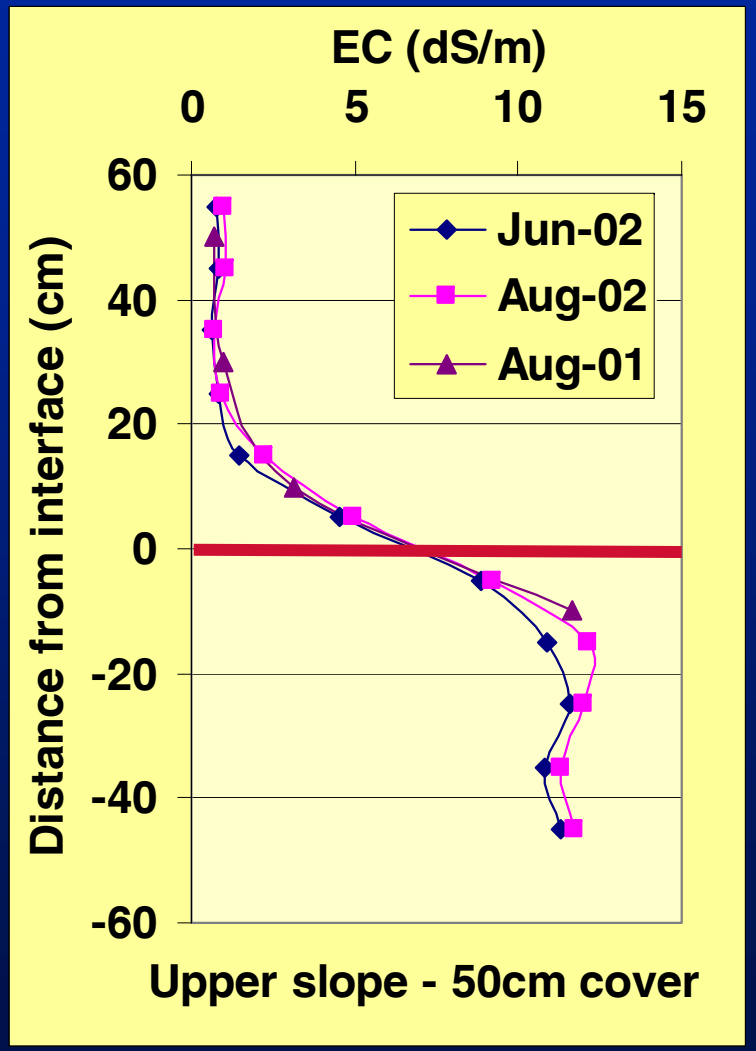
• measured (mean ± 1 s.d.)

Preliminary Modelling of Gas Profiles:



Salt Ingress into Cover

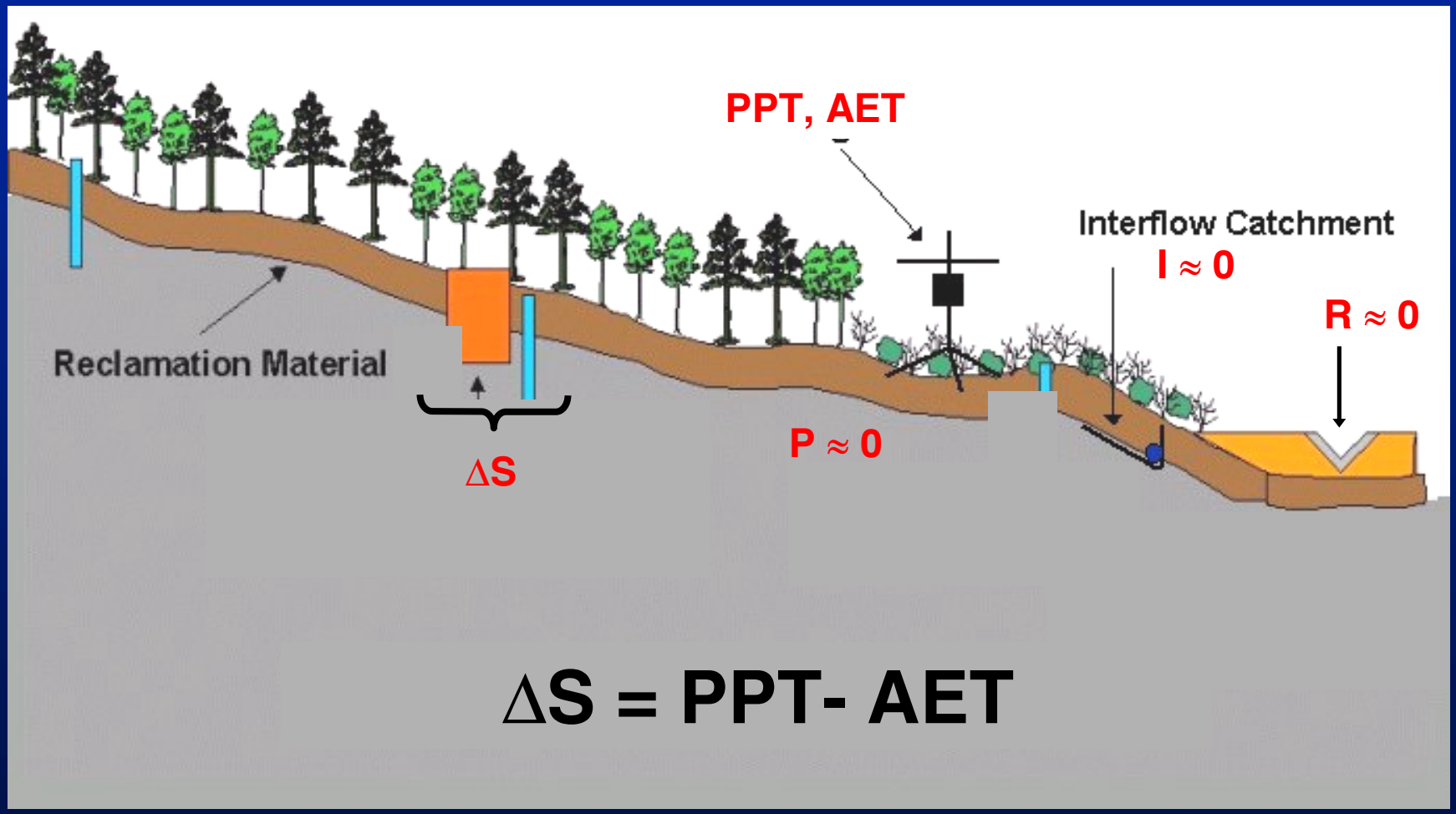




Key Analyses and Interpretations

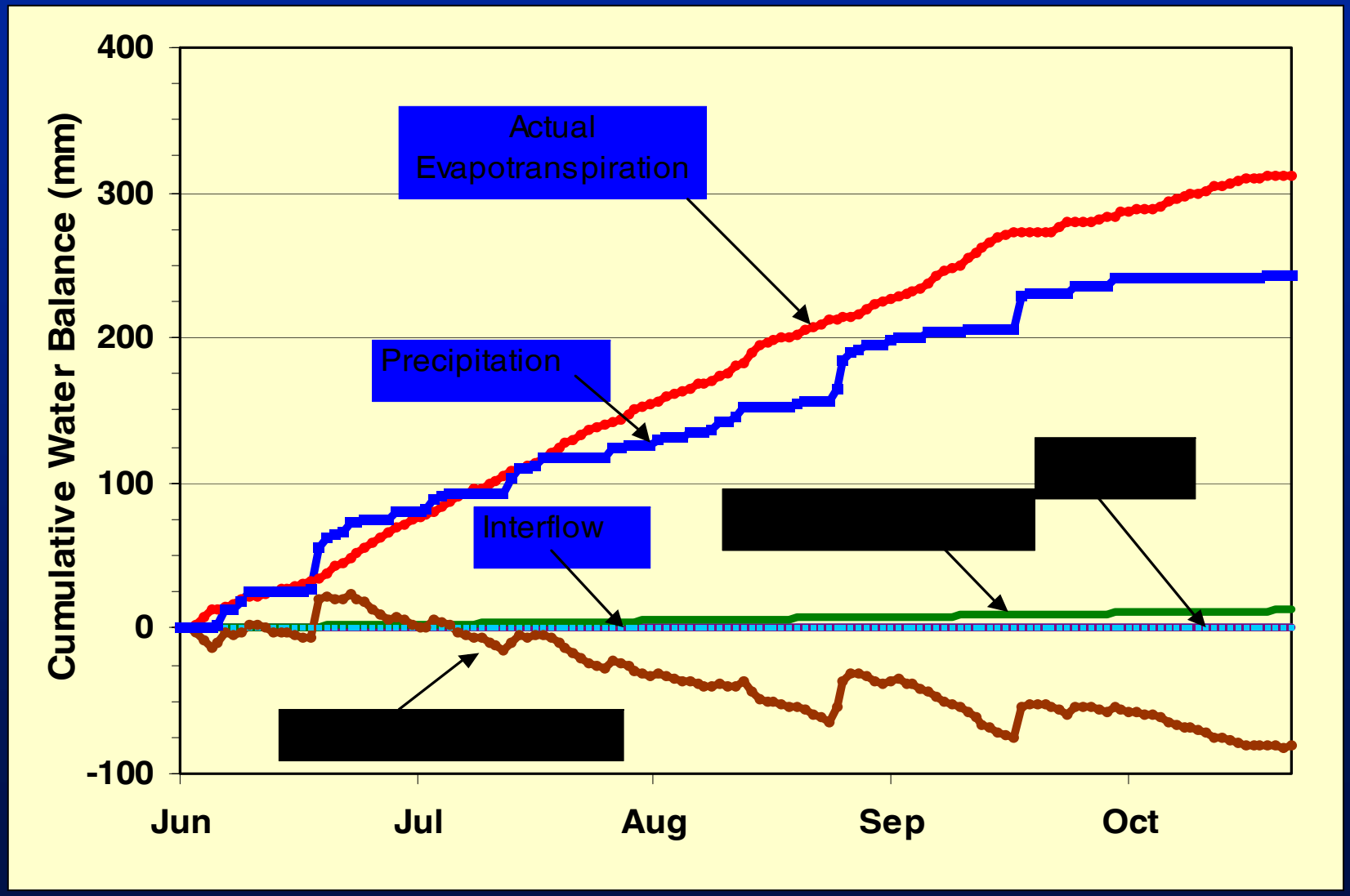
- **Interpretation of Water and Salt Fluxes**
  - **FLOW and STORAGE**
  - **Water and Salt Balance**
  - **Mechanisms**
- **Role of Modelling**
  - **1D and 2D water flux modelling**
  - **Salt flux modelling**

Water Balance Analysis

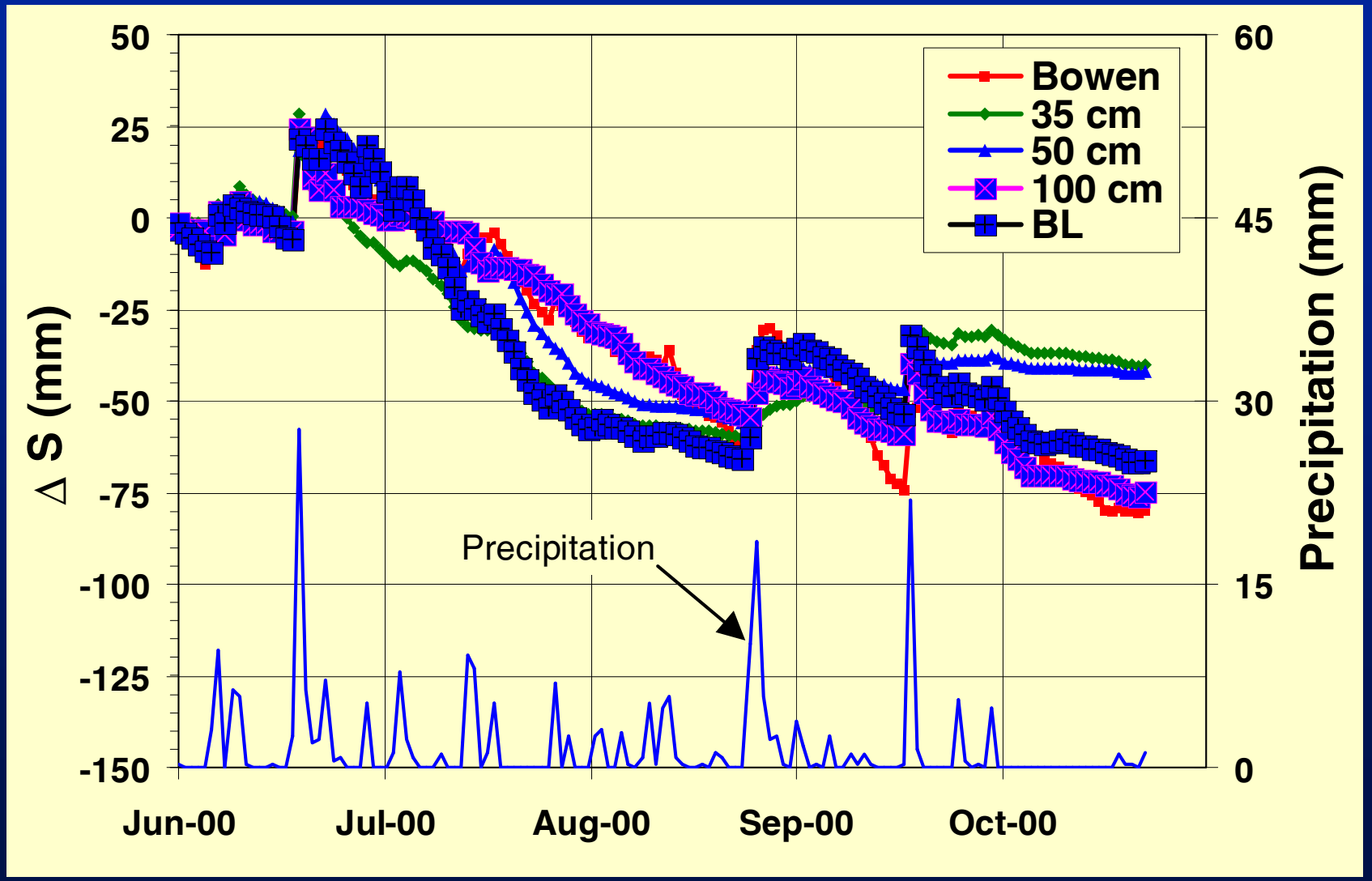


$$\Delta S = PPT - AET$$

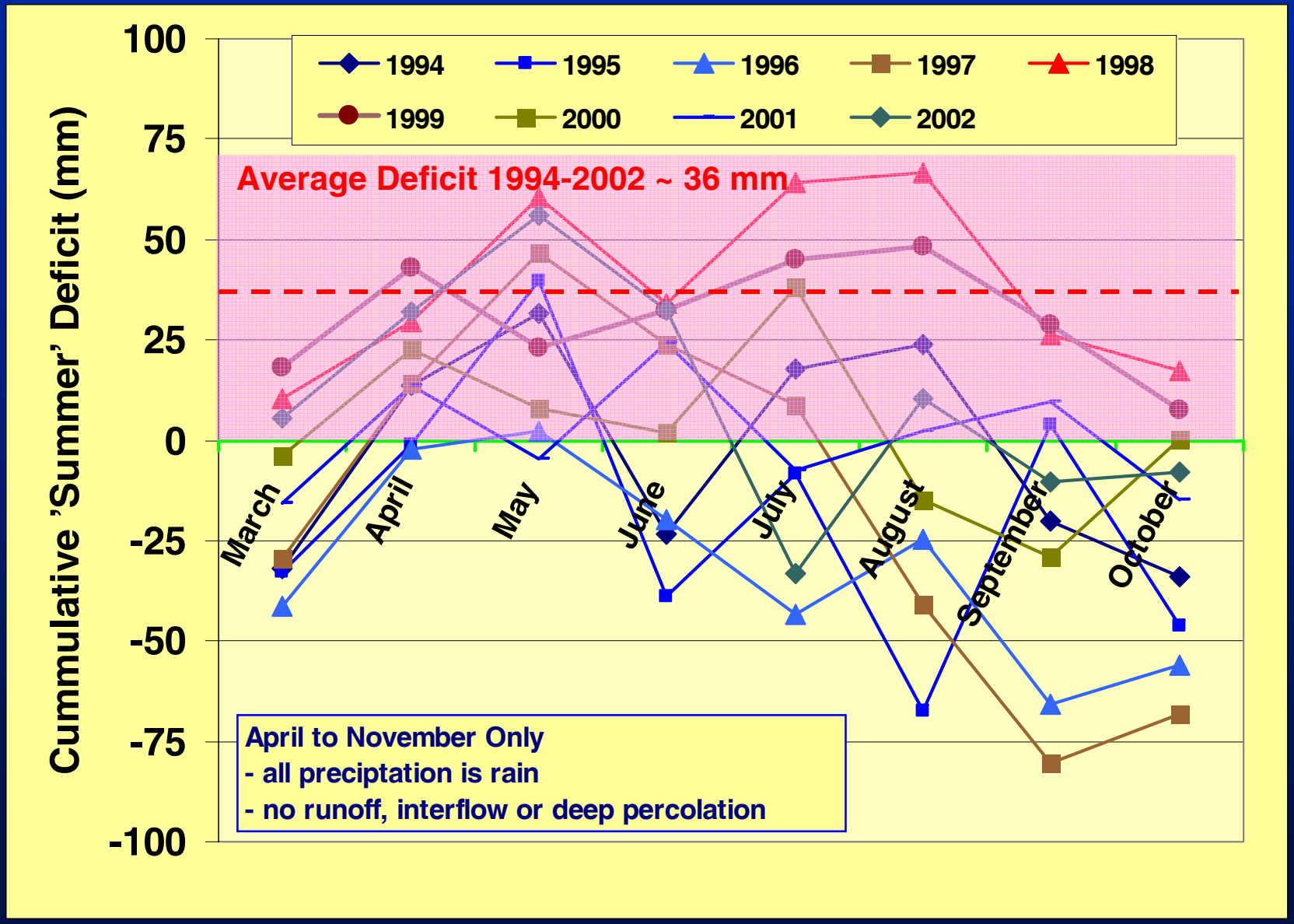
Calculated Change in Storage



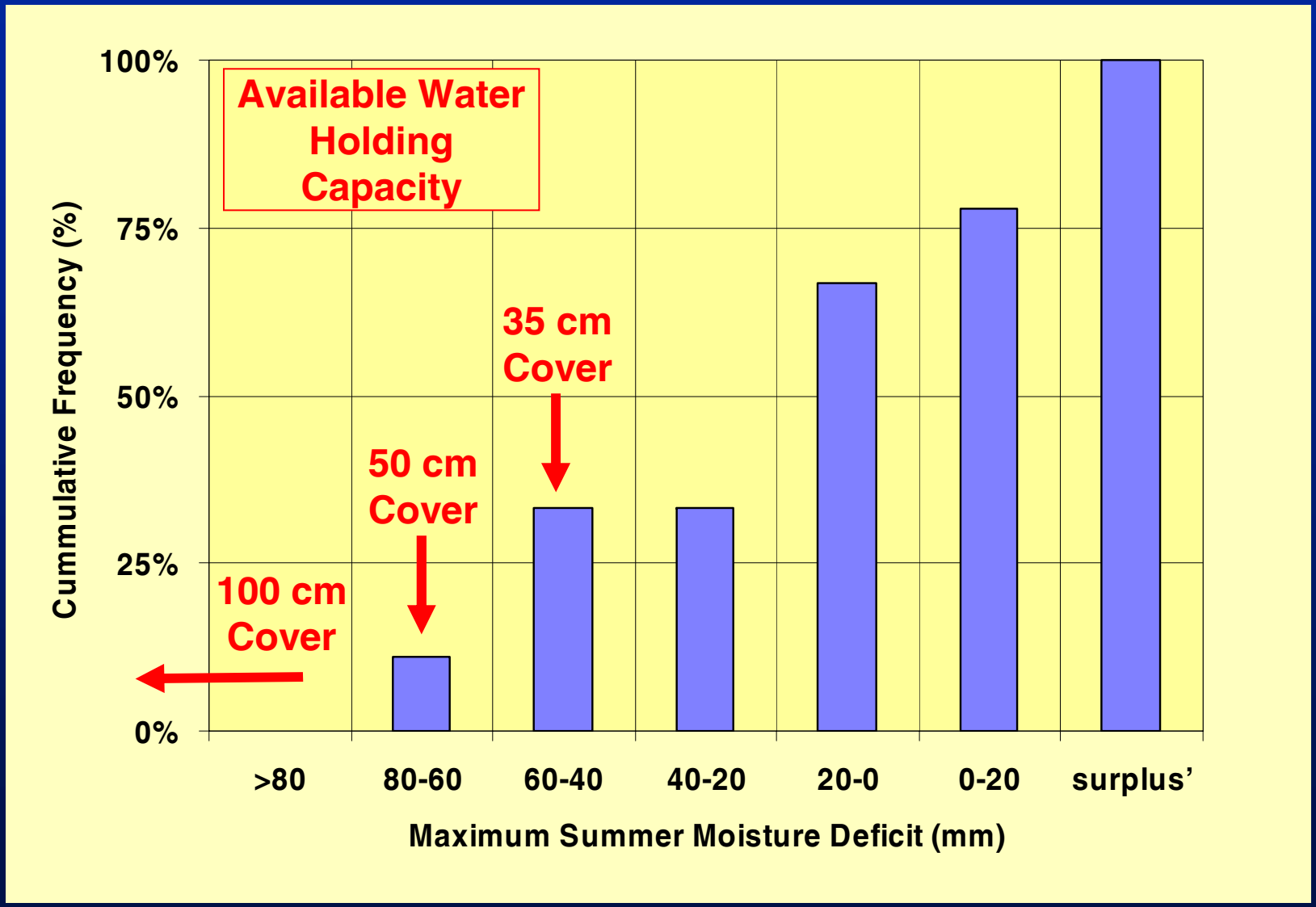
Cover Water Balance



Precipitation / Summer Deficit



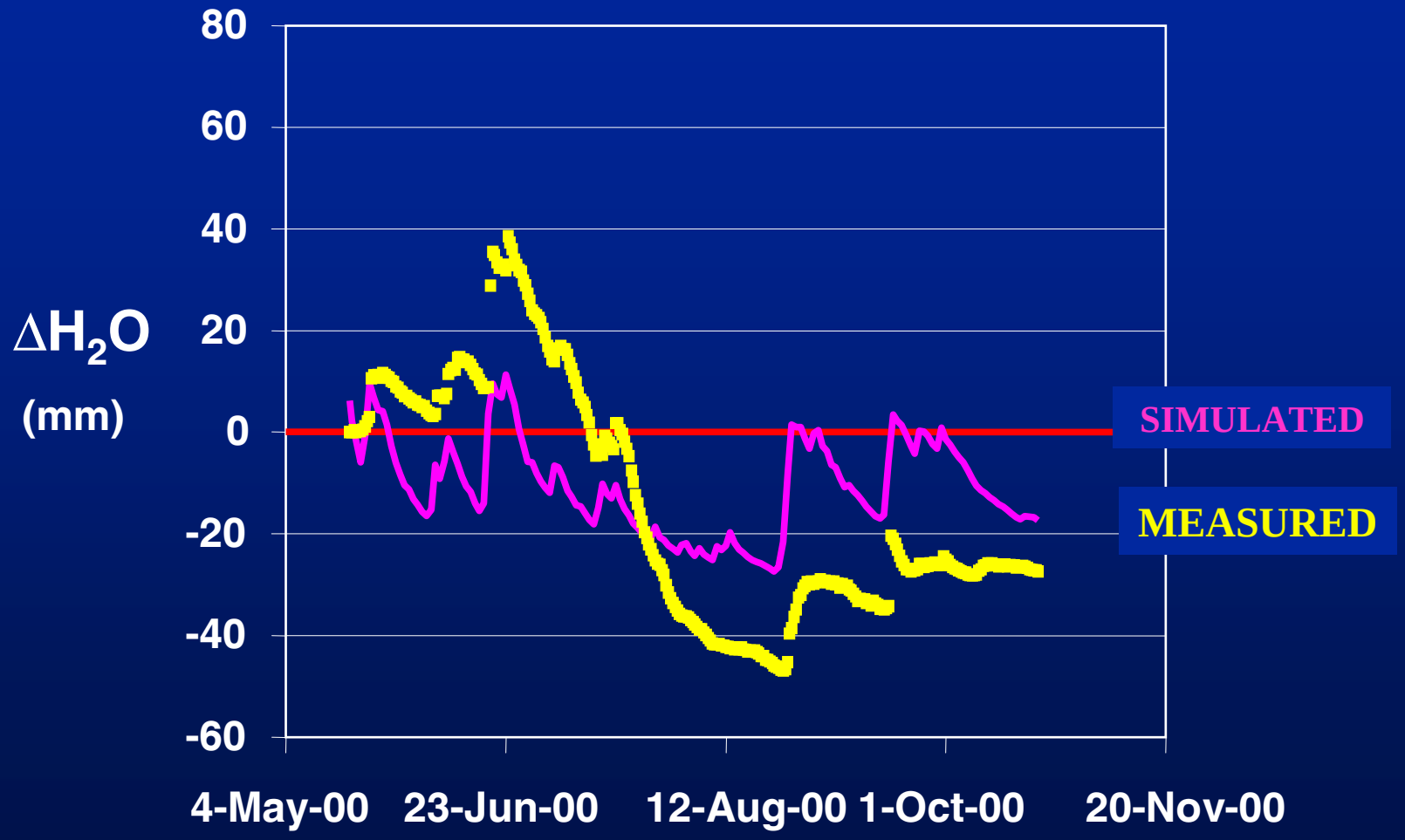
Moisture Deficient Frequency



Soil Moisture Modelling

- **Model Description**
  - **Finite Element models**
  - **Coupled heat and moisture transfer**
    - » **Heat – Conduction / Phase change**
    - » **Moisture – Vapour Diffusion and Darcian Flow**
  - **Atmospheric coupling**
    - » **Transpiration (LAI, root depth, growth limiting suctions)**
    - » **Evaporation (Modified Penman)**
- **1D Modeling (“SOILCOVER)**
  - **Preliminary Interpretation**
  - **Calibration and Sensitivity**
  - **Cover Performance**
  - **Limitations**
- **2D Modelling (“VADOSEW)**
  - **Impact of microtopography**
    - » **On water and salt transport**
  - **Future research**

1D Model
Laboratory Derived Properties

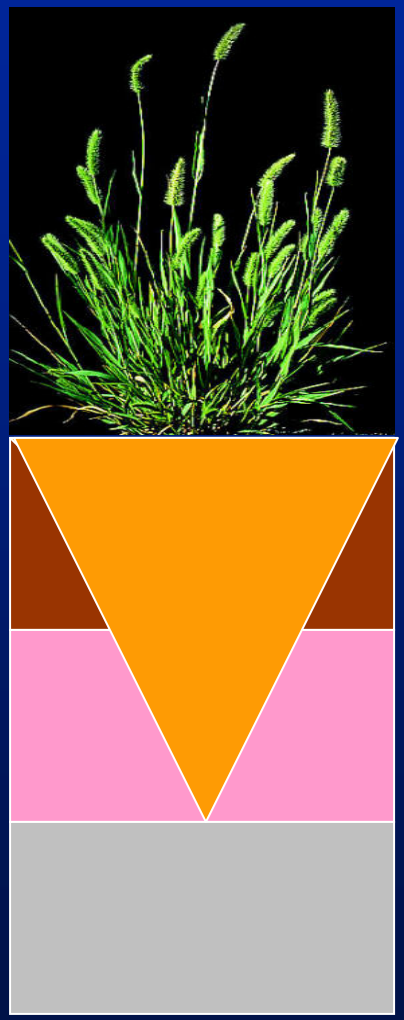


1D Model
Field Derived Properties

1D Model
Field Derived Properties with Vegetation

END OF GROWING SEASON:

First Day of Freezing Temperatures



EMERGENCE:

17 days after Germinations

Germination at 15 ^{o}C

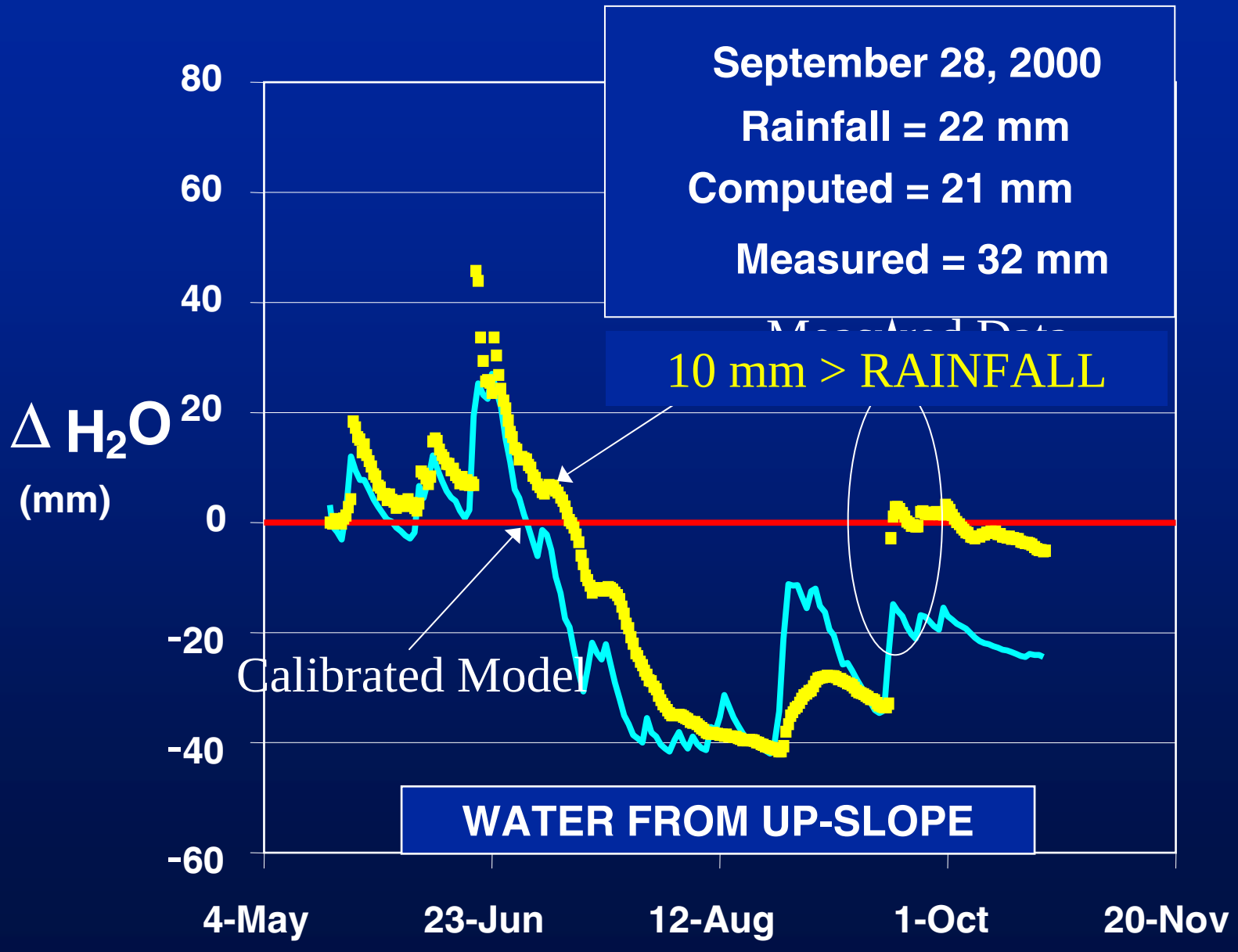
Root Growth:

1 cm/day

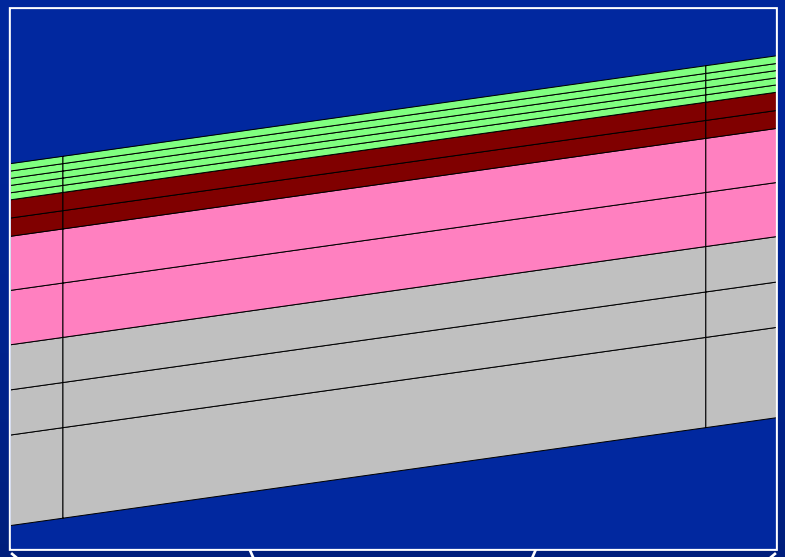
Roots extend to Interface

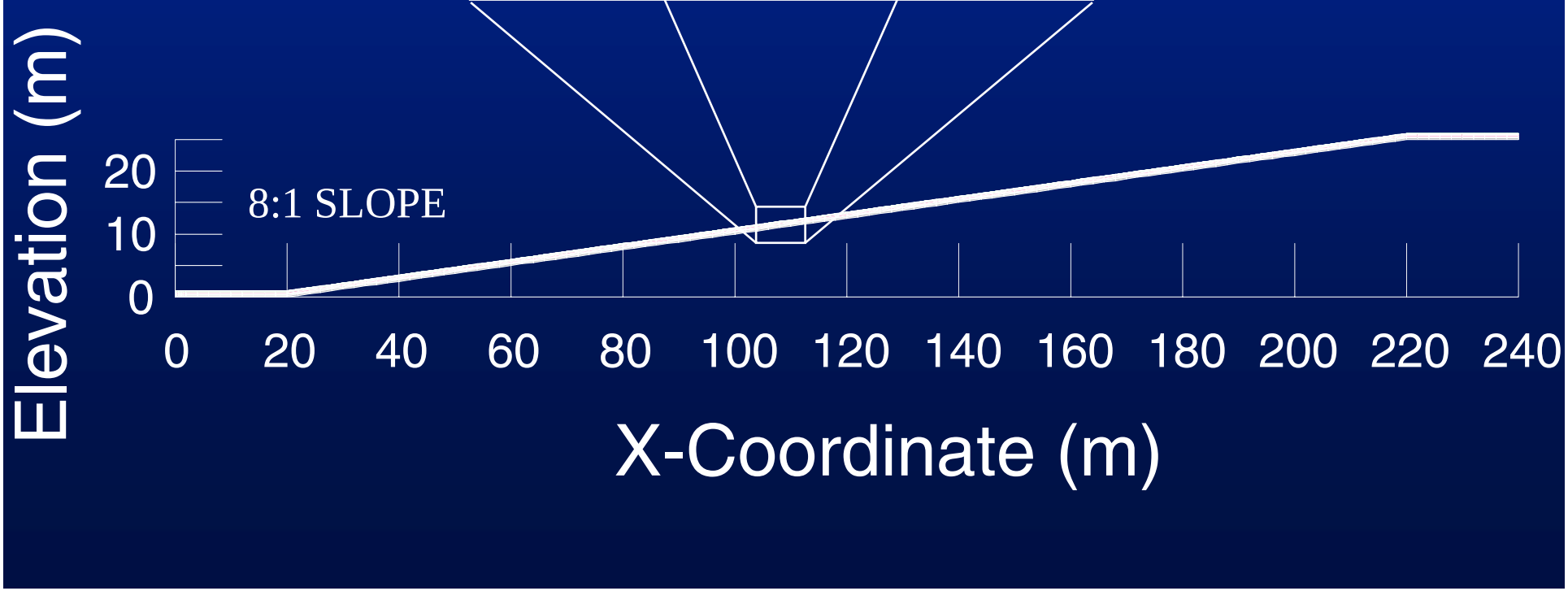
1D Model
Field Derived Properties with Vegetation

LIMITATIONS – D2 Cover Results

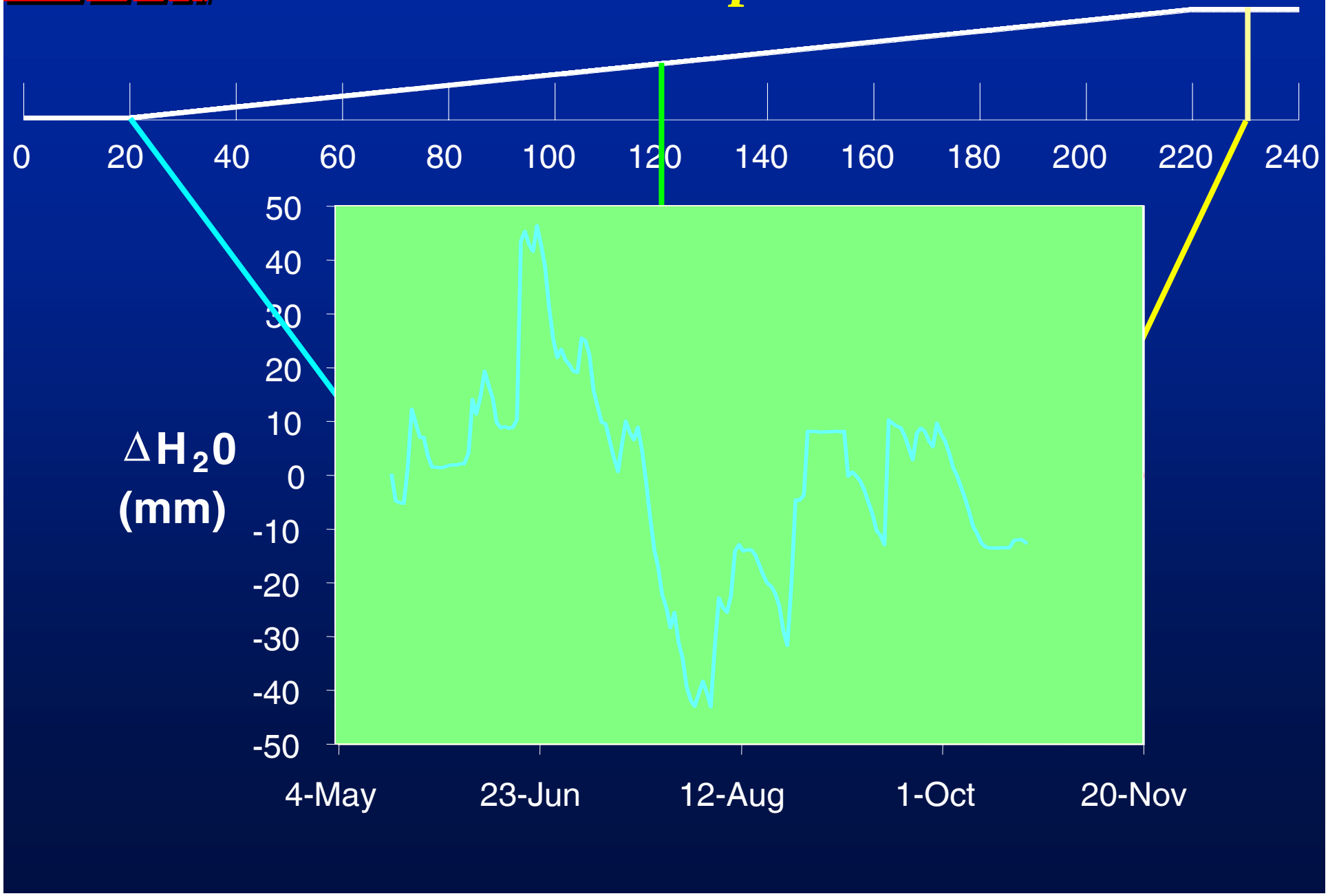


2-D VADOSE – Sloped Mesh

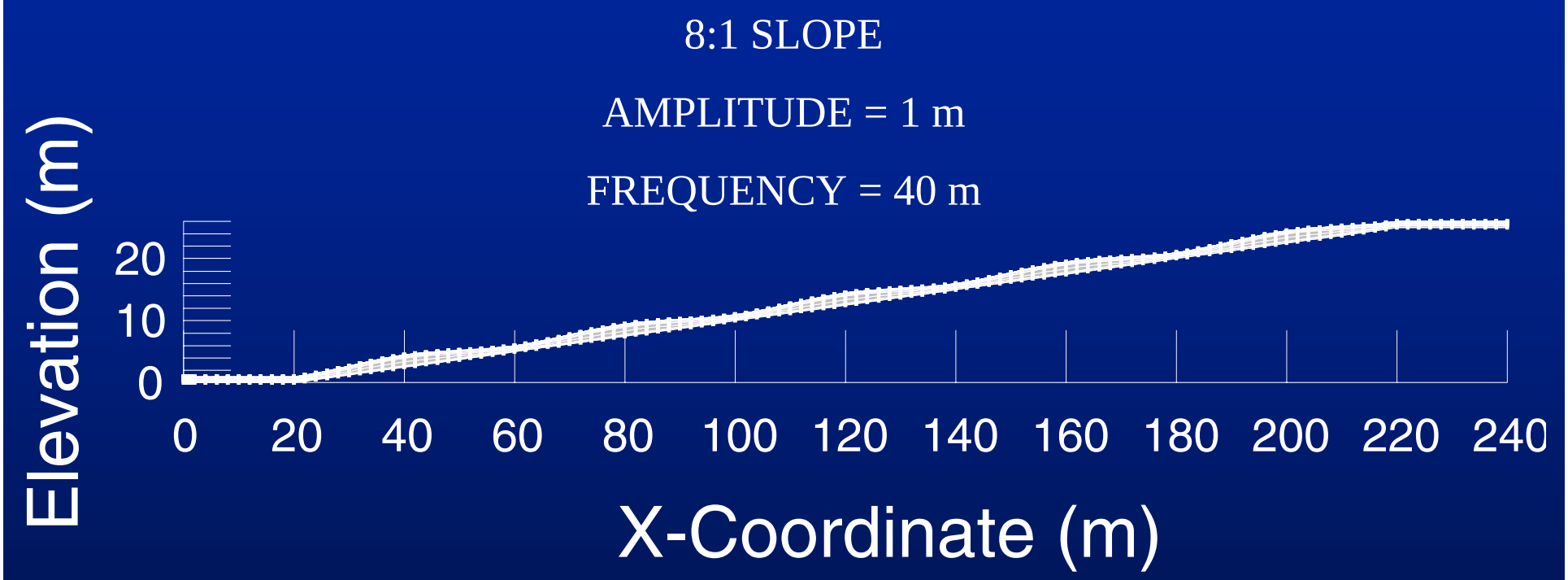




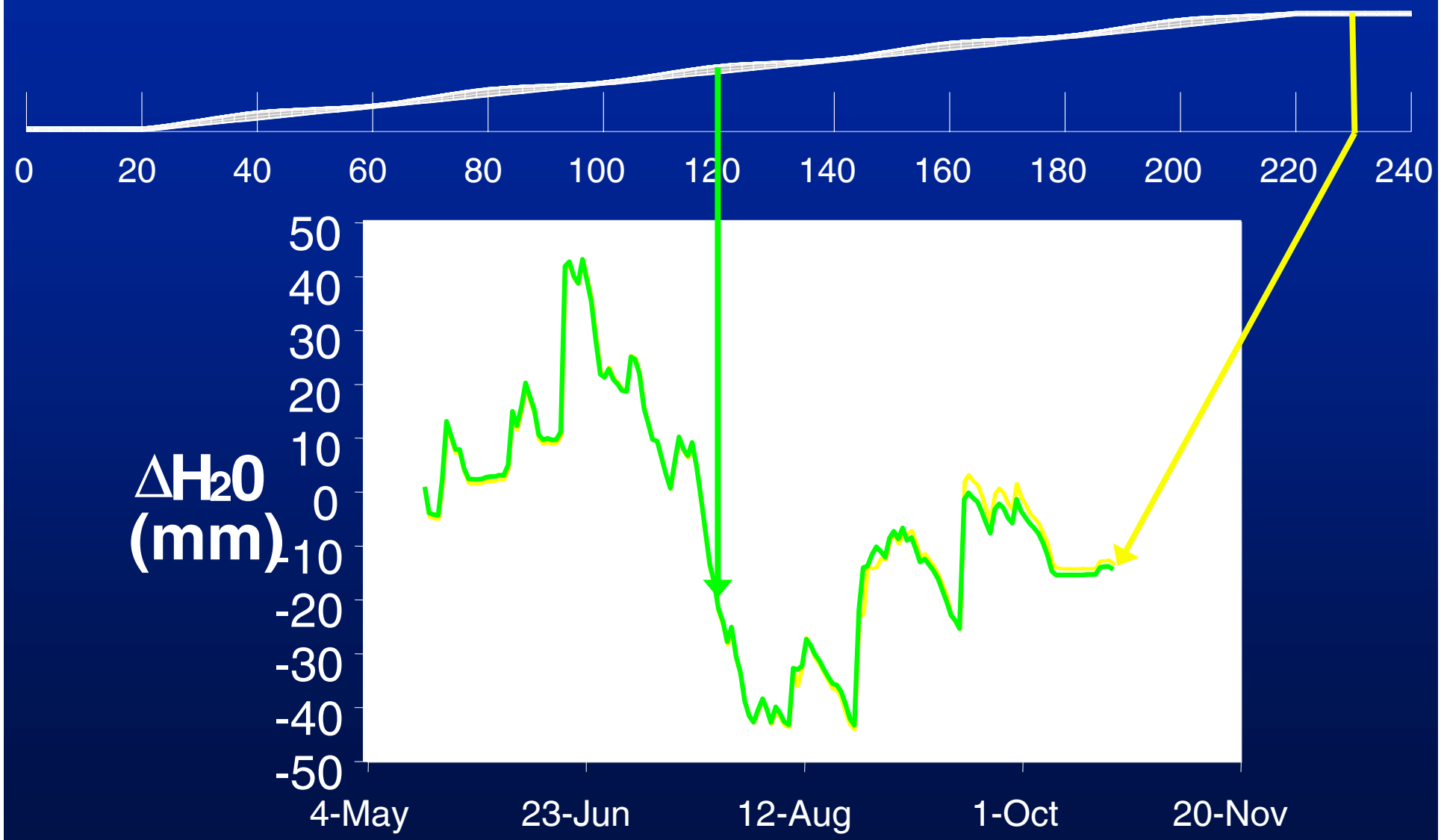
2-D VADOSE – Sloped Mesh Results



2-D VADOSE – Undulating Mesh



2-D VADOSE – Undulating Mesh Results

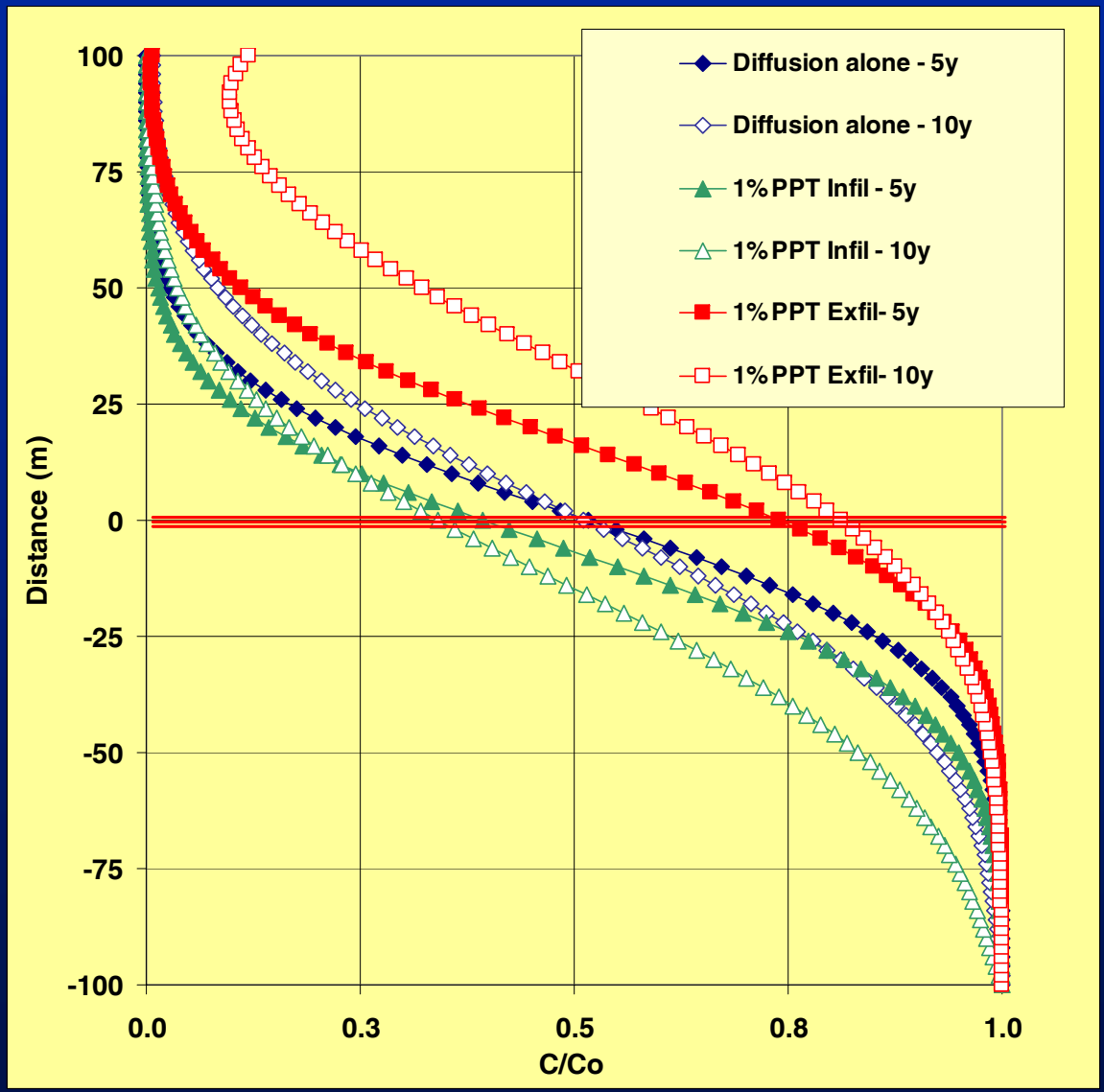


Prediction Concentration Profiles:

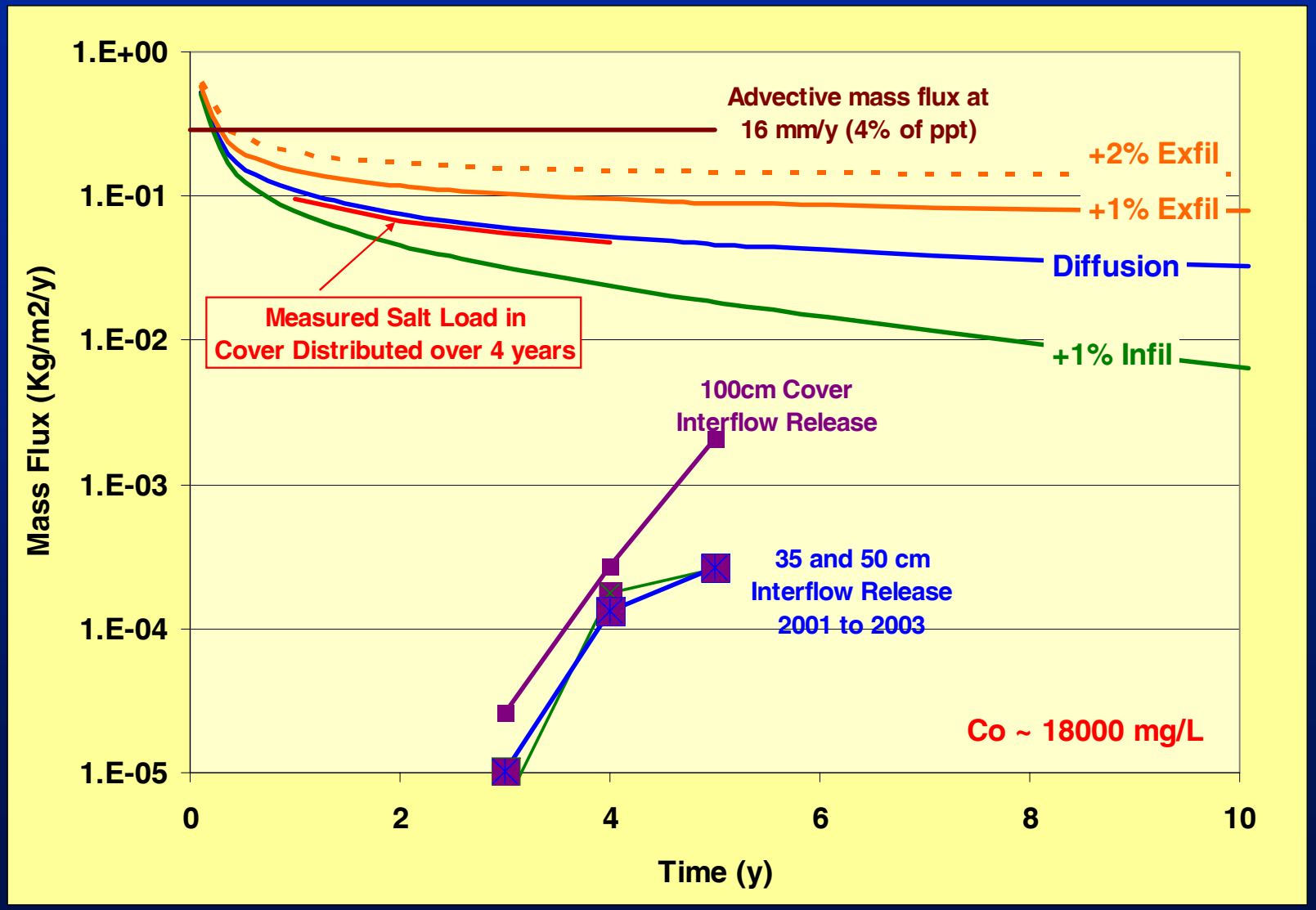
Cases:
1 - Diffusion Alone

2 - 1% PPT Infil

3 - 1% PPT Exfil



S04 Release Rates (Source ~ 18000 mg/L)



Conclusions

- **Monitoring:**
  - **Reliable monitoring methods**
    - **Research and operational monitoring**
- **Measurement:**
  - **Guelph permeameter and Interflow System**
    - **rapid evolution of hydraulic properties in < 5 y**
  - **Geochemistry**
    - **Oxidation of disseminated framboidal pyrite**
    - **Salt transport: vertical diffusion / lateral flushing**
- **Modelling:**
  - **Moisture Migration – 1D Water Balance**
    - **Storage**
      - **Increase –rainfall/snowmelt (spring / fall increase)**
      - **Decrease – transpiration (vegetation response)**
      - **Available Water Holding Capacity verified**
        - **35 cm and 50 cm frequently stressed, 100 cm unstressed**
  - **Calibrated 1D model**
    - **importance of layering**
      - **Peat: infiltration, store, release**
      - **Mineral Soil: minimize preferential flow / matrix salt transport**

Optimal Cover Performance

	FLOW	STORAGE
WATER	• Minimize Runoff – limit erosion – maximize water storage • Control Run-on	• Water Balance – Adequate Available Water Holding Capacity • Storage in Peat – Minimize Preferential flow
SALT	• Encourage Interflow – Salt Leaching – Control of 'discharge' zones	• Minimize Salt Ingress • Source – Limit O_2 ingress • Store until Q-leaching > Q-diffusion – sufficient depth of 'clean' cover – Shale 'Diffusion' not 'advection'

- Apply to 'variability' by encouraging 'diversity'
  - Spatial variability (sloping vs flat areas)
  - Temporal variability (evaluate on 'risk' basis)

Management

- **Incorporation in Industry Guidelines:**
  - **'The Land Capability Classification System for Forest Ecosystems',**
    - **Water balance, In situ SWCC, Available Water Holding Capacity, hydraulic conductivity and soil chemistry data are being incorporated directly into which is the government issued manual for soil reclamation in the Oil Sands Region.**
  - **Landform design Guidelines for the Oil Sand Region**
    - **Background is data and publications from program**
- **Design**
  - **optimize landscape designs & reclamation activities**
  - **direct tech transfer to Sulphur burial design**
- **Landform 'Biography'**
  - **reclamation certification**

THANKYOU!!!

- **Funding**
  - Syncrude Canada Limited
  - NSERC
- **Support - Syncrude**
  - ‘continuing financial, logistical, and moral support’ is gratefully acknowledged
- **People**
  - Special thanks to graduate students and research staff, without which none of this work would have been ever been completed
  - Any ‘success’ in the development of an ‘instrumented’ watershed is due primarily to them.
  - THANKYOU Cal, Rob, Sophie, Dale, Denise, Greg, Marty, Curtis, Sue, …. and so many others

Key Unresolved Questions:

- **How will the water balance for the reclaimed areas be affected by geomorphic conditions (slope angle, slope direction, elevation etc.)?**
- **What impact is the surface water balance having on both water shed performance (surface water) and groundwater formation (hydrogeology) of Bison Hill?**
- **How will the performance of the covers be altered by successional vegetation changes? What impact will this will have on hydrology and wetland formation?**
- **What are the rates and speciation of mobile 'salts' that are being released as a result of shale oxidation? What are the release pathways and transport rates for these salts?**
- **Will physical (soil structure/moisture availability) or chemical (nutrient availability/ soil chemistry) conditions control forest growth within reclaimed areas?**

Matrix of 'Process' Questions:

	Water Distribution/Migration	Salt Distribution/Migration
Surface (Cover)	• 'Dry' Hydrology – 1D water balance – 2D/3D water shed modeling – Micrometeorology – Soil evolution/soil structure – Influence of vegetation • Wetlands Hydrology – Surface water/groundwater interaction	• 'Dry' Hydrology – Mechanisms of salt movement through cover » 1D - upward into cover » 2D - down slope migration • Wetlands Hydrology – Biogeochemical evolution – Surface water /groundwater interaction
Sub surface	• Hydrogeology – Rate of rise of 'water table' – 3D hydrogeologic model – Mapping of groundwater recharge/discharge	• Geochemistry – Oxidation of shale – Rates and magnitude of salt generation – Effect of salt leaching

Key Issue

- **Ecosystem development, water balance, and salt migration are intrinsically coupled and integrated over a complex multi-dimensional pile geomorphology.**
  - **Salt (dissolved chemical constituents) and Water Balance**
- **Significance – these processes control...**
  - **Ecosystem development (rate and target)**
  - **Surface and subsurface releases to mine site hydrology**
  - **Impact downstream wetlands**

Epilogue – The Journey Continues…

- **Jim Hendry**
  - **Quantifying Geochemical Reactions in Mine Waste Piles**
- **Sean Carey**
  - **Measurement and Modeling of Evapotranspiration**
- **Ahmet Mermut, Lee Barbour and Ken Van Rees**
  - **Salt Profiling and Redistribution within Soil Covers**
- **Amin Elshorbagy**
  - **Watershed Modeling of South Bison Hill**
- **Bing Si**
  - **Impact of Multi-dimensional Preferential Flow and Interflow on Salt Leaching**
- **Lee Barbour**
  - **Hydrogeology of South Bison Hill**
  - **Impact of Cover Geomorphology on Water and Salt Transport**
  - **Structure evaluation by Guelph Permeameter testing**