THE pebble PARTNERSHIP

Groundwater Flow Model



November 28, 2007

Rod Smith, Hugh McCreadie
WMC

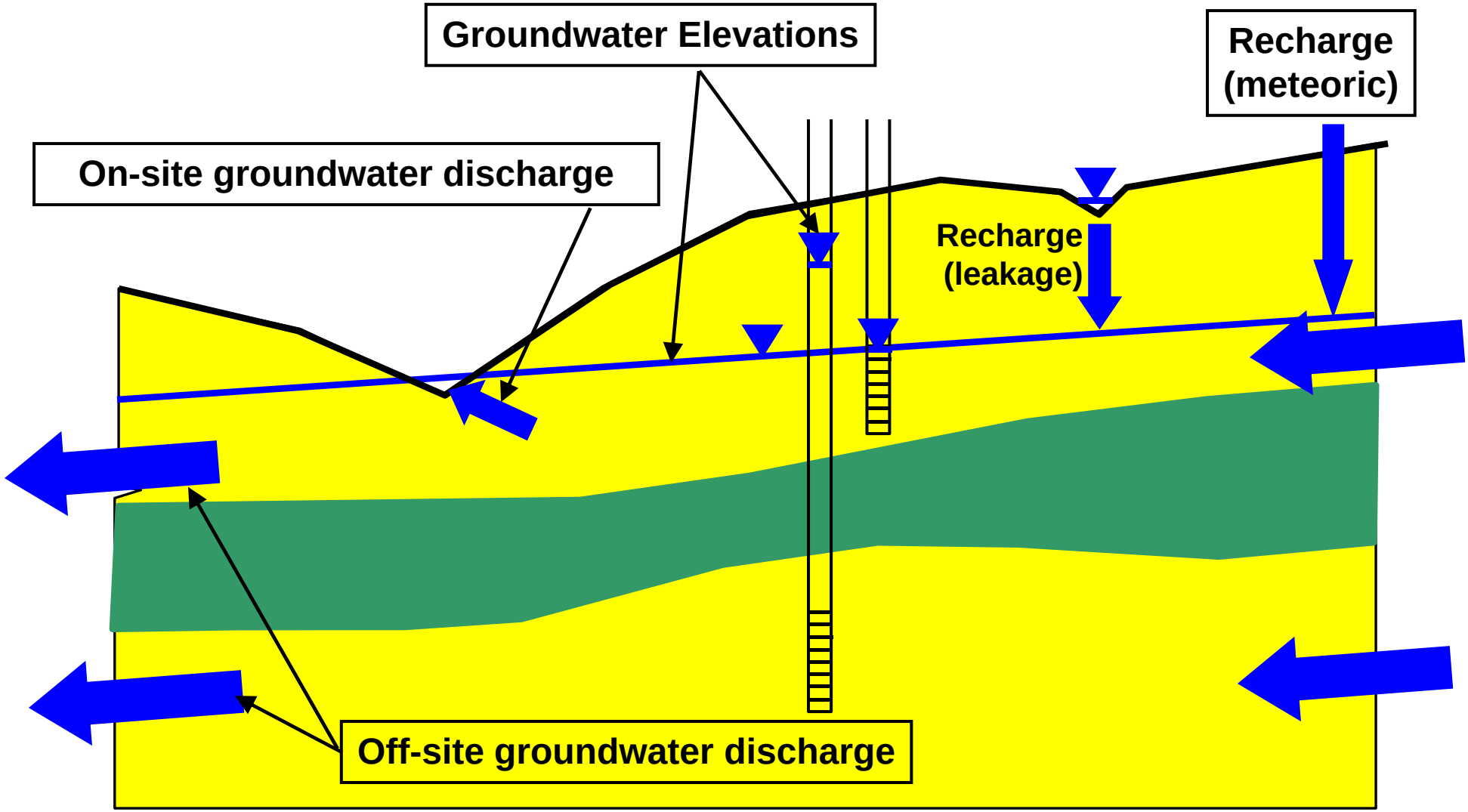
Agenda

1. Modelling Objectives
2. Conceptual Model
3. Integrated Modelling Approach
4. Input Parameters
5. Calibration Process
6. Model Assessment
7. Summary
8. Where we go from here!

Objective of modelling for EBD

- Develop a model that simulates baseline conditions

Baseline Conditions



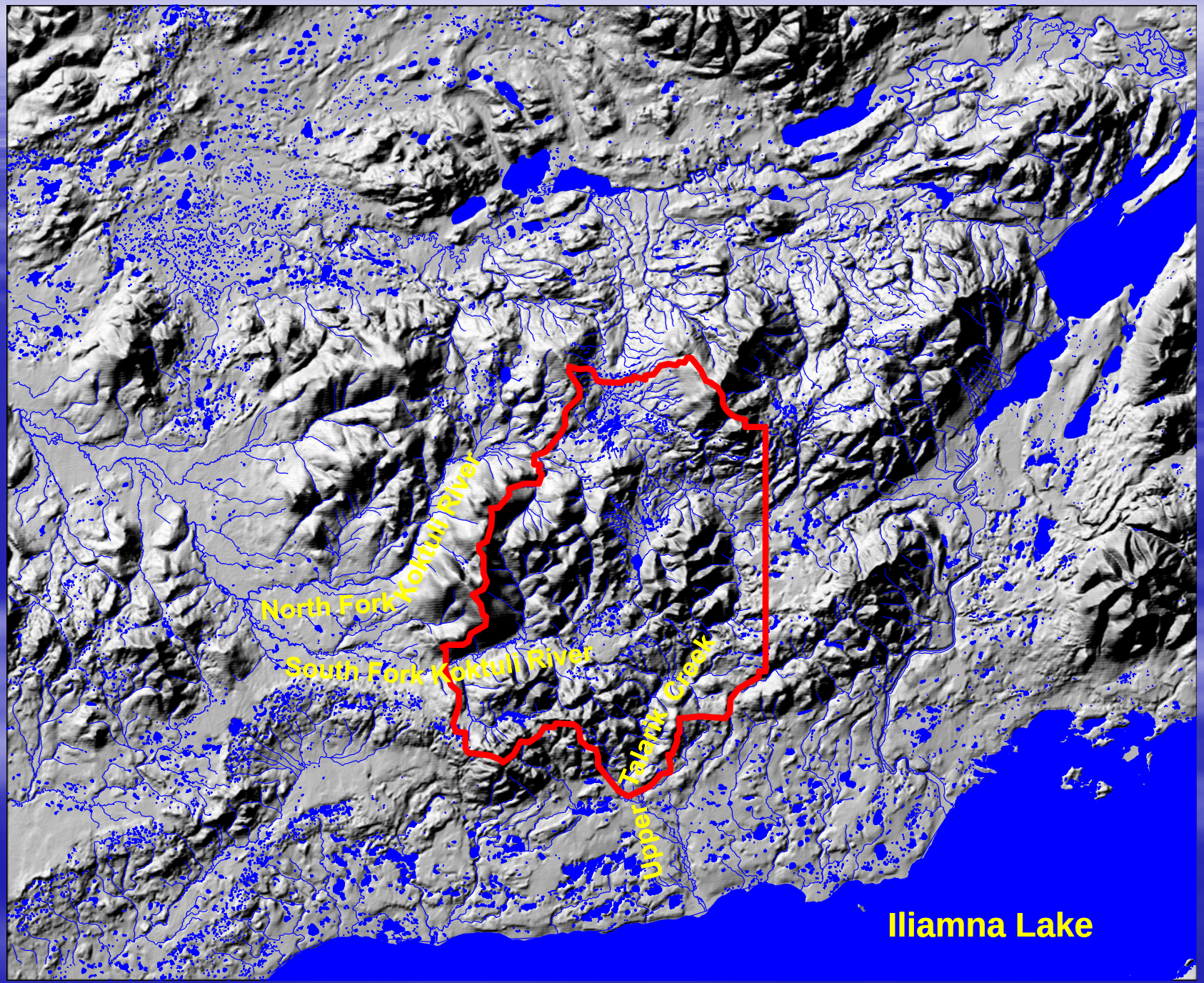

Groundwater Discharge

Agenda

1. Modelling Objectives
2. Conceptual Model
3. Integrated Modelling Approach
4. Input Parameters
5. Calibration Process
6. Model Assessment
7. Summary
8. Where we go from here!

THE pebble PARTNERSHIP

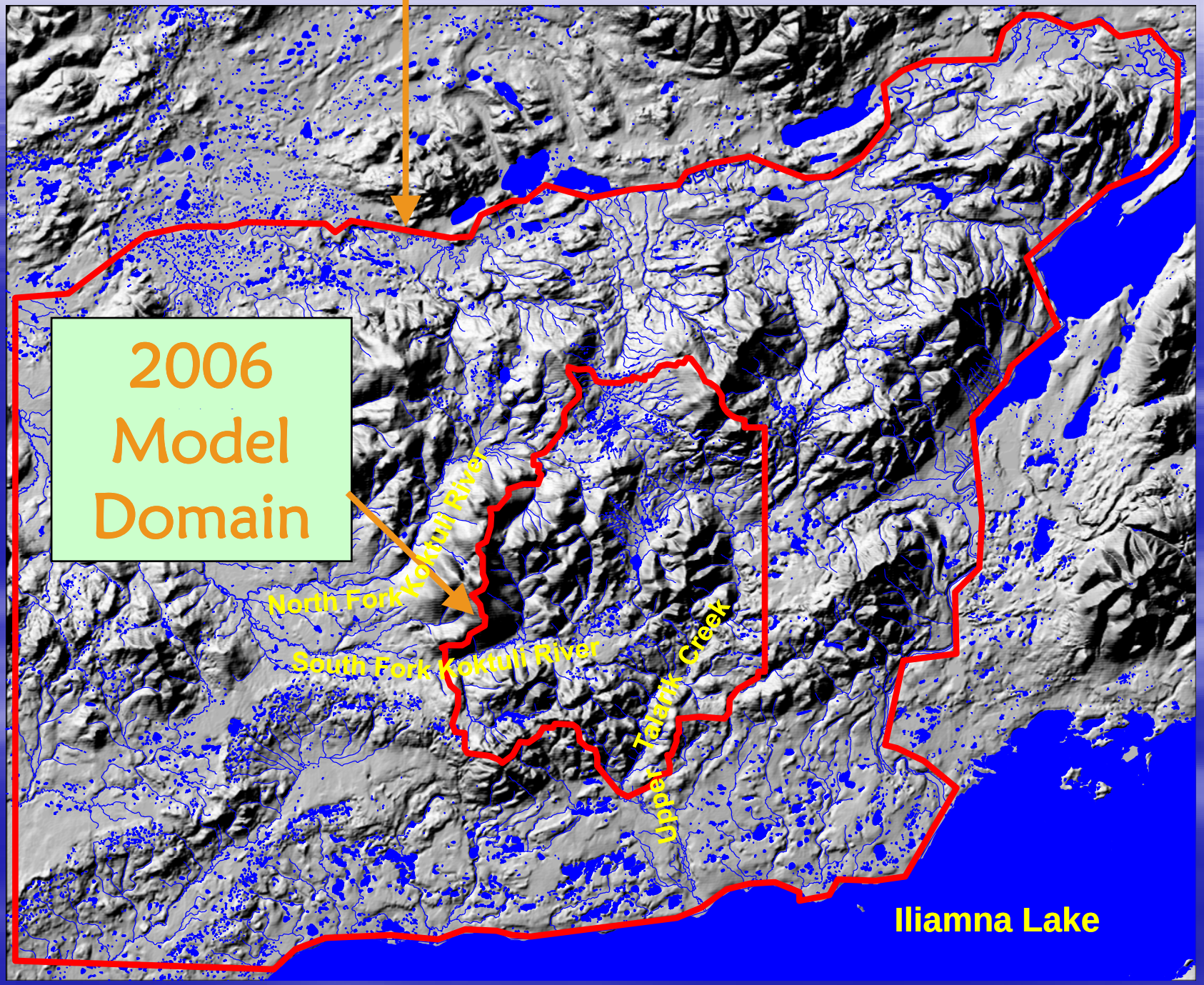
2006 Model Domain



WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

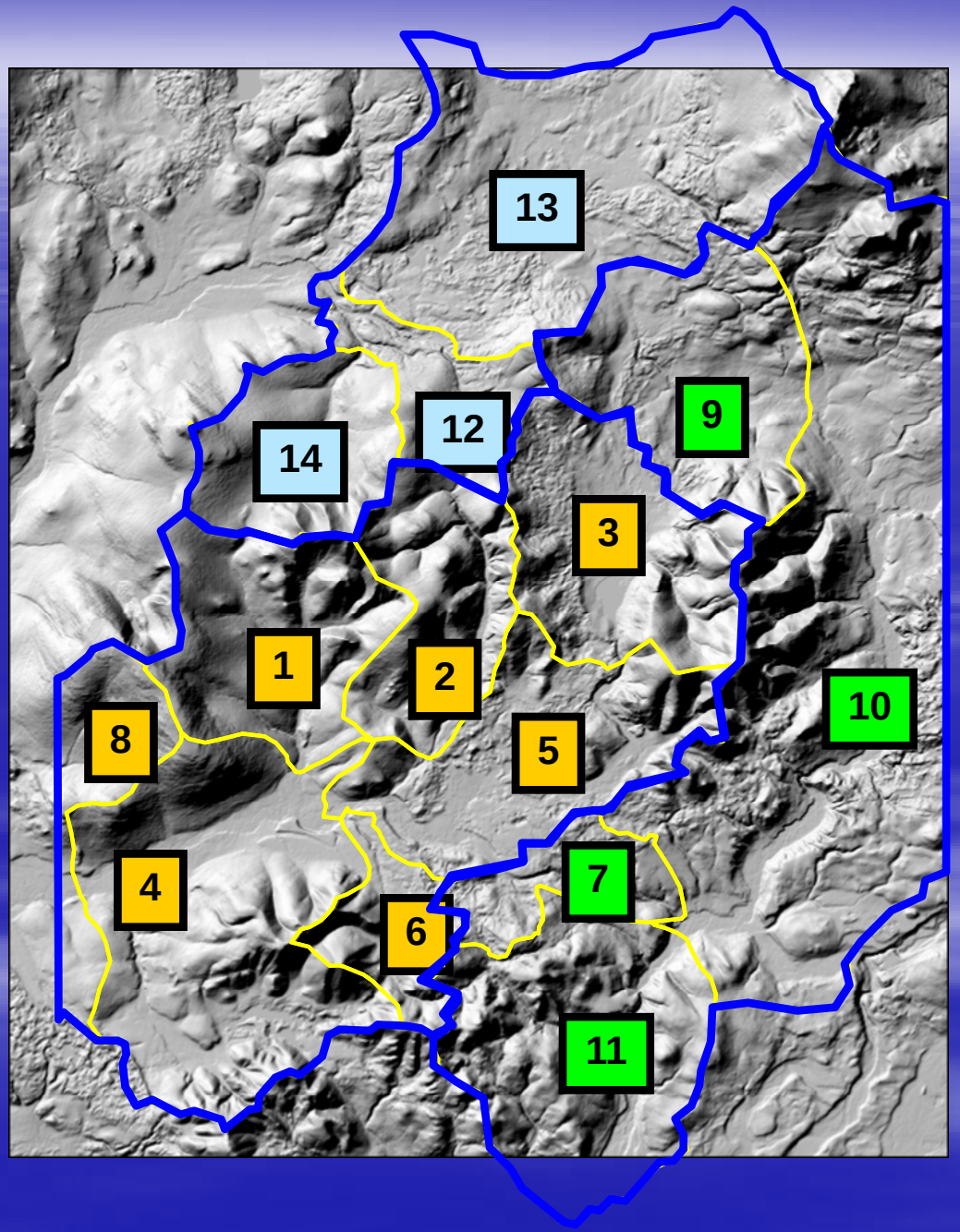
THE pebble PARTNERSHIP

2007 Model Domain

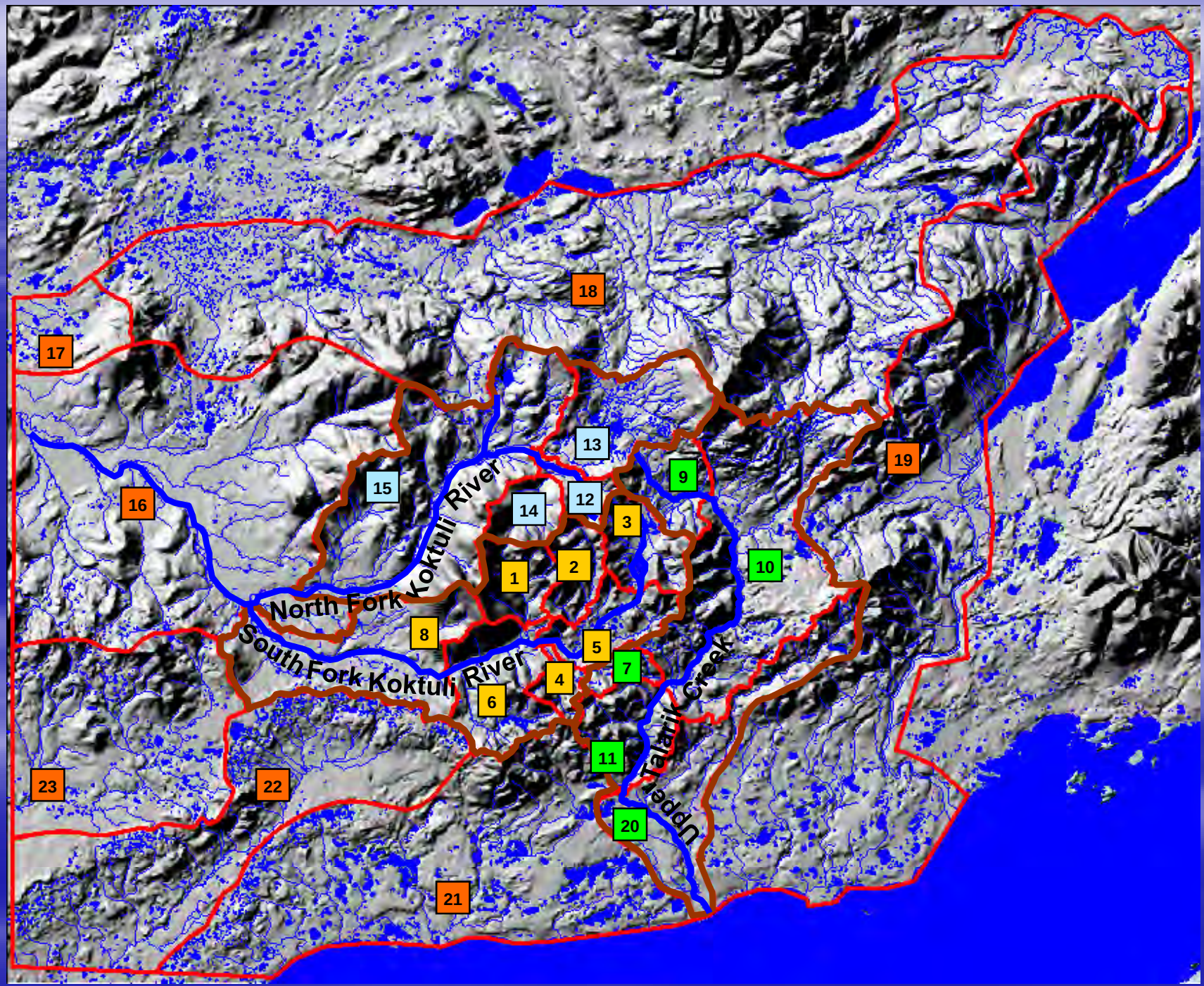


WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

2006 model Sub-watersheds

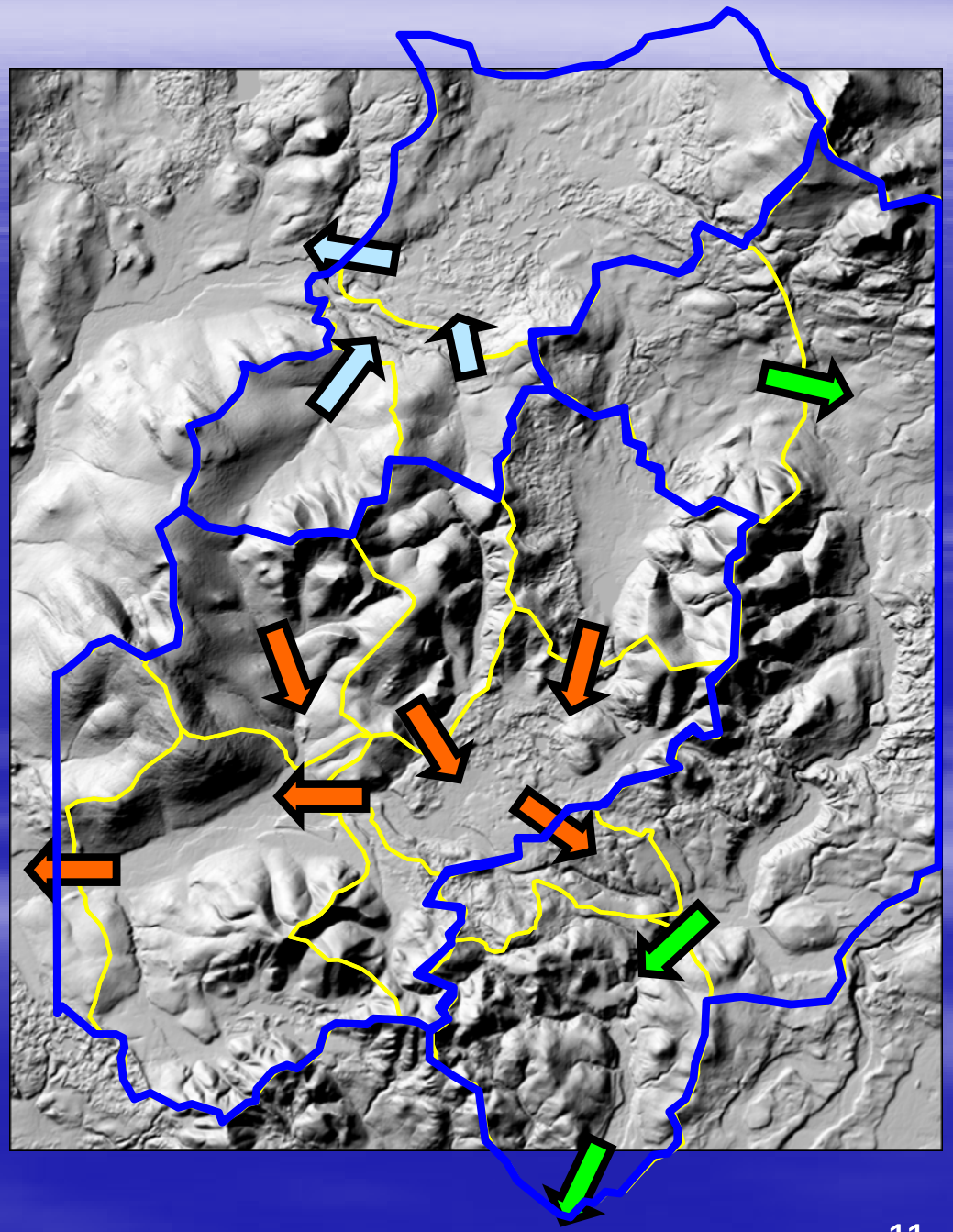


2007 model: Sub-watersheds



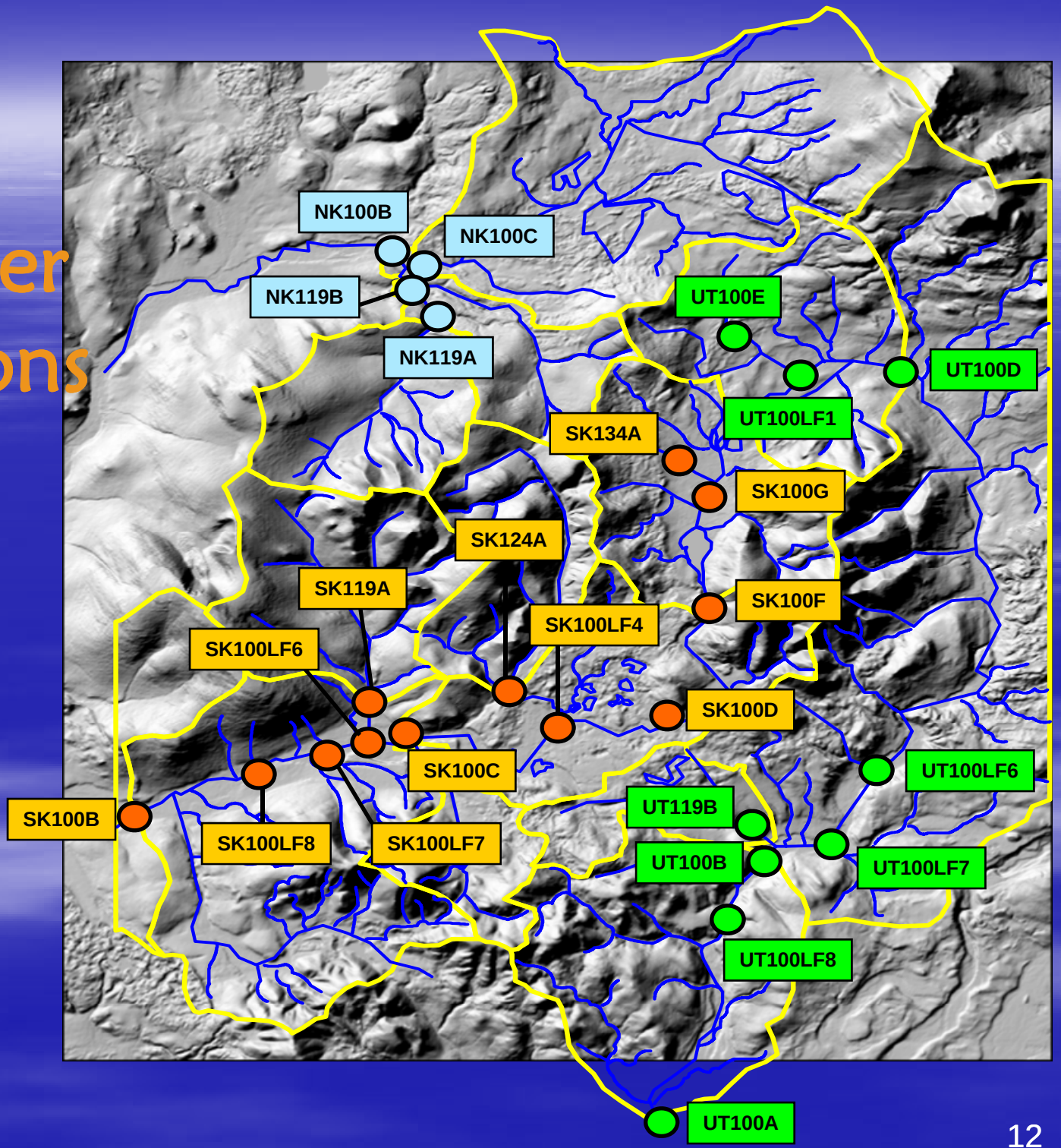
THE pebble PARTNERSHIP

Inter-watershed flow for water balance

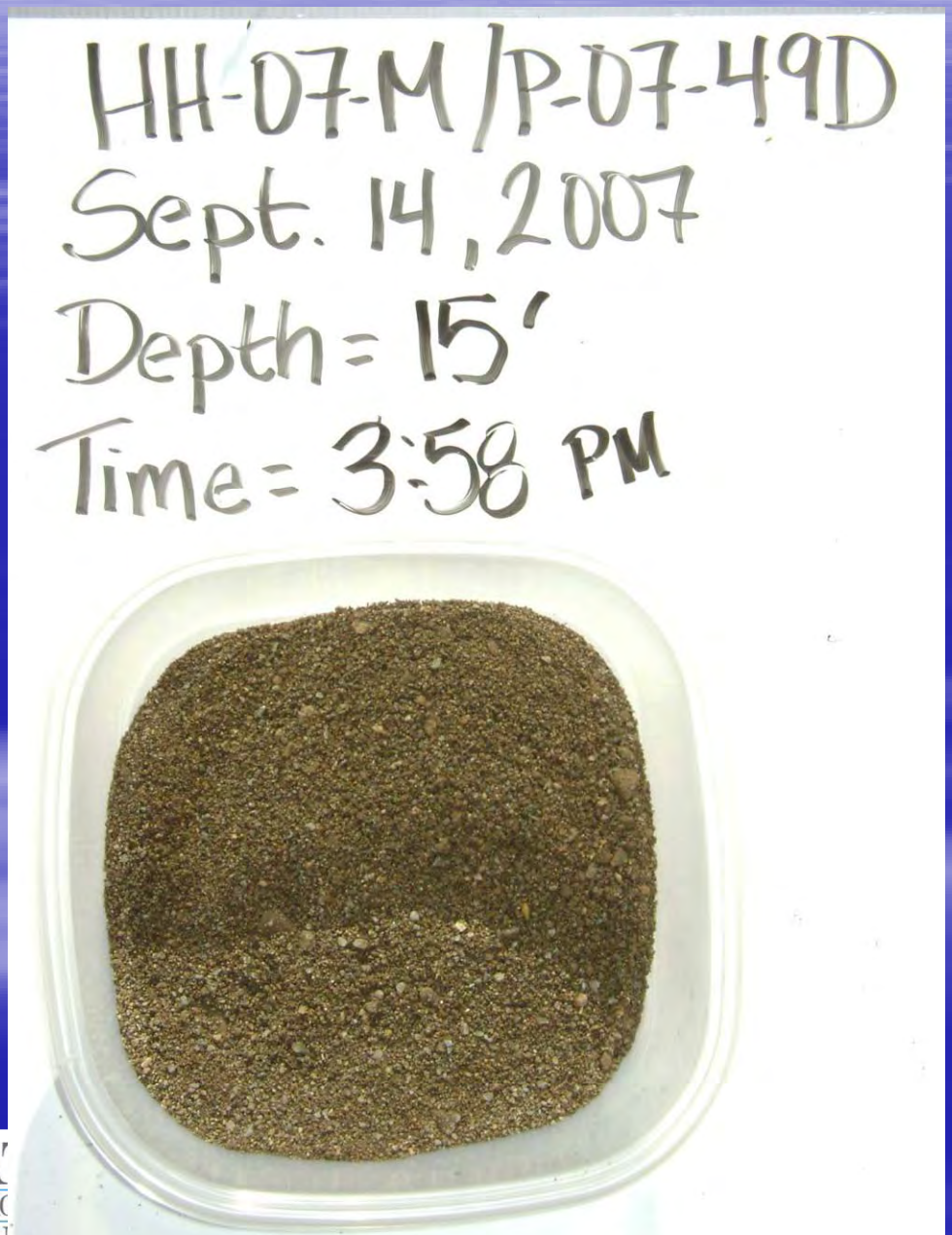


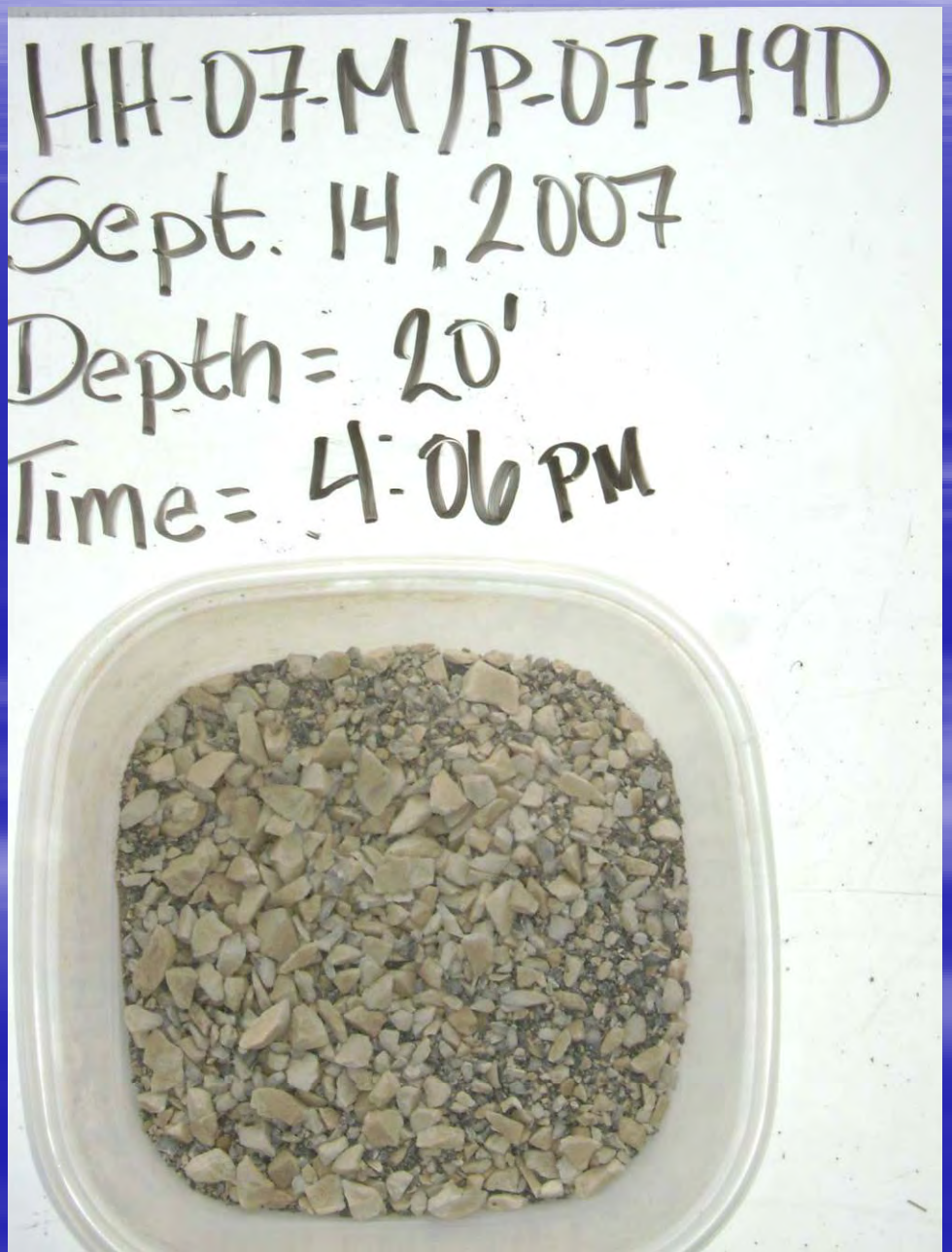
WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

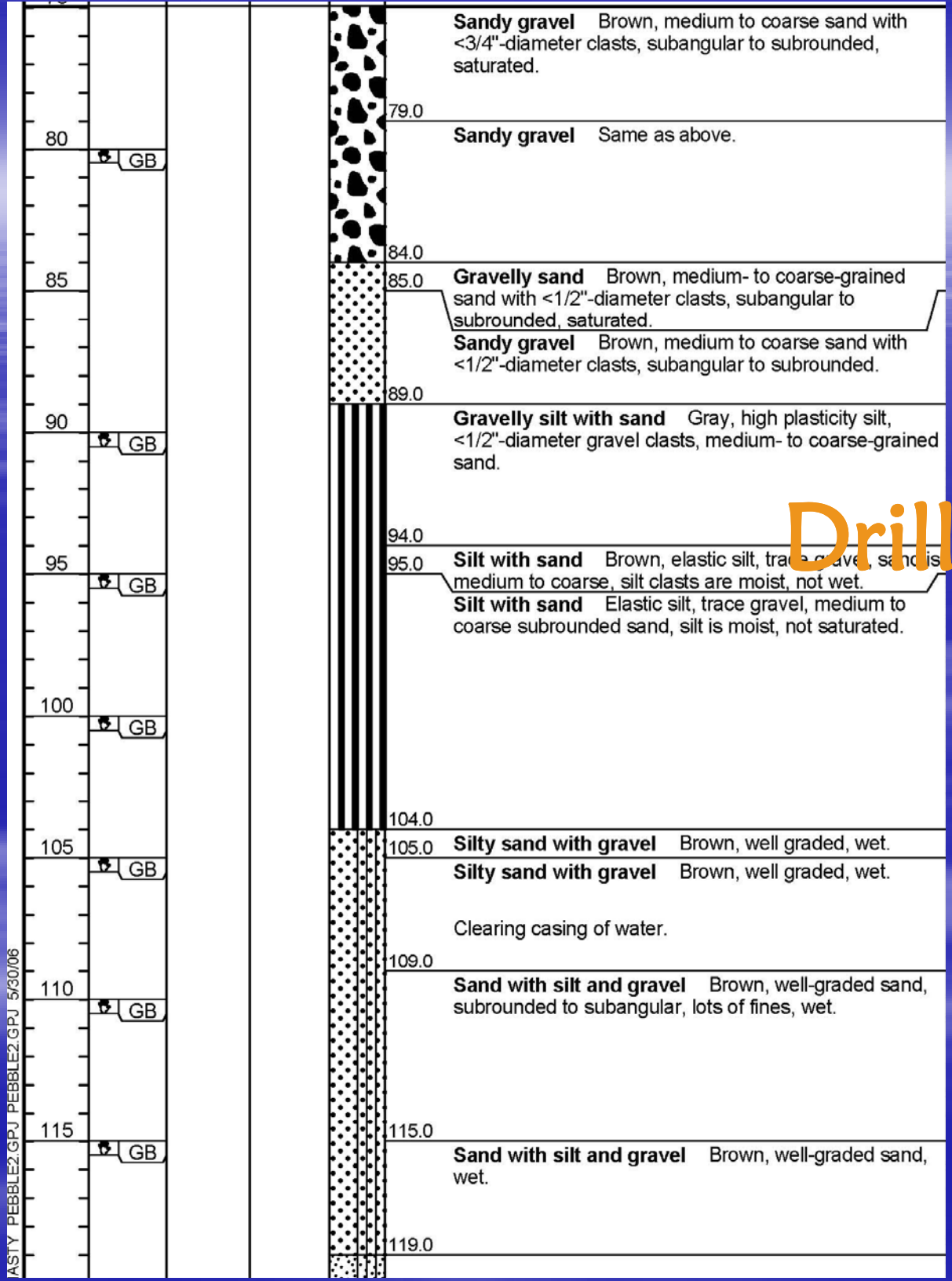
Surface water gaging stations



Geology Samples



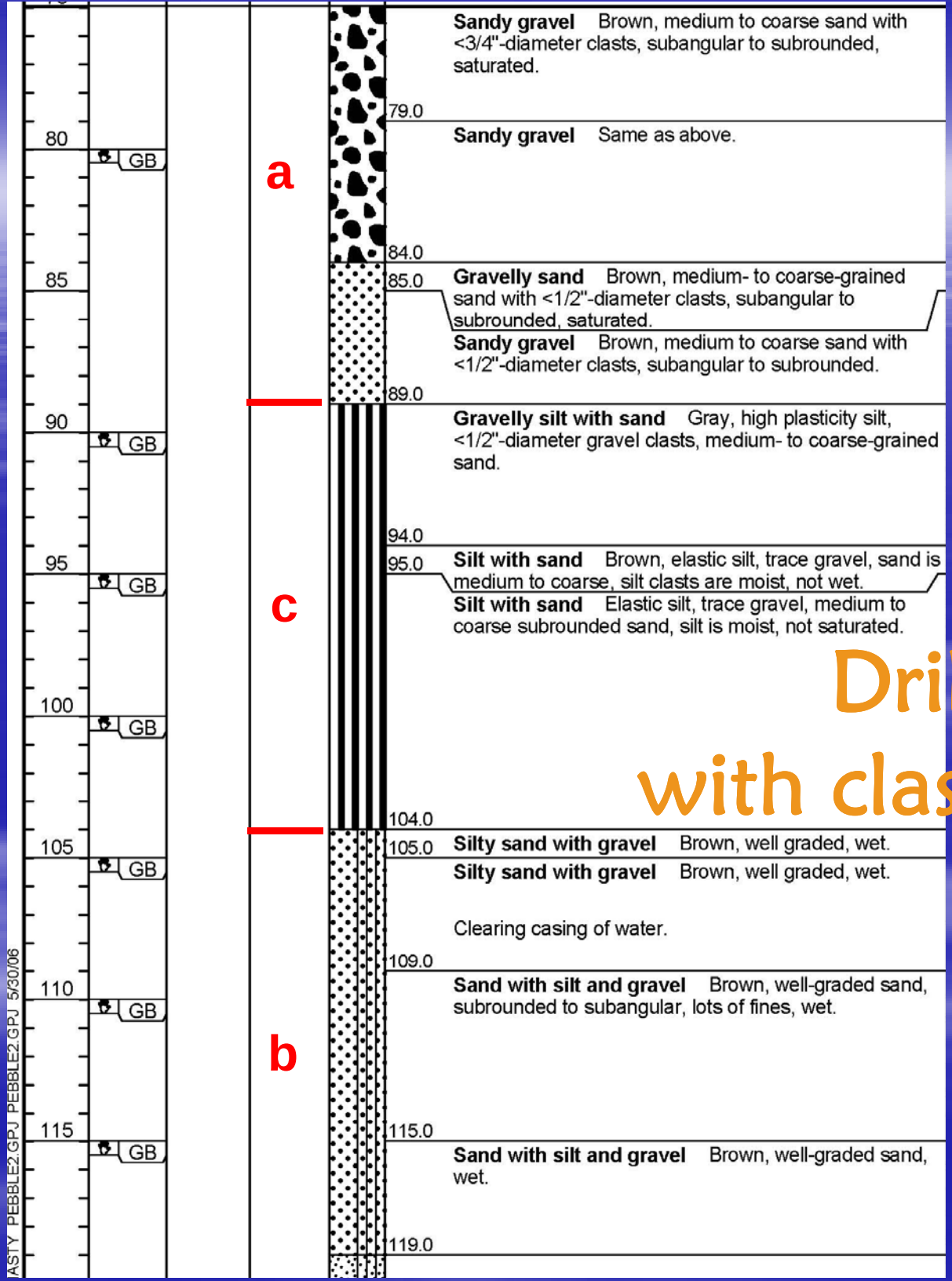




Geology
Drill hole log

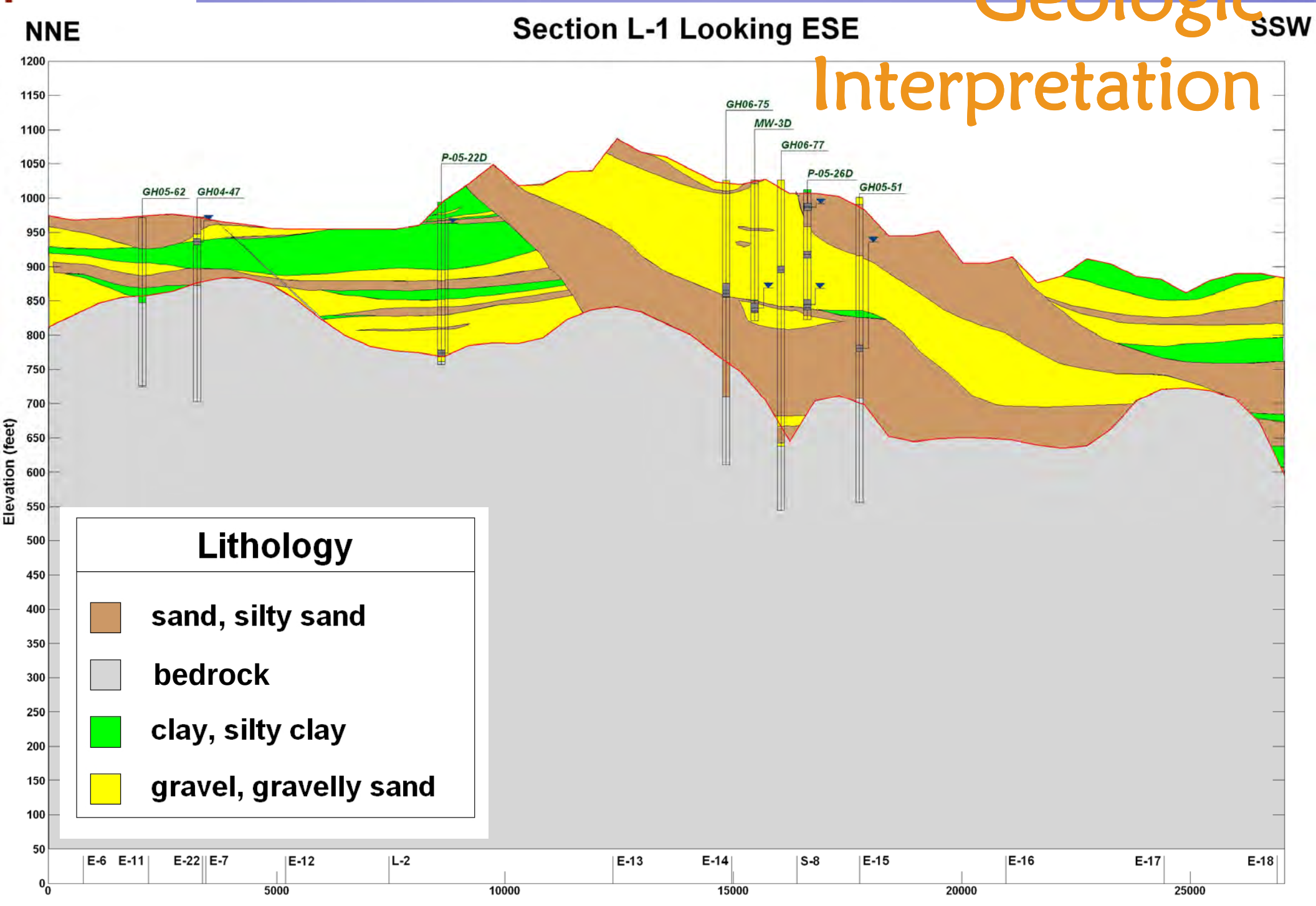
Geology simplification

- Geologic type a:
  - Clean gravels
  - major aquifers
- Geologic type b:
  - Silty materials with sands
  - minor aquifers
- Geologic type c:
  - Primarily silt
  - aquitards

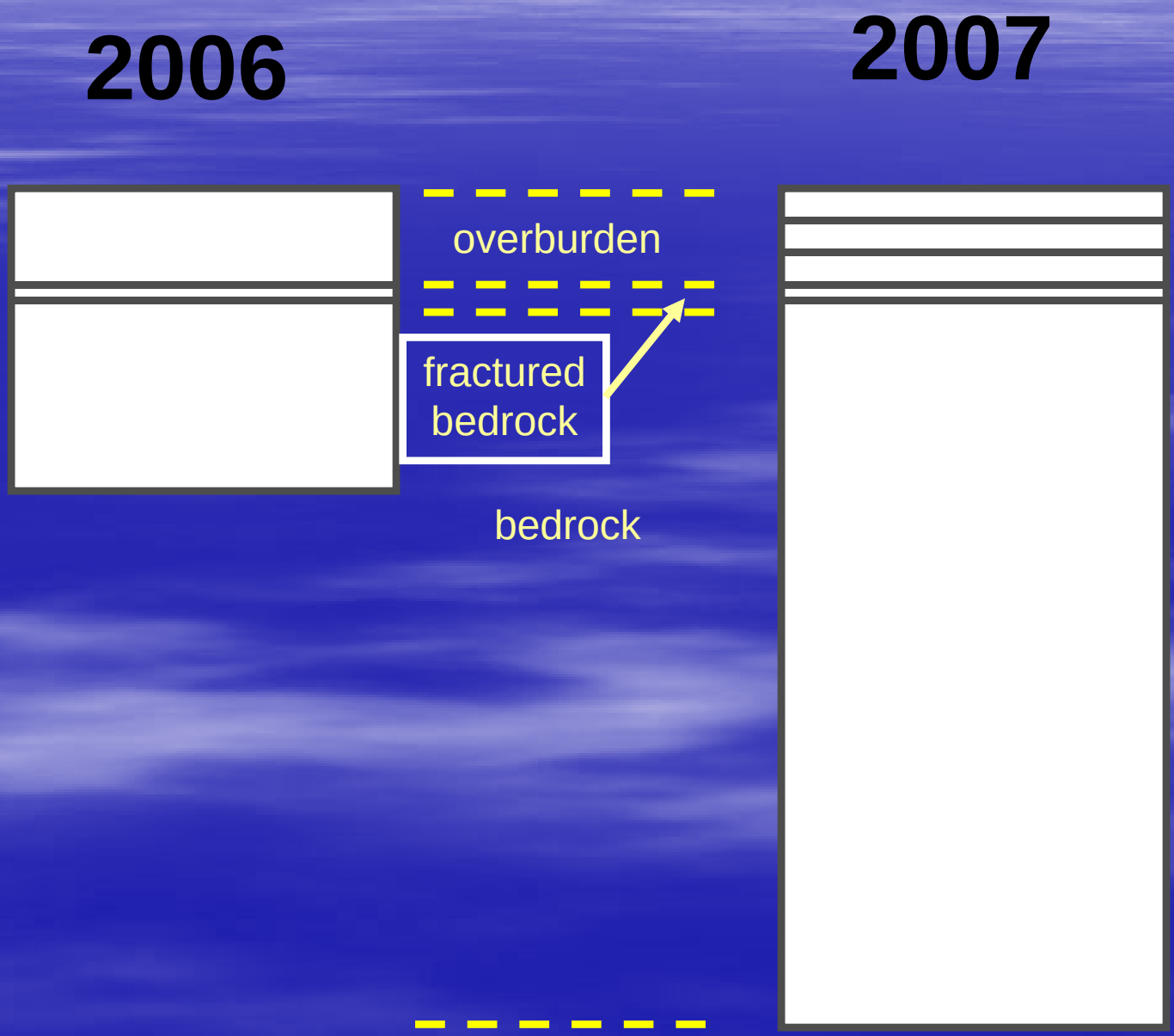


Geology
Drill hole log with classifications

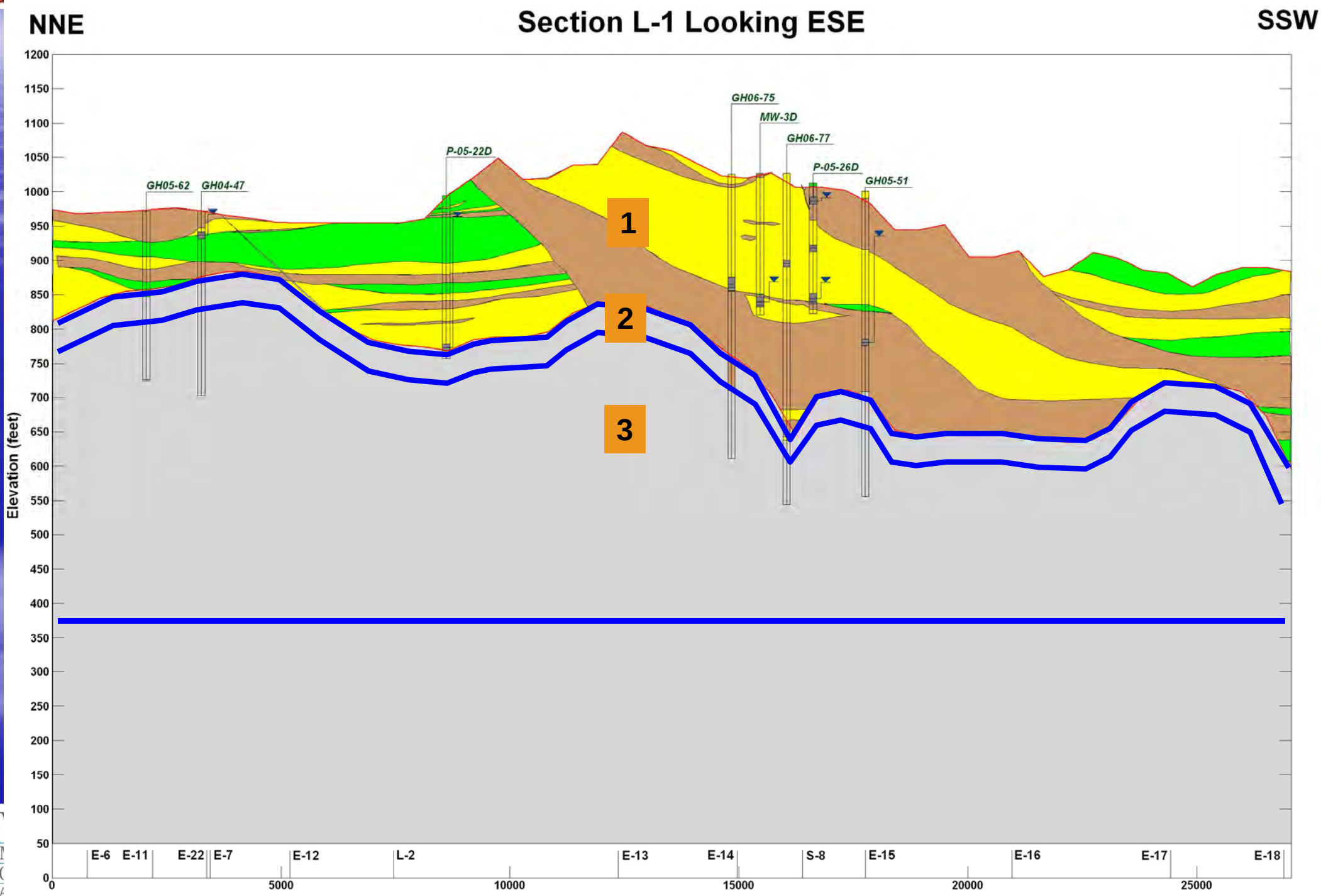
Geologic Interpretation



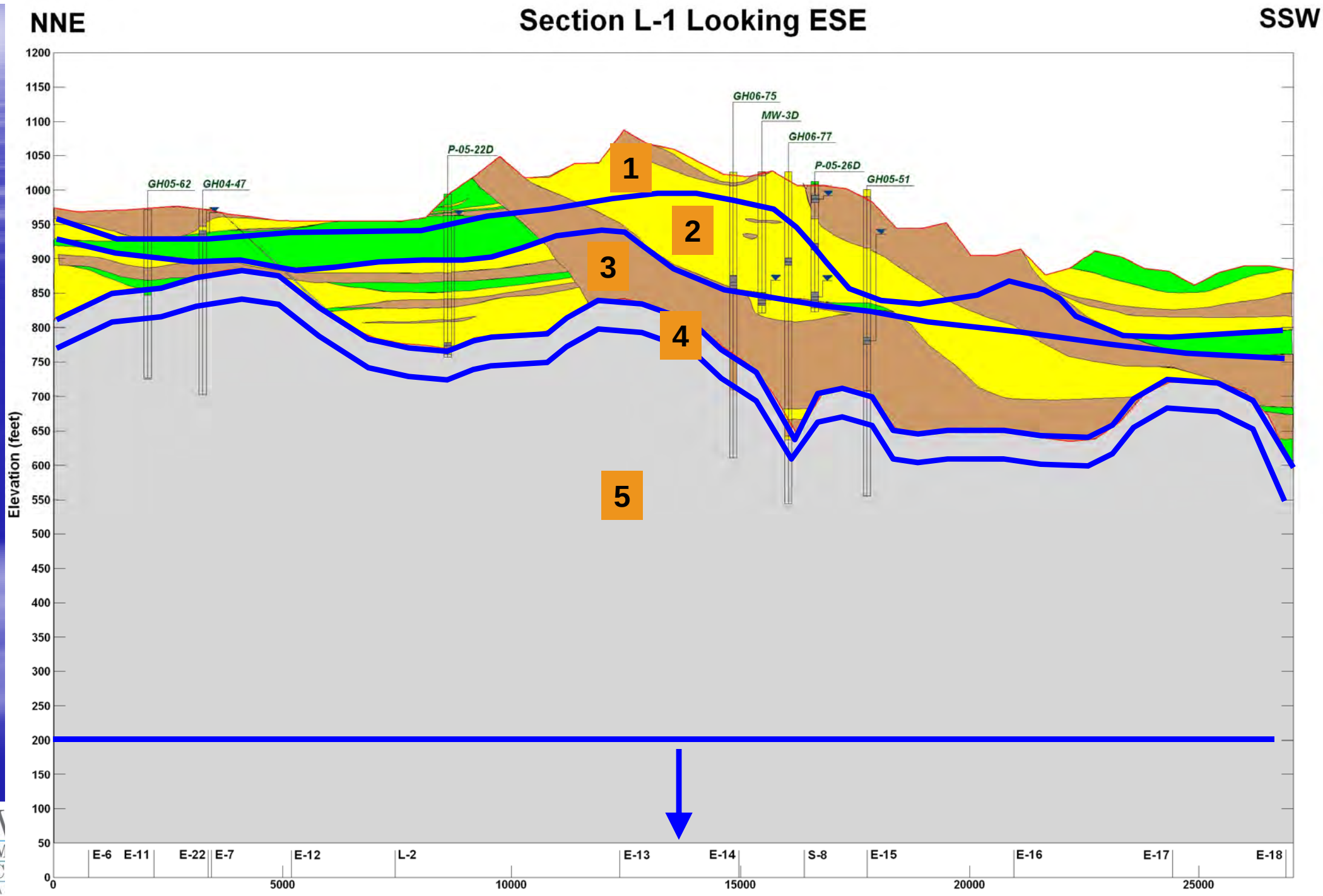
Model Layers



Model Layers (2006)



Model Layers (2007)



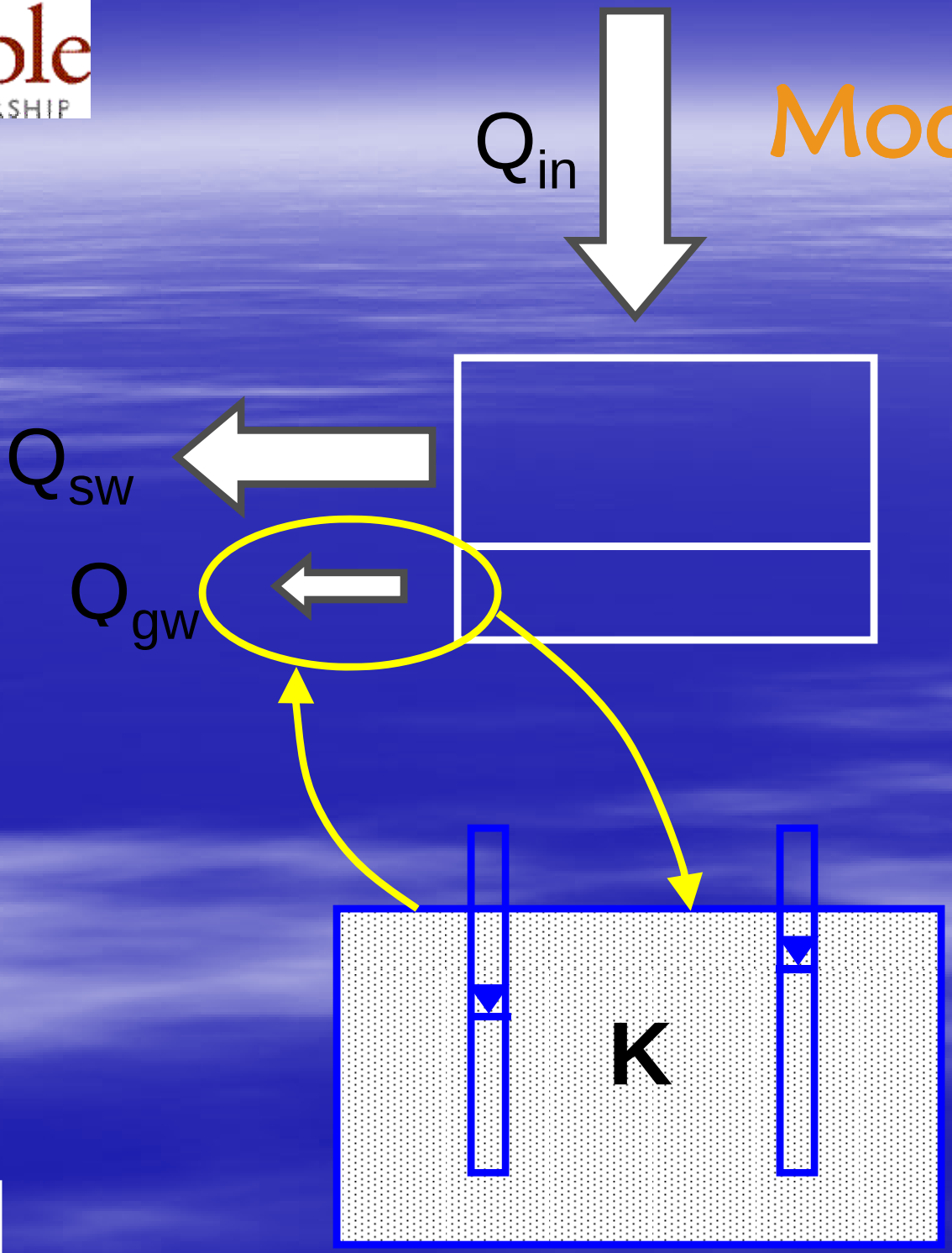
Agenda

1. Modelling Objectives
2. Conceptual Model
3. Integrated Modelling Approach
4. Input Parameters
5. Calibration Process
6. Model Assessment
7. Summary
8. Where we go from here!

Integrated Approach

- Water balance model
- Groundwater model

Model Schematic



Water Balance

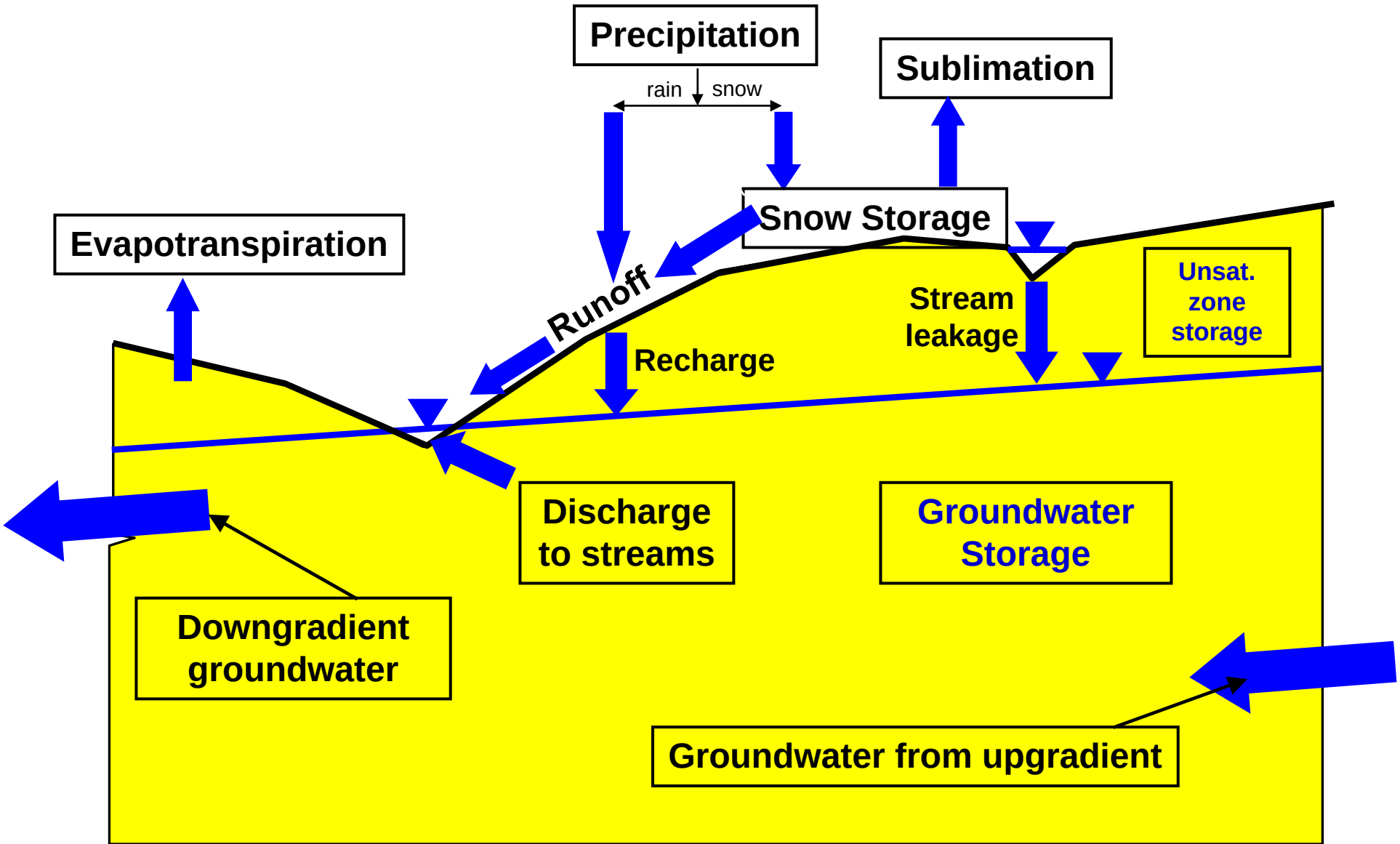
Groundwater Model

Reasons for integrated modelling

- Water Balance:
  - Groundwater flows consistent with overall water balance
  - Increases uniqueness of groundwater model
- Numerical groundwater model:
  - Checks the validity of groundwater component of water balance

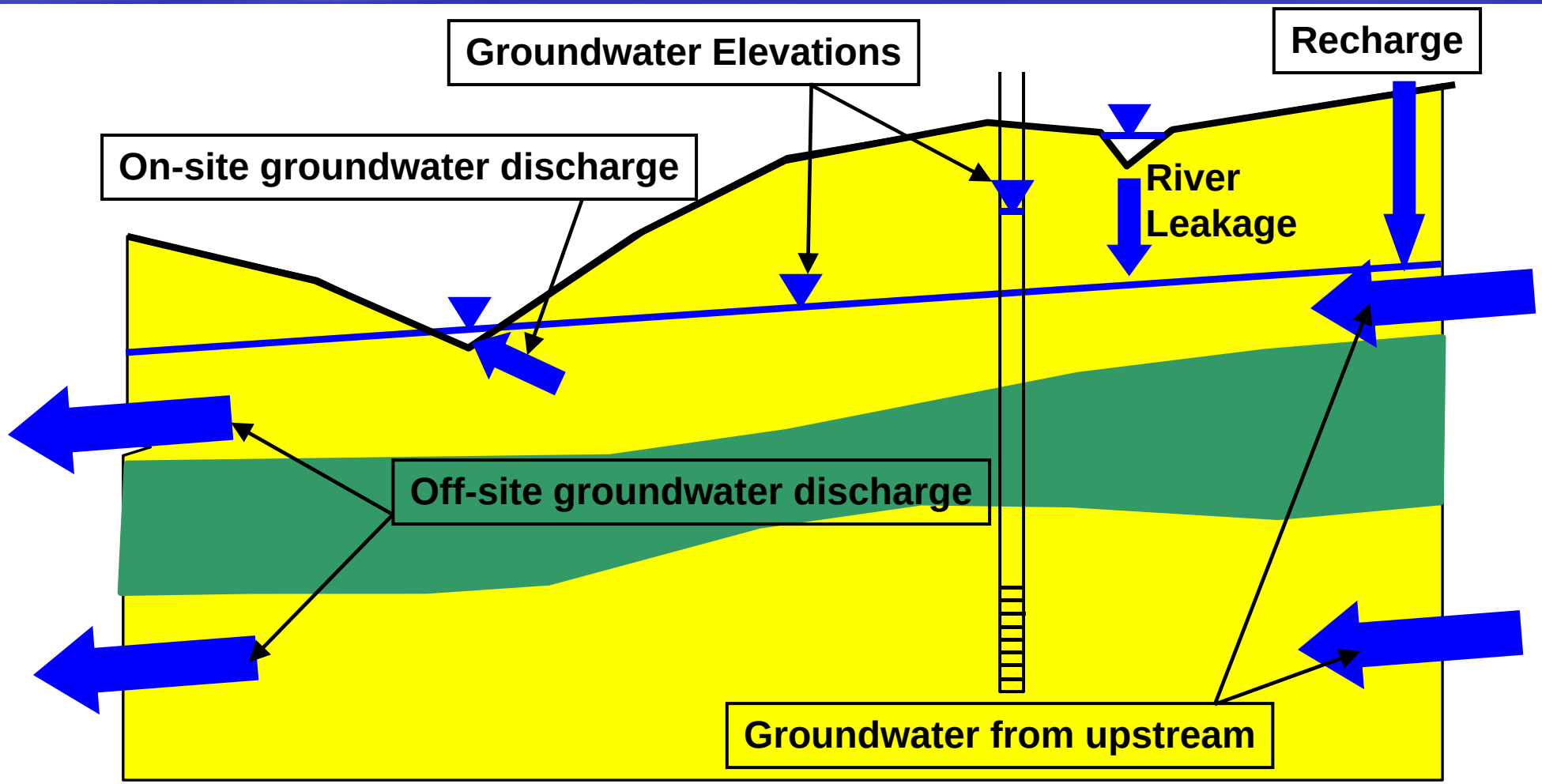
Water Balance Model

- analytical spreadsheet model
- calibrated to monthly streamflow



Groundwater Model

- Numerical finite difference model (MODFLOW-SURFACT)
- Calibrated to observed groundwater elevations (heads), output from water balance *and* low-flow streamflows



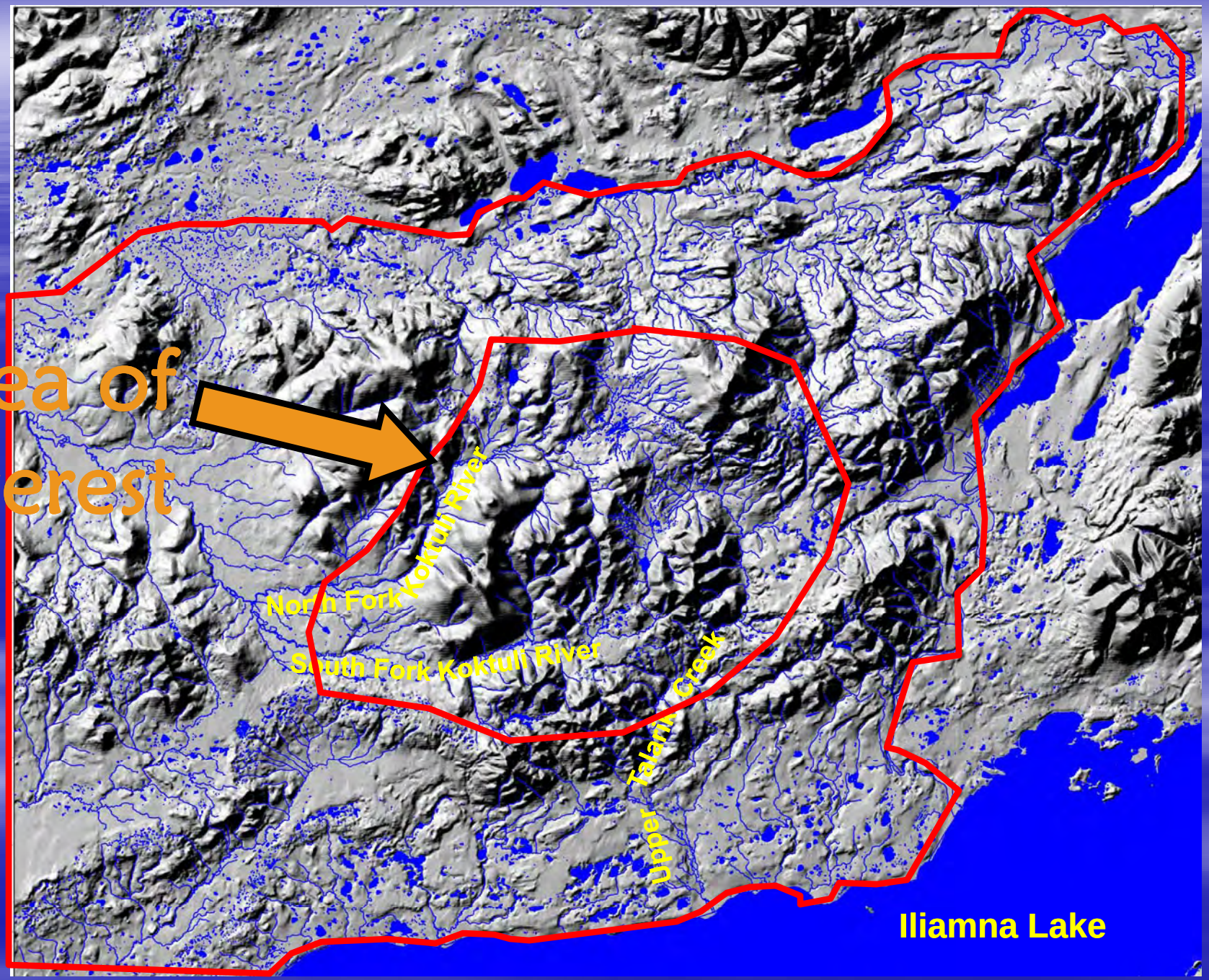
Modelling Time Period

- Water Balance Model
  - Inputs: January 1942 – July 2006
  - Calibration: July 2004 – May 2006
- Groundwater Model
  - Phase I: steady state
  - Phase II: Jan 05 – Dec 05
  - Phase III: Jan 05 – Dec 06
  - Phase IV: Jan 05 – Dec 07

Agenda

1. Modelling Objectives
2. Conceptual Model
3. Integrated Modelling Approach
4. Input Parameters
5. Calibration Process
6. Model Assessment
7. Summary
8. Where we go from here!

THE pebble PARTNERSHIP



WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

THE pebble PARTNERSHIP

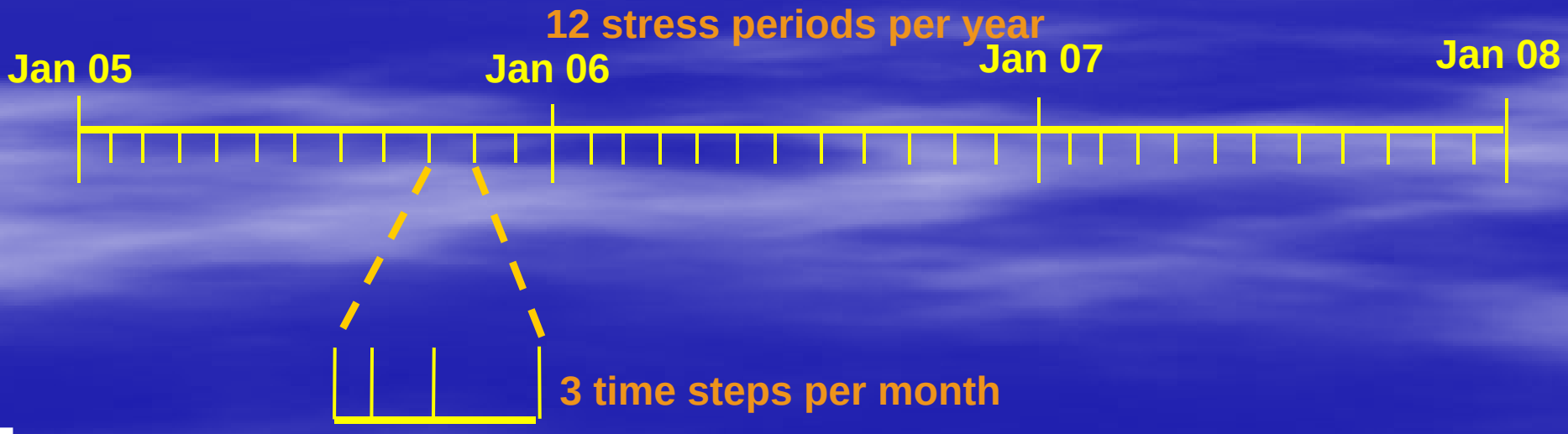
Numerical Model Inputs

- Temporal Discretization
- Layer Elevations
- Recharge
- Hydraulic Conductivity
- River Elevations
- River Conductance
- Seep Locations
- Seep Conductance
- Edge Boundaries

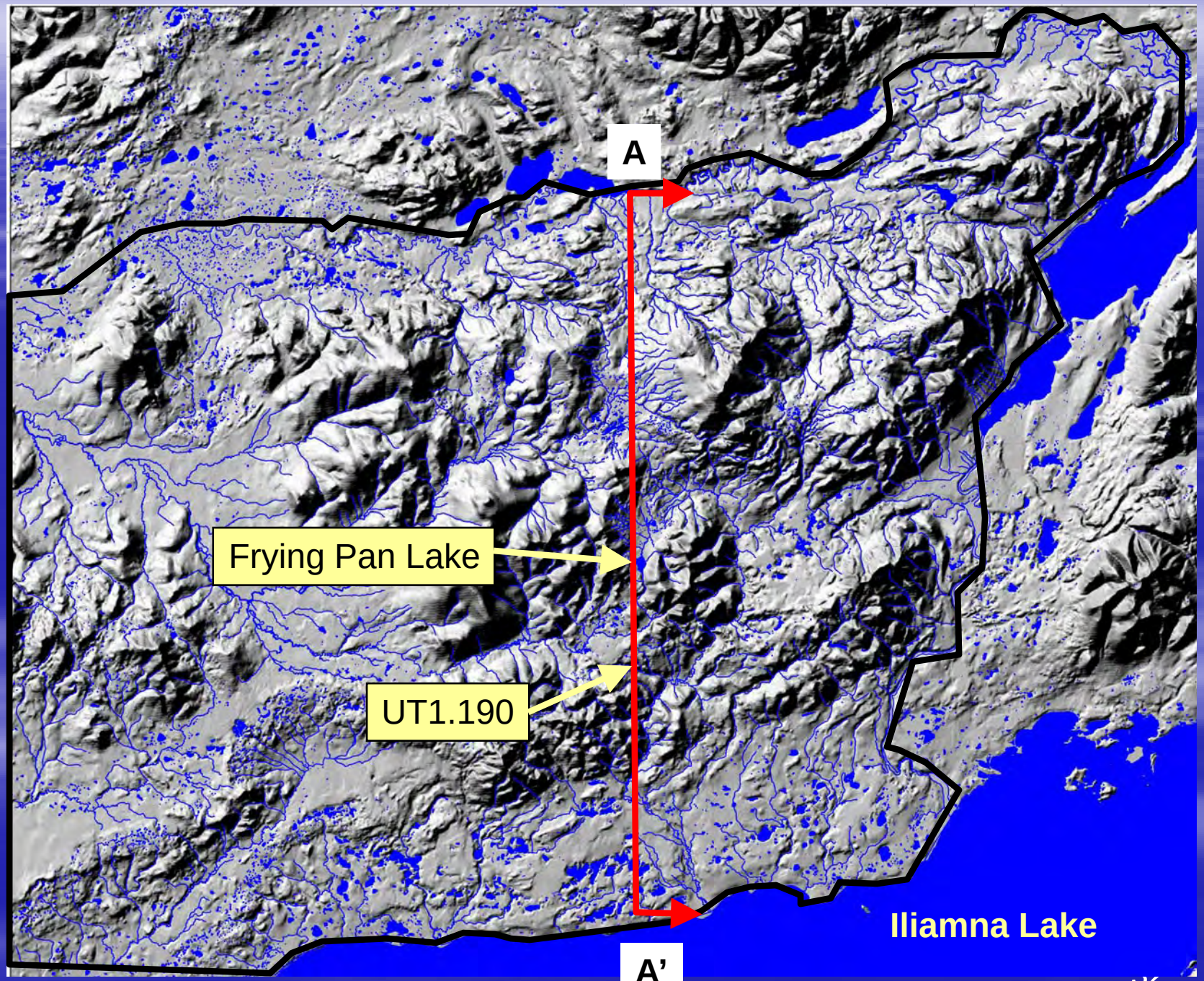
WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

Temporal Discretization

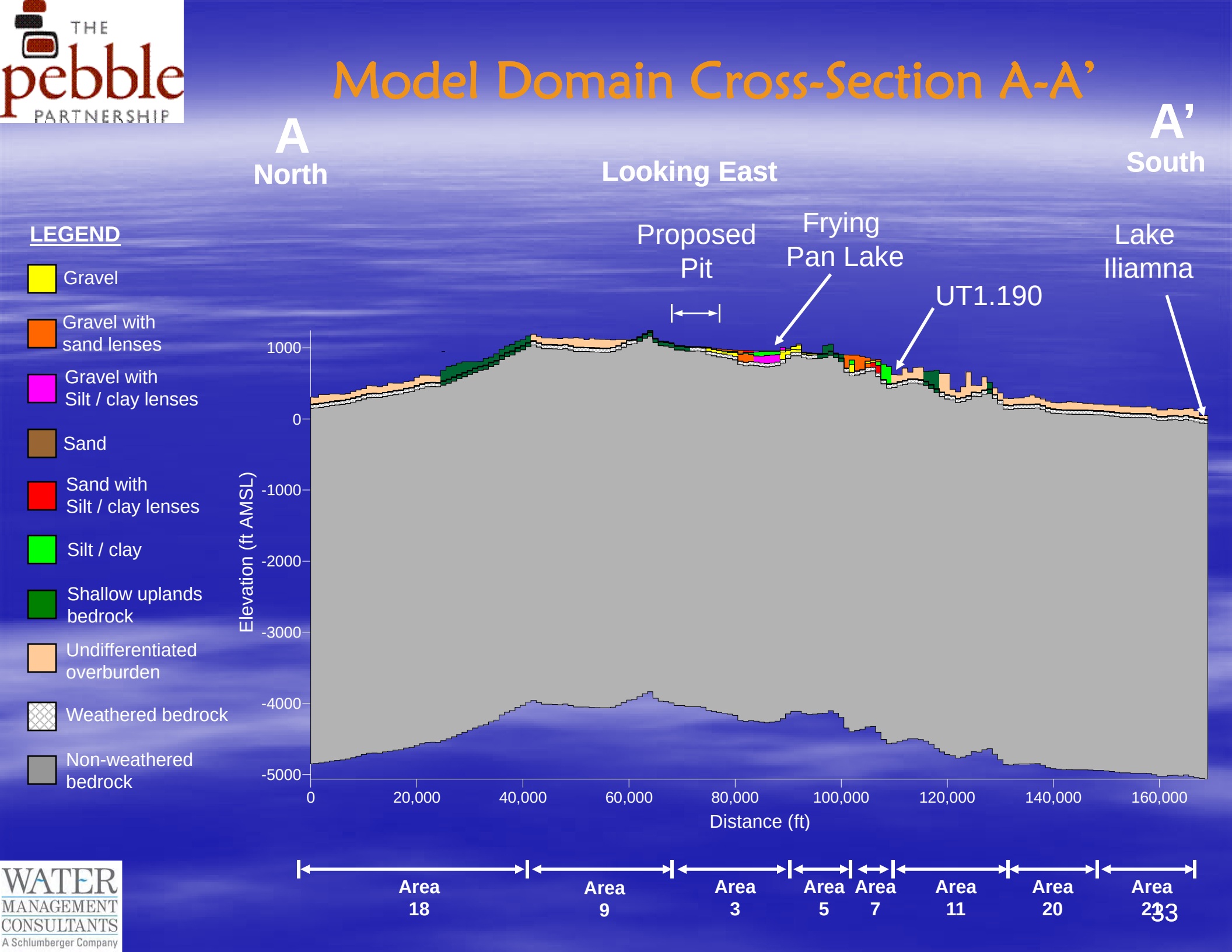
- Water balance:
  - calibrated to average monthly flows
- Groundwater model:
  - Monthly "stress periods"
  - three time steps per stress period



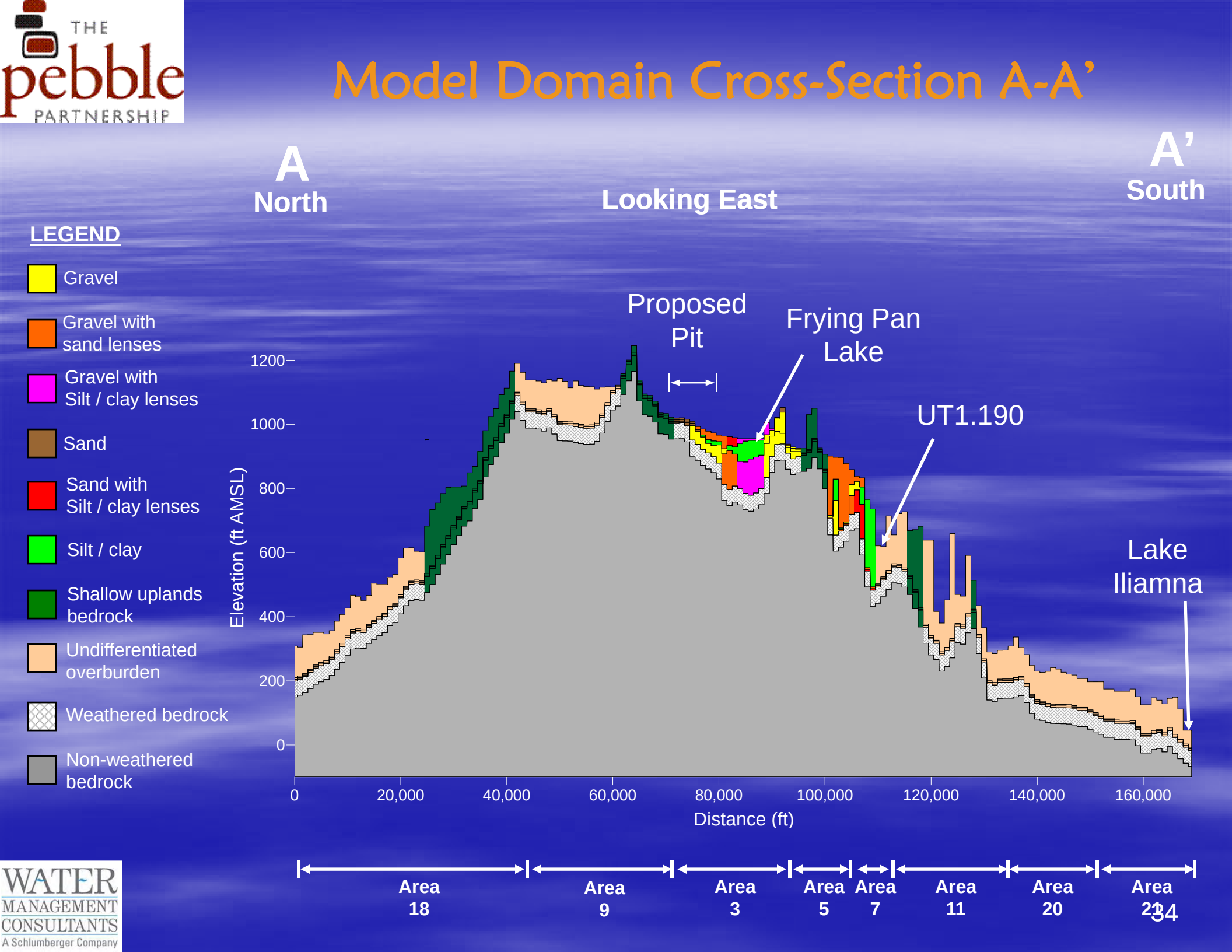
Model Cross-Section Location



Model Domain Cross-Section A-A'



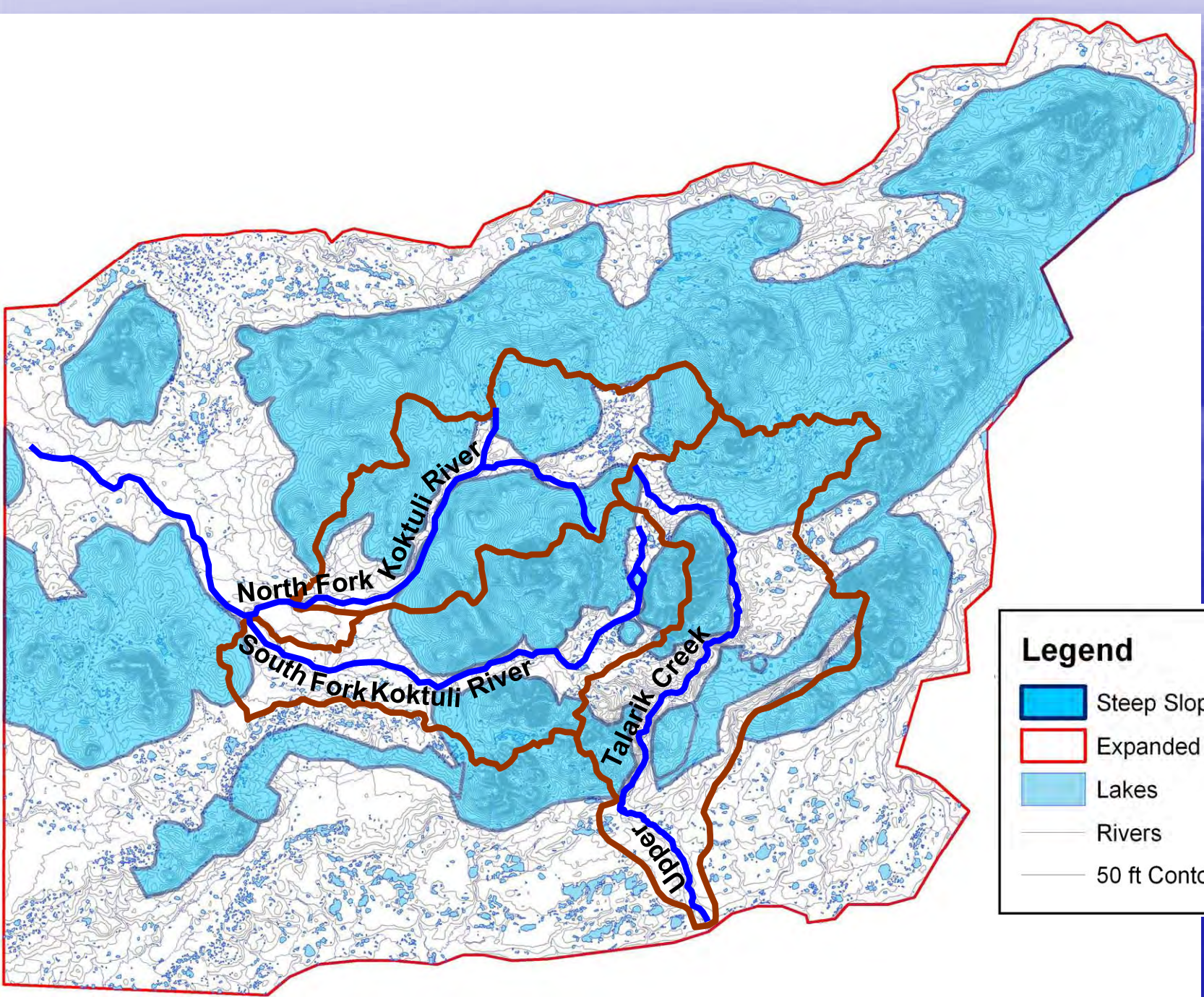
Model Domain Cross-Section A-A'



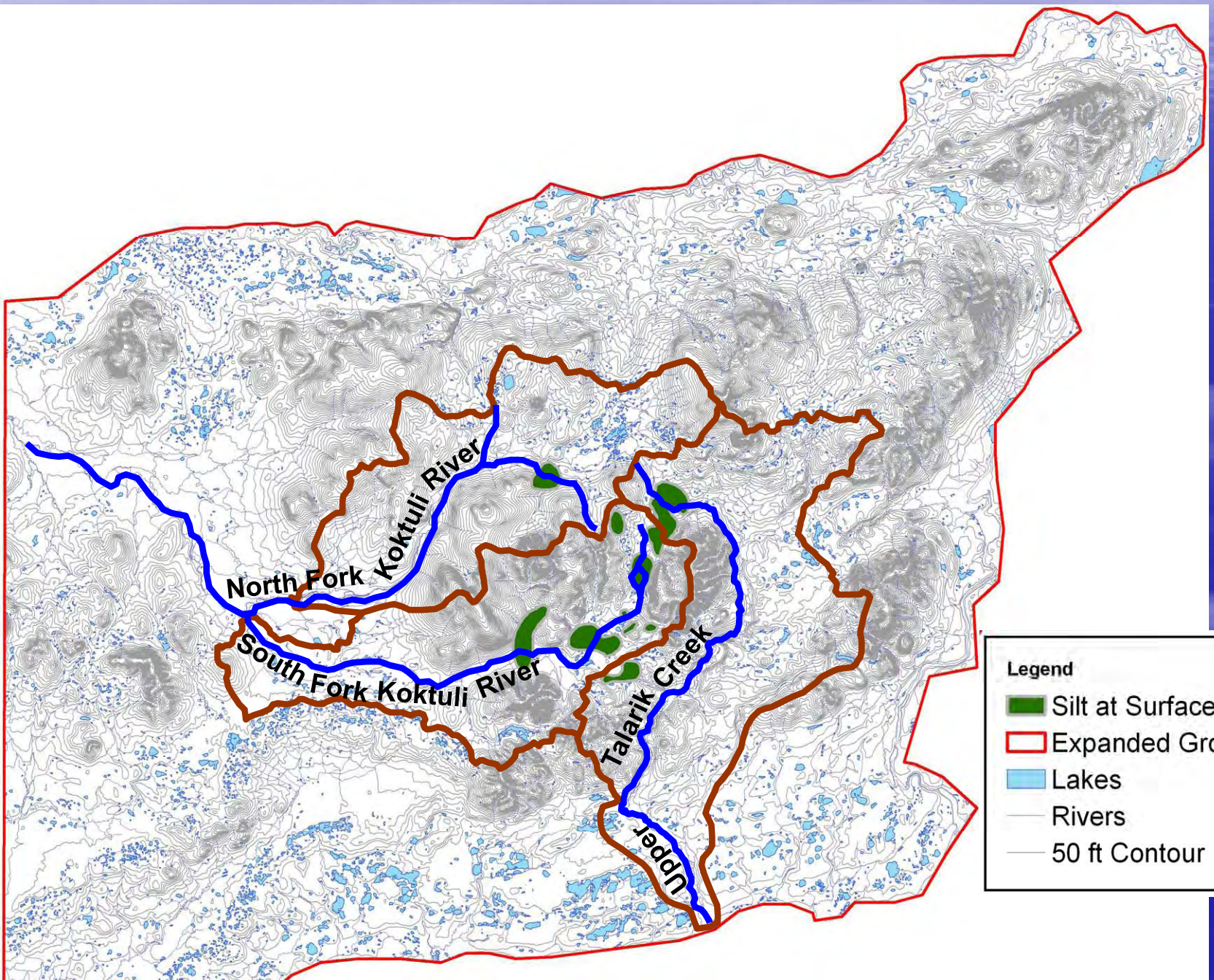
Meteoric Recharge Zones

- Total recharge for a given watershed derived from water balance model
- Factors considered distributing meteoric recharge within a watershed
  - slope
  - hydraulic conductivity

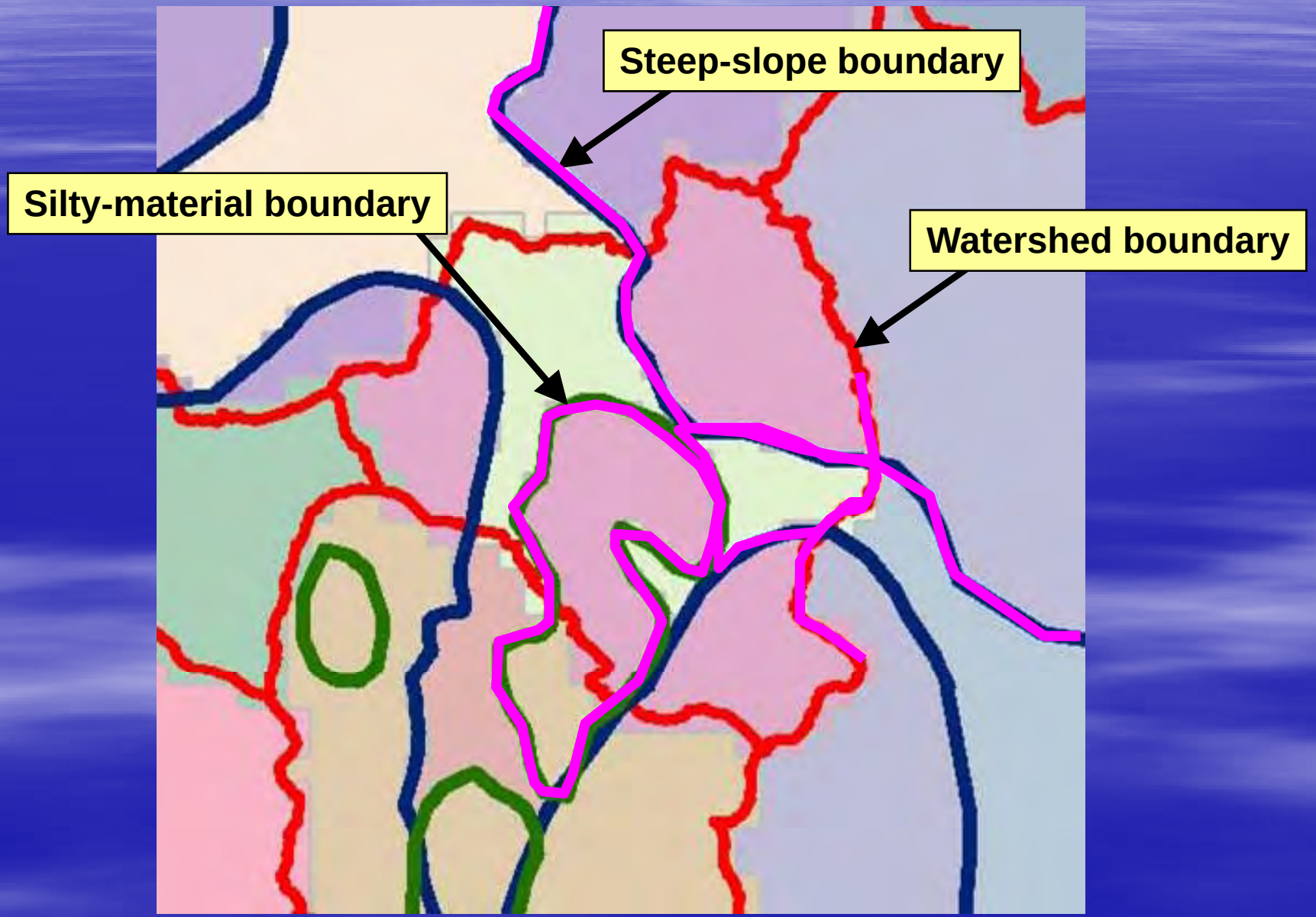
Steep slope zones



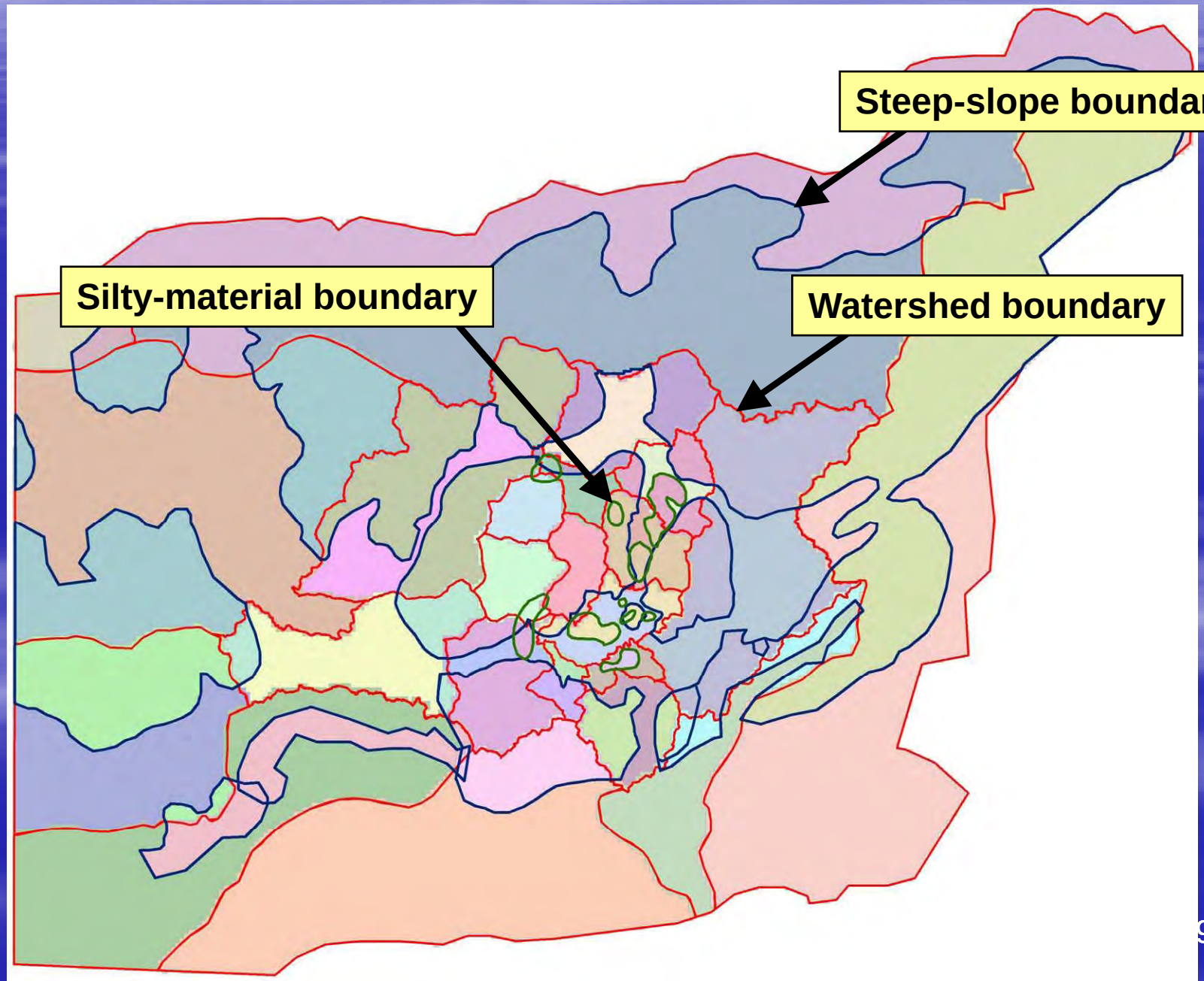
Silty materials at surface



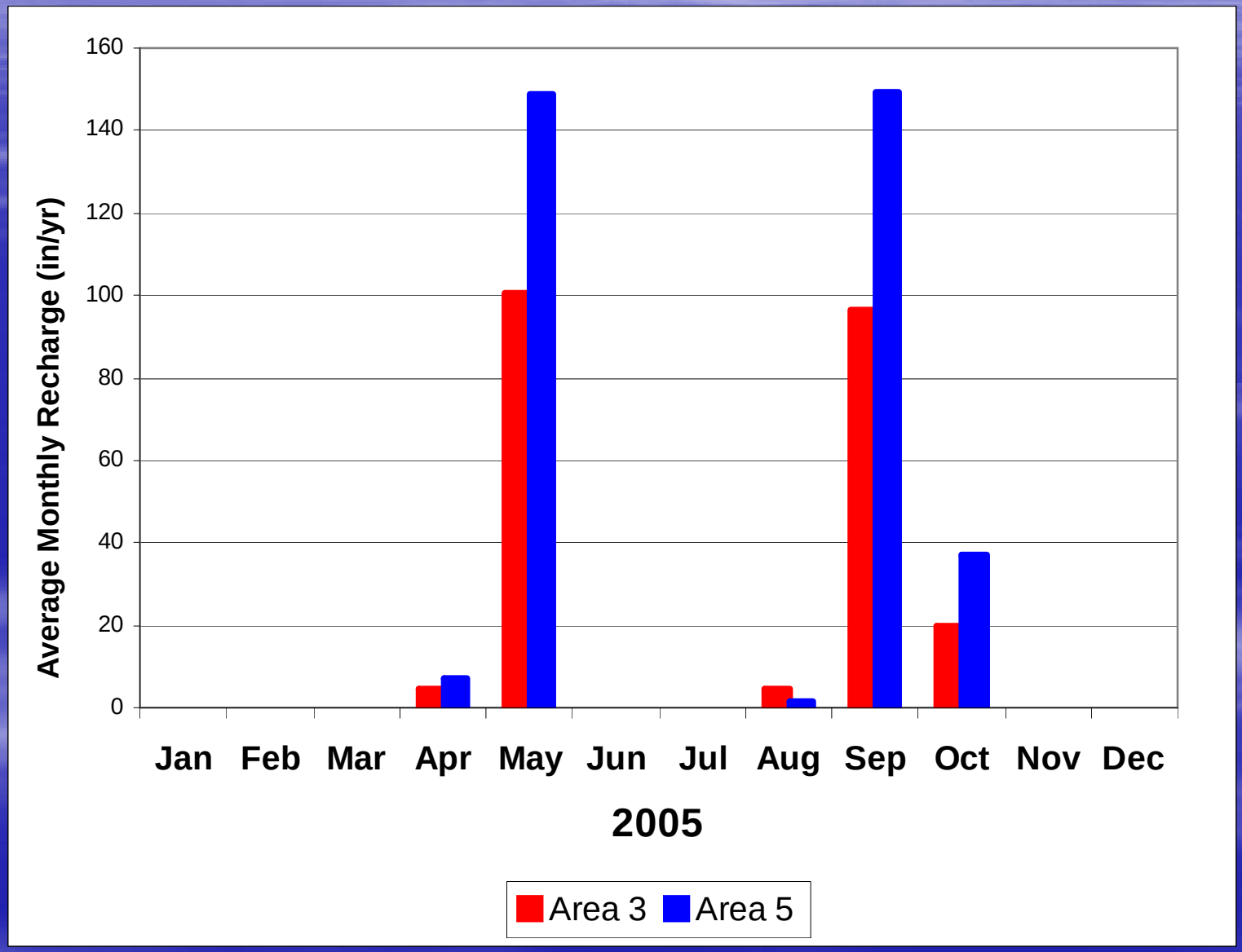
Meteoric Recharge Zones Close-up



Meteoric Recharge Zones
Full Model Domain



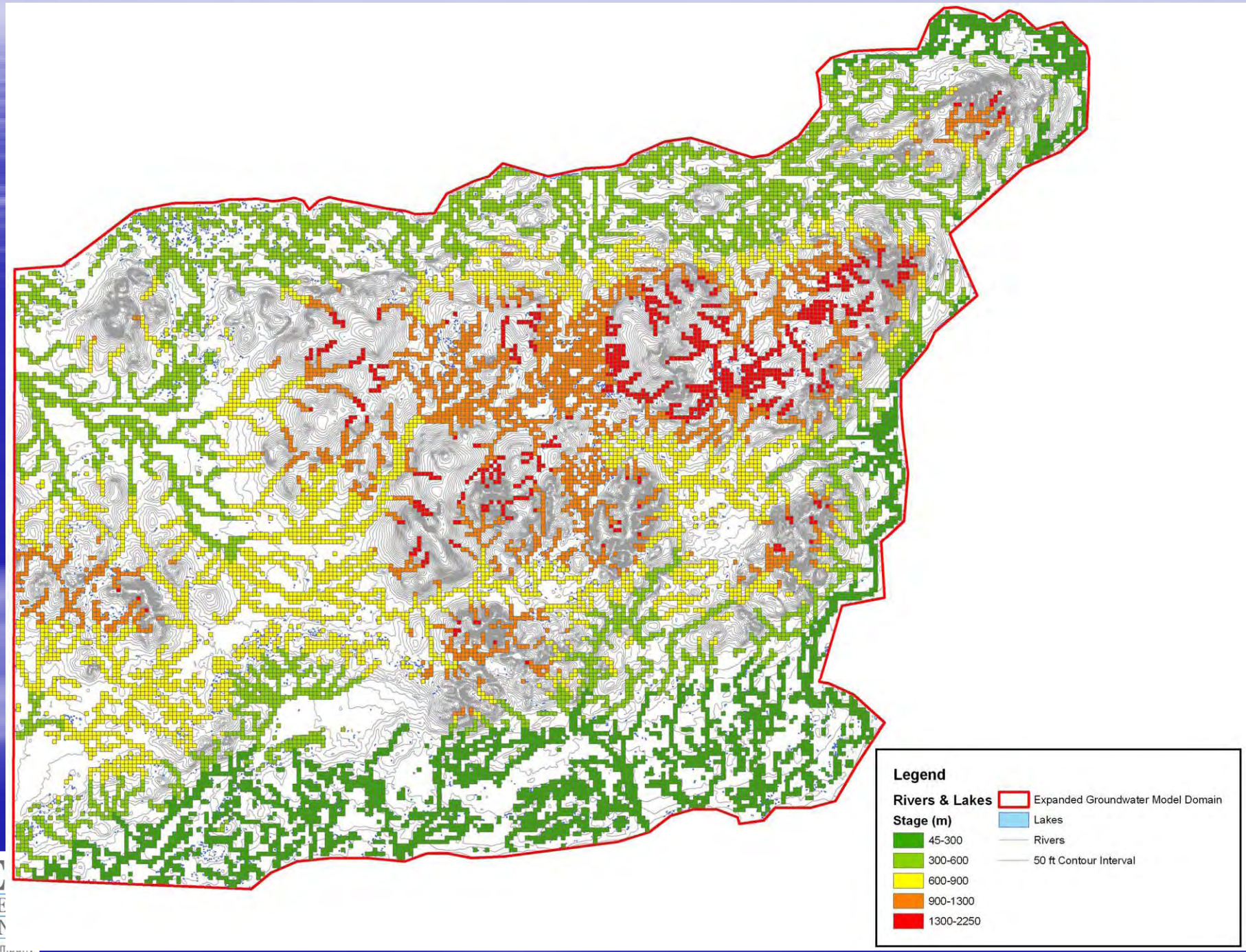
Transient Meteoric Recharge
Areas 3 and 5



THE pebble PARTNERSHIP

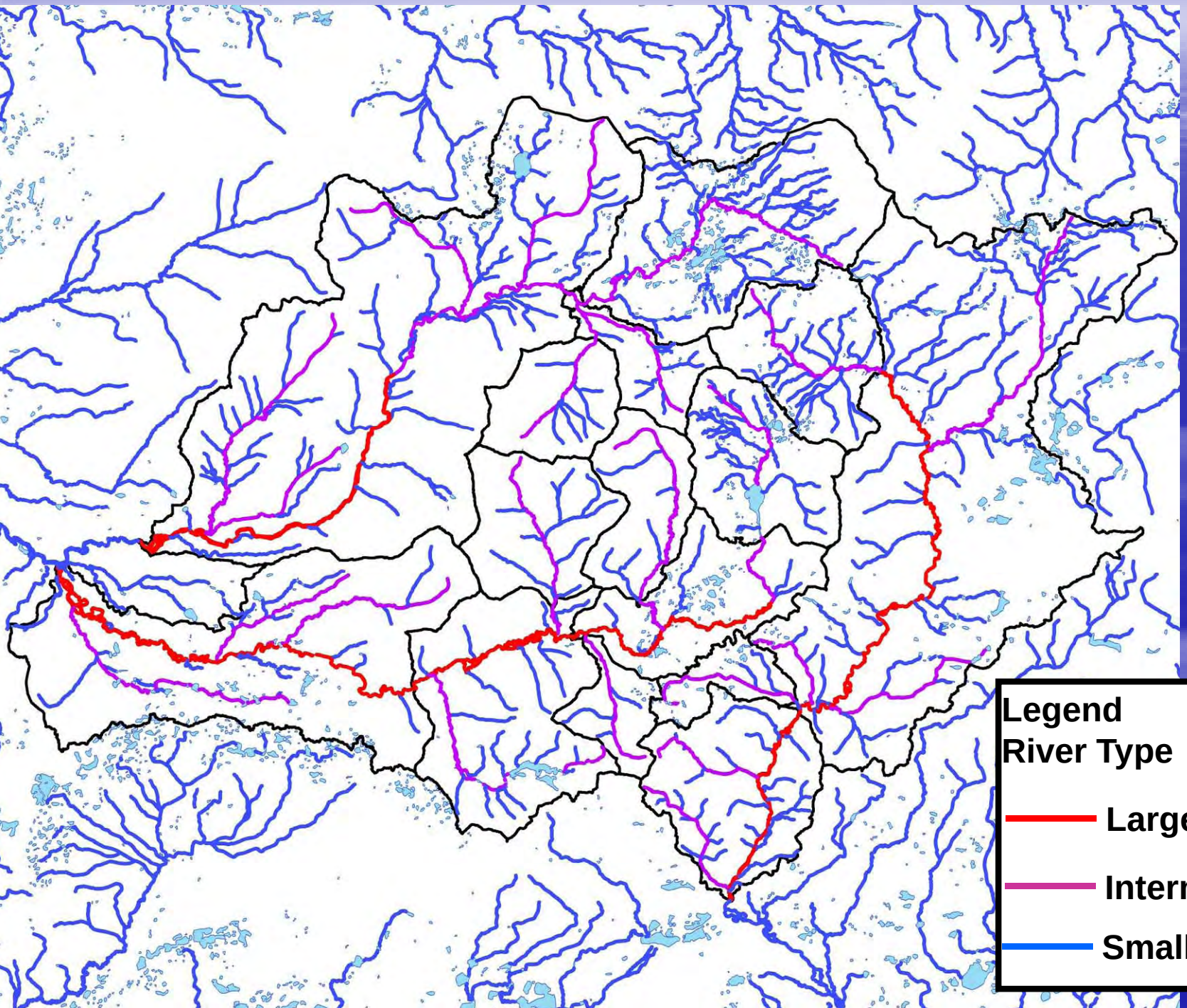
River Boundaries

River Stage

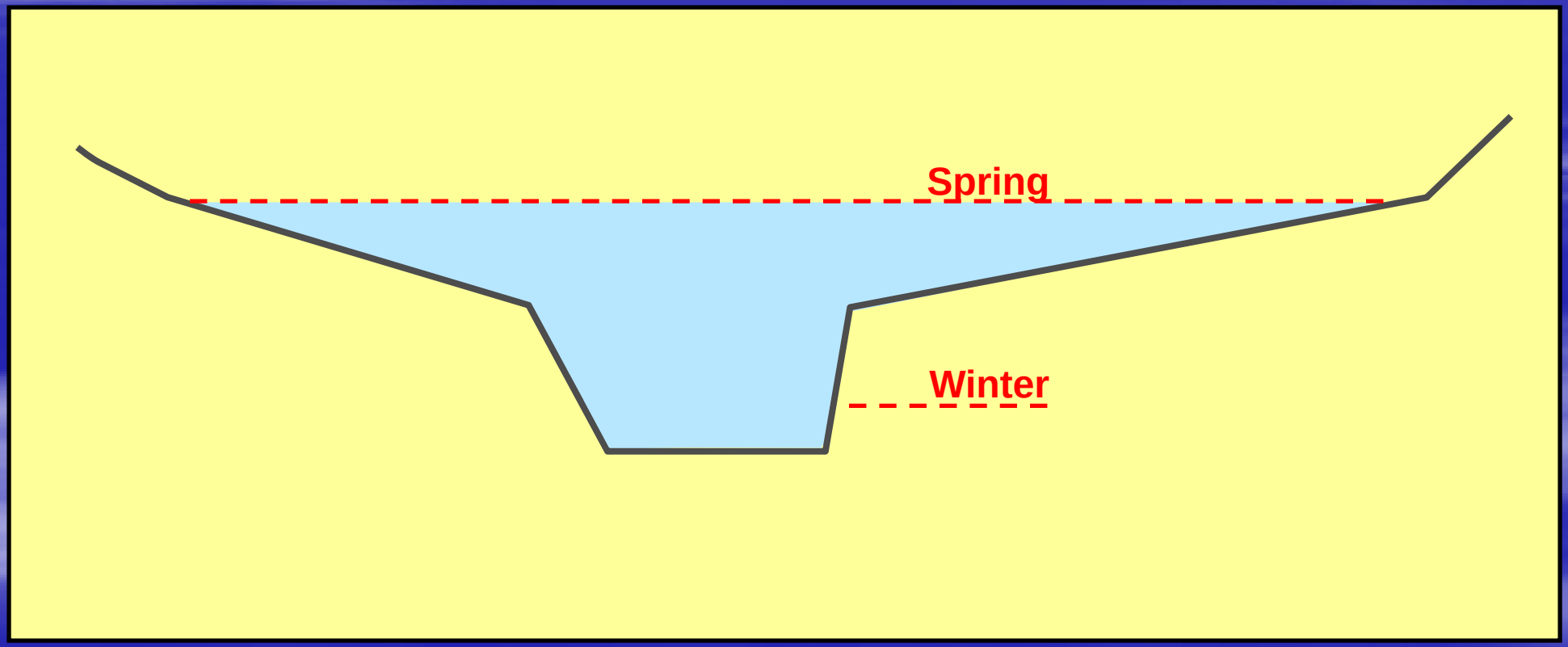

Legend
Rivers & Lakes
Stage (m)
45-300
300-600
600-900
900-1300
1300-2250
Expanded Groundwater Model Domain
Lakes
Rivers
50 ft Contour Interval

THE pebble PARTNERSHIP

River Type

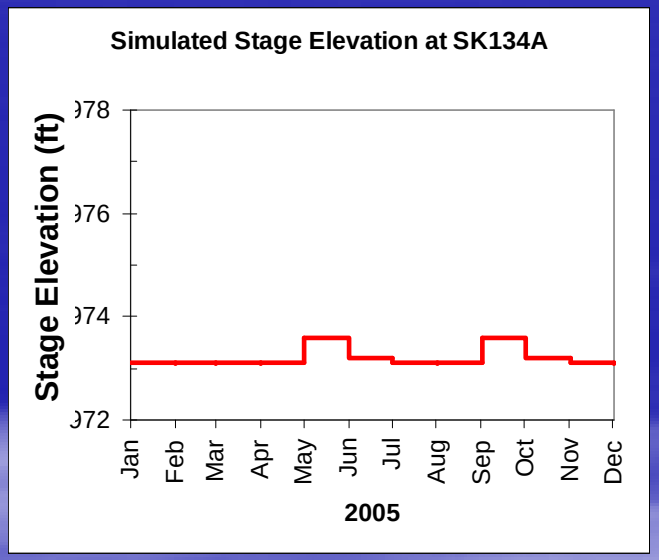


Transient River Stage and Width

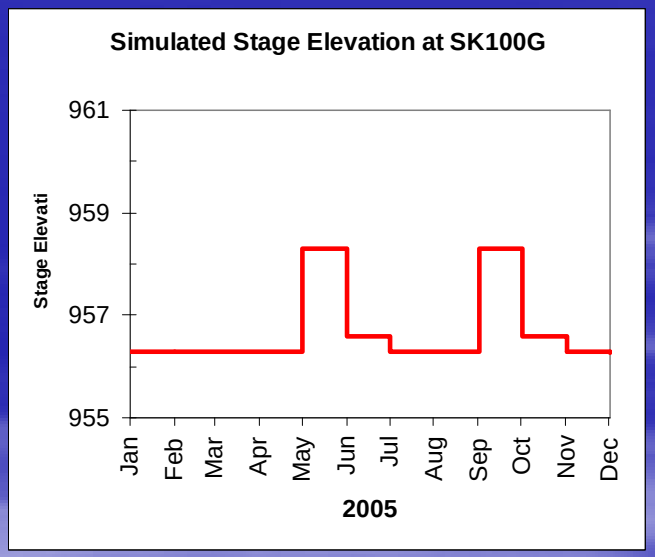


Transient River Stage

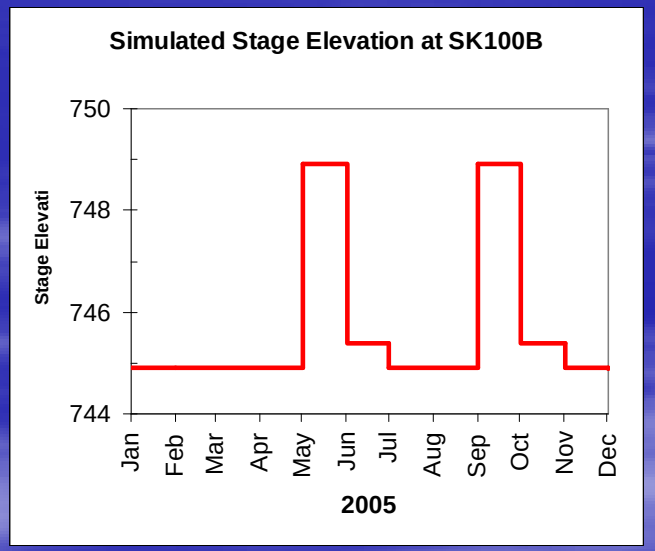
Small Catchment



Intermediate Catchment



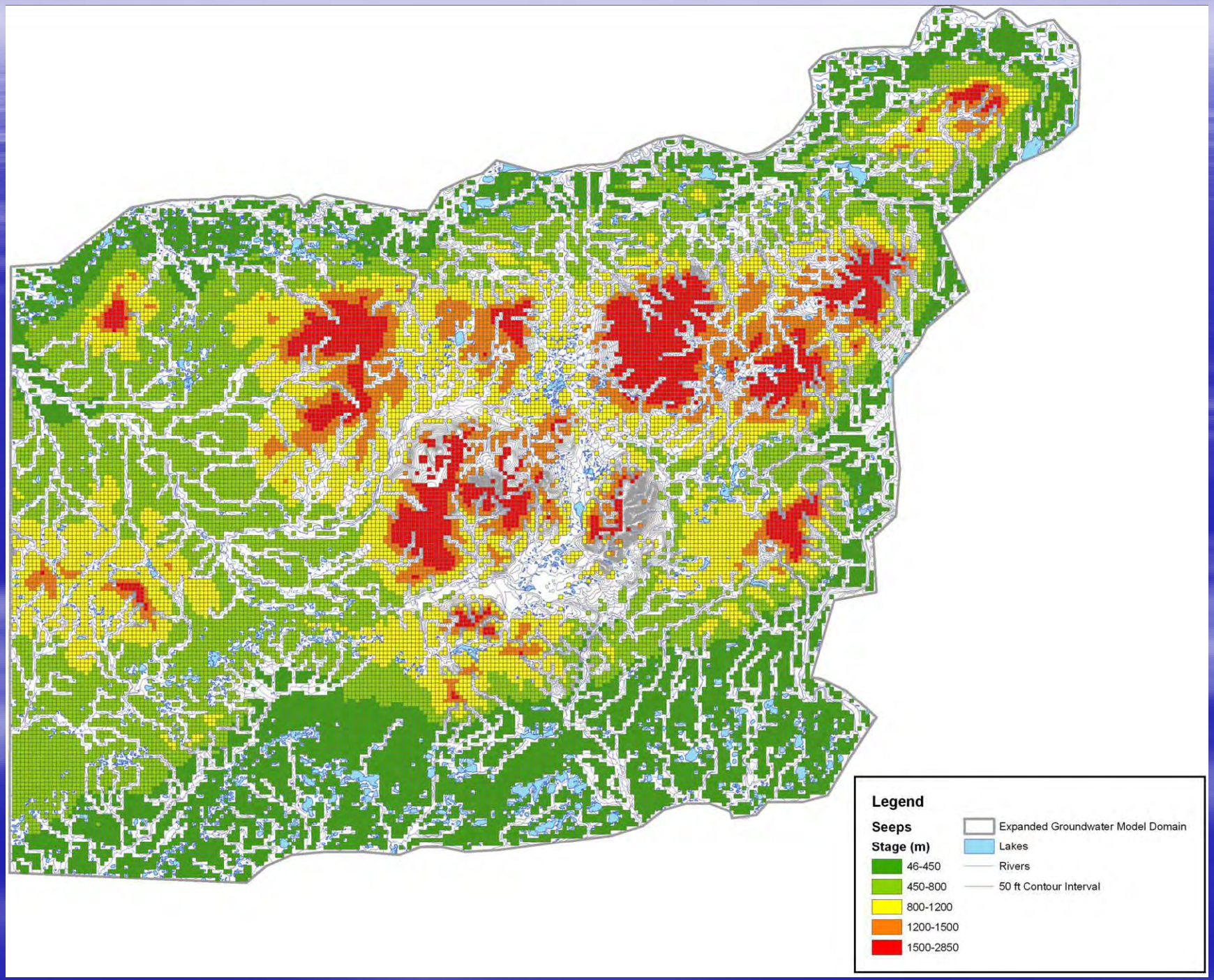
Large Catchment




Seeps

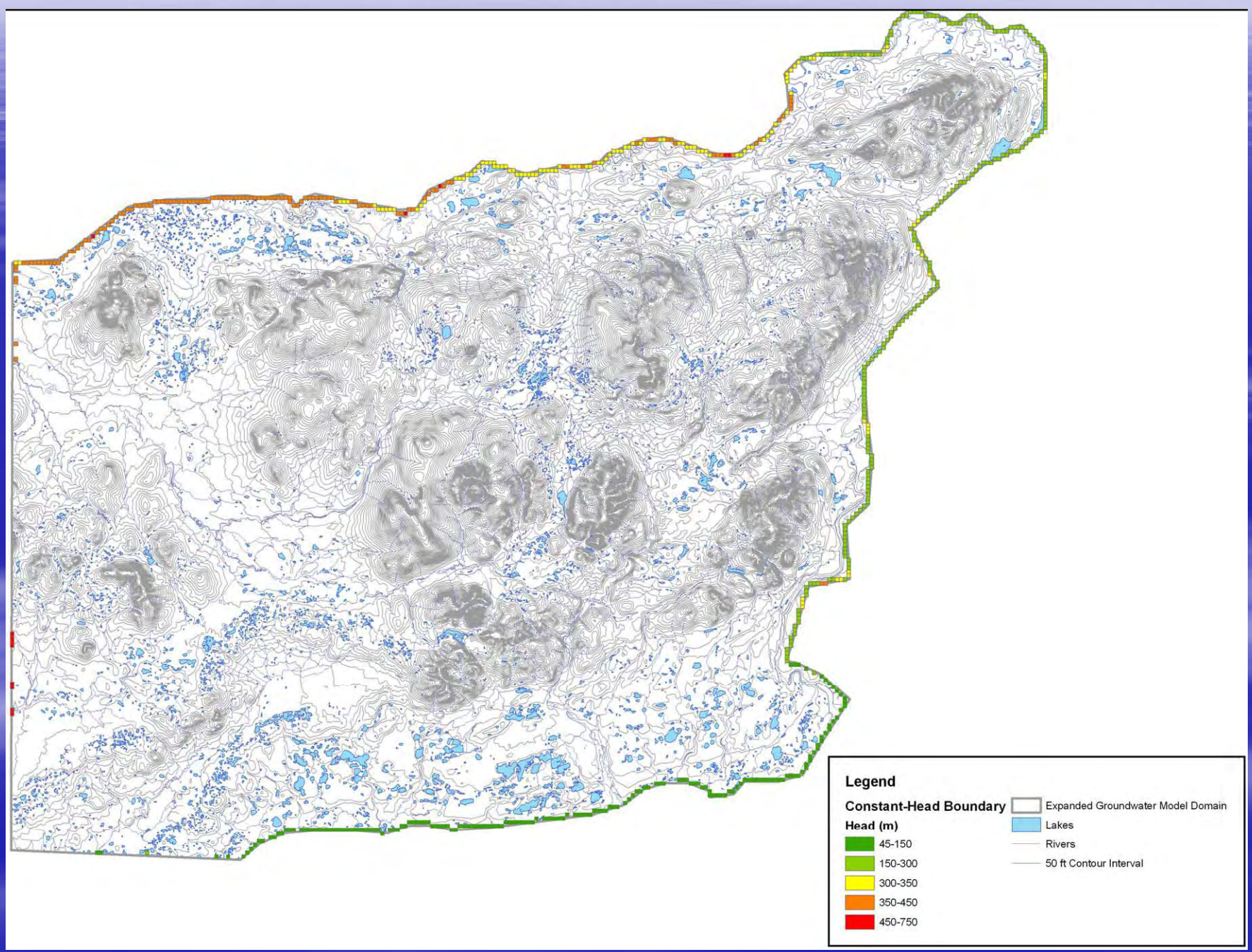
THE pebble PARTNERSHIP

Seepage Boundaries

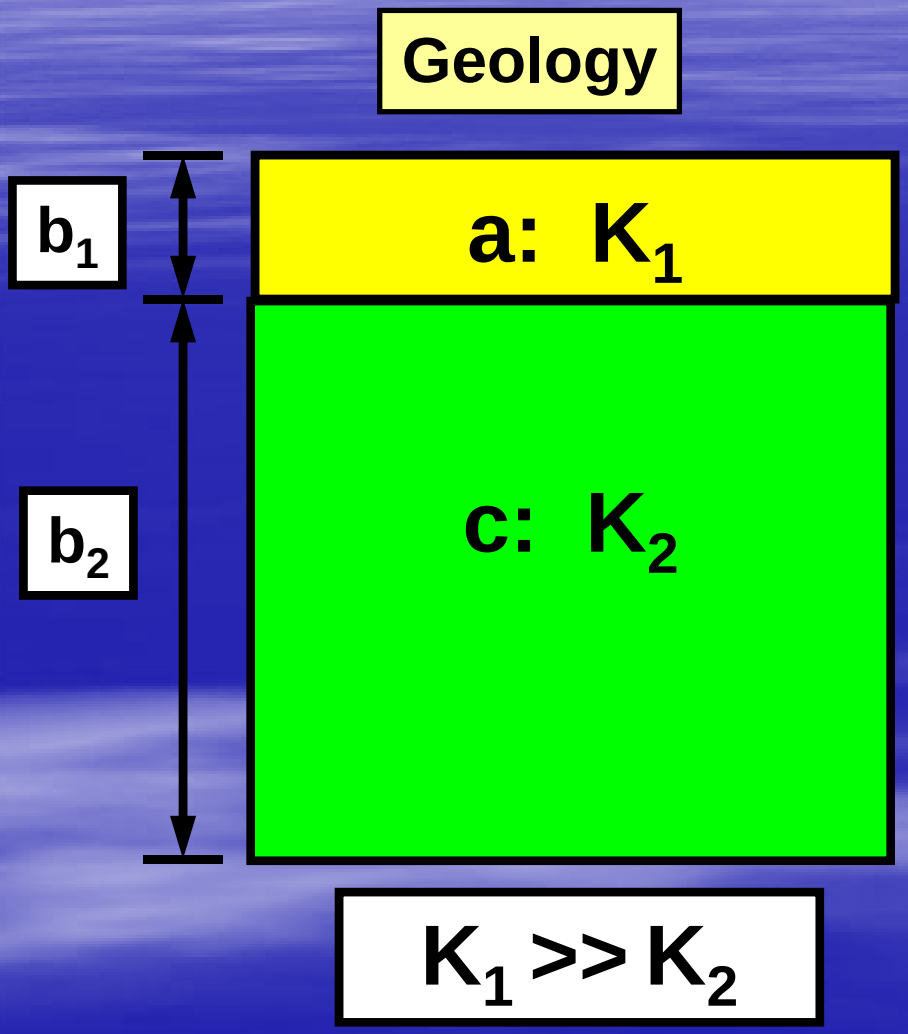


WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

Specified Head Boundary



Equivalent K_h's and K_v's

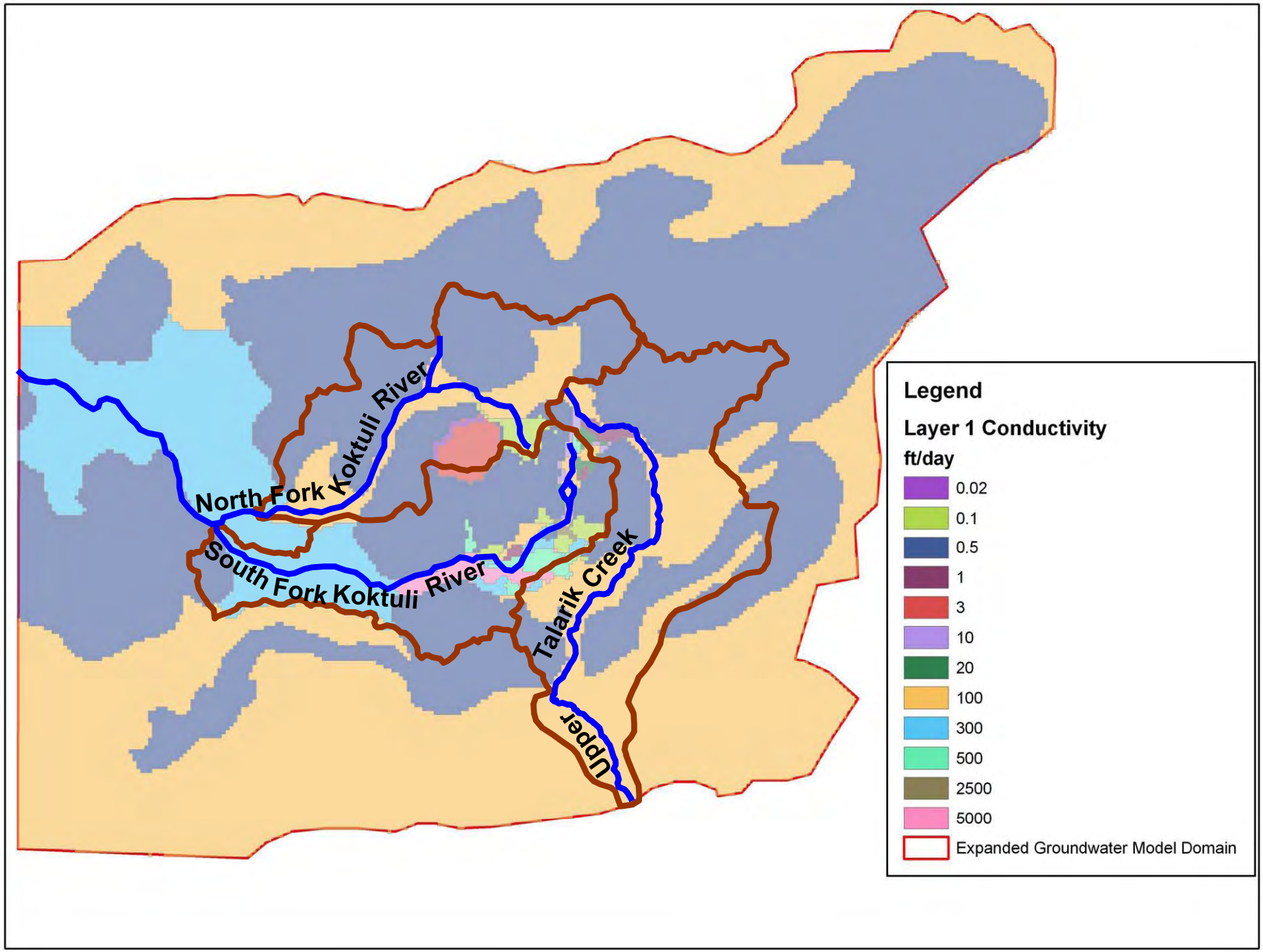


Model Layer

$$K_h = \frac{K_1 b_1 + K_2 b_2}{b}$$

$$K_v = \frac{b}{b_1/K_1 + b_1/K_2}$$

Layer 1 Hydraulic Conductivity



Eq

Agenda

1. Modelling Objectives
2. Conceptual Model
3. Integrated Modelling Approach
4. Input Parameters
5. Calibration Process
6. Model Assessment
7. Summary
8. Where we go from here!

THE pebble PARTNERSHIP

Calibration Targets

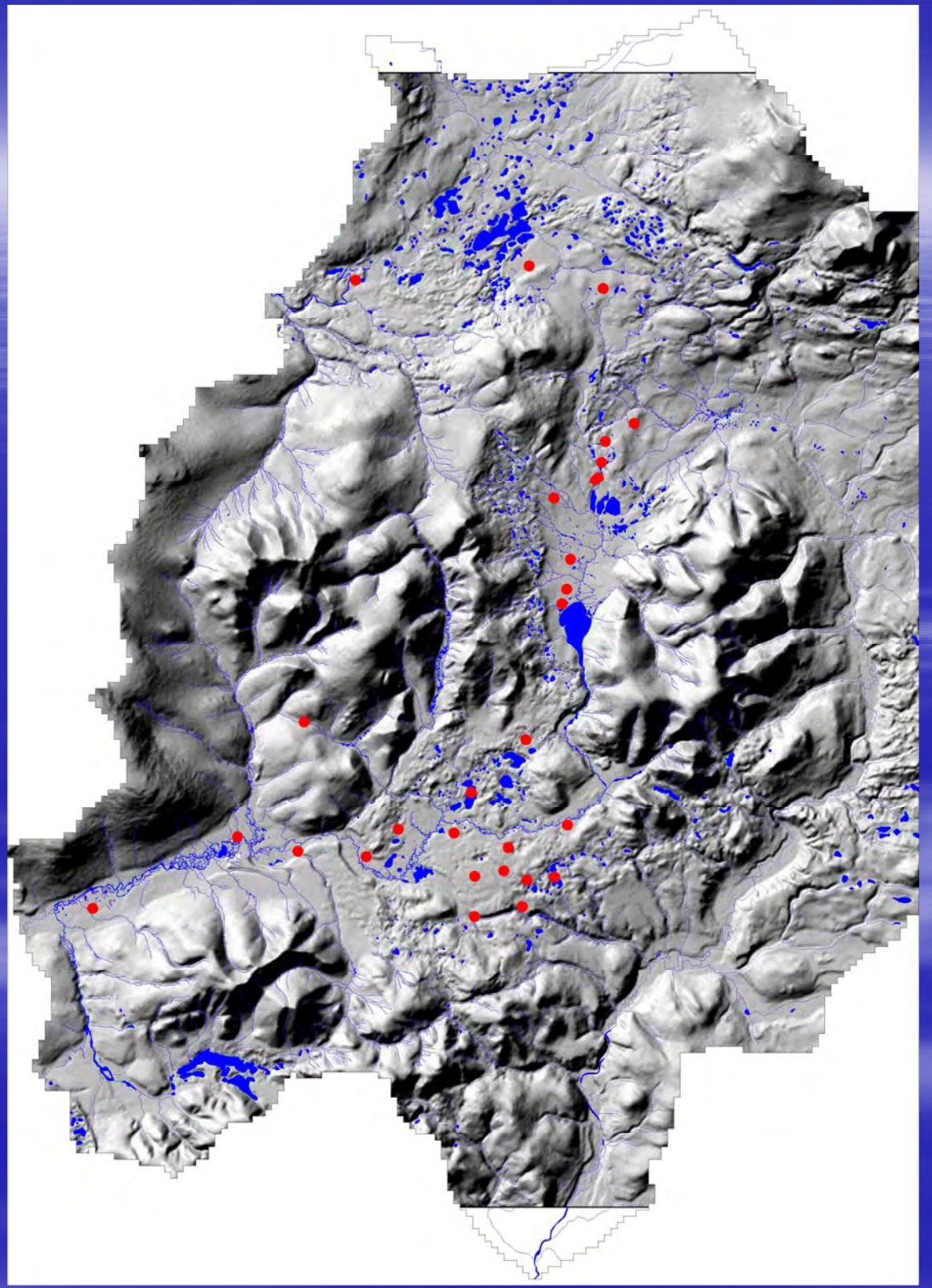
- Observed data:
  - Groundwater elevations (heads)
  - Low-flow streamflows
- Estimated flows:
  - Recharge rate
  - Off-site groundwater discharge
  - On-site groundwater discharge
- Calibrating to both heads *and* flows increases model uniqueness

WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

THE pebble PARTNERSHIP

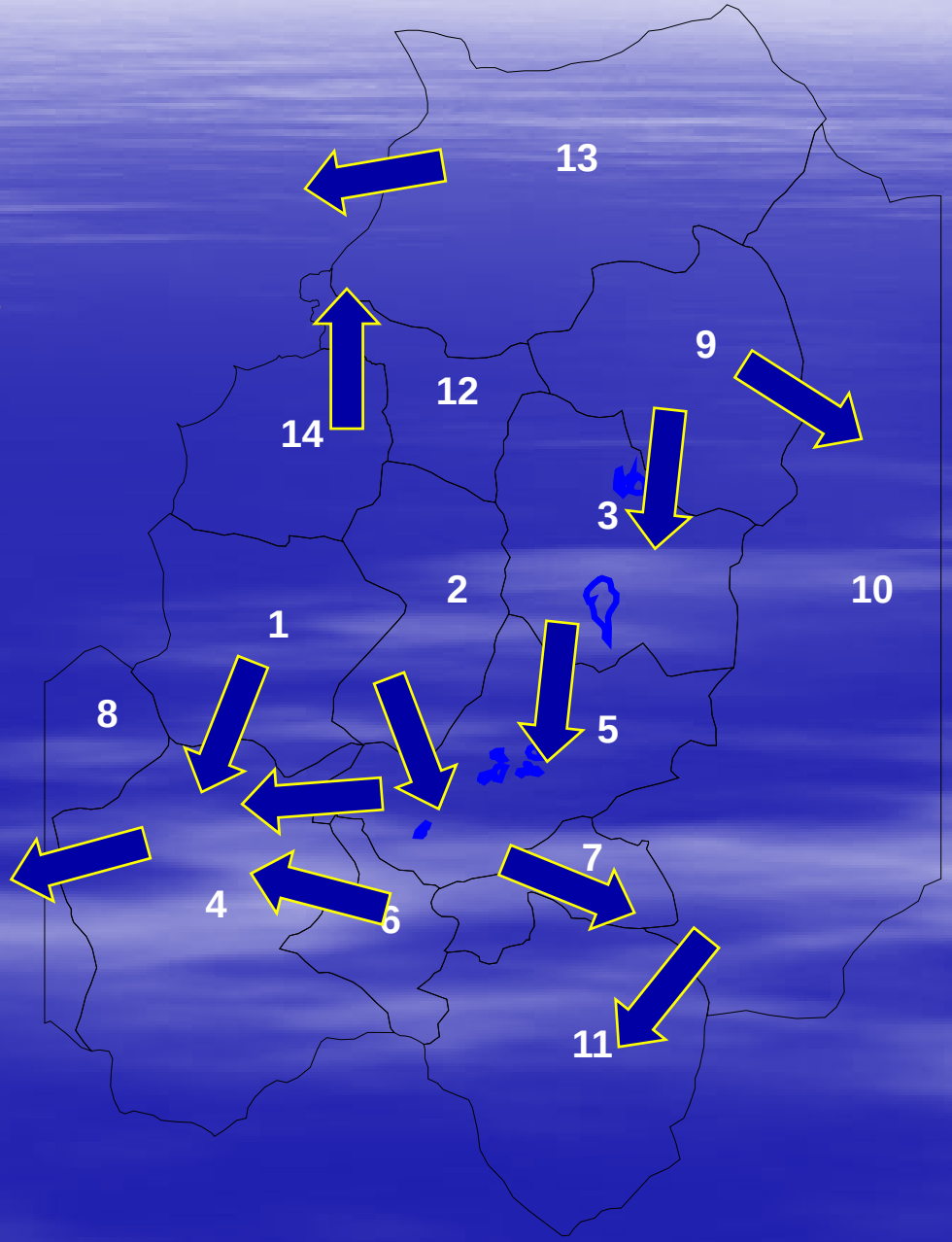
Groundwater Elevation Calibration Targets:

Layer 1, Overburden

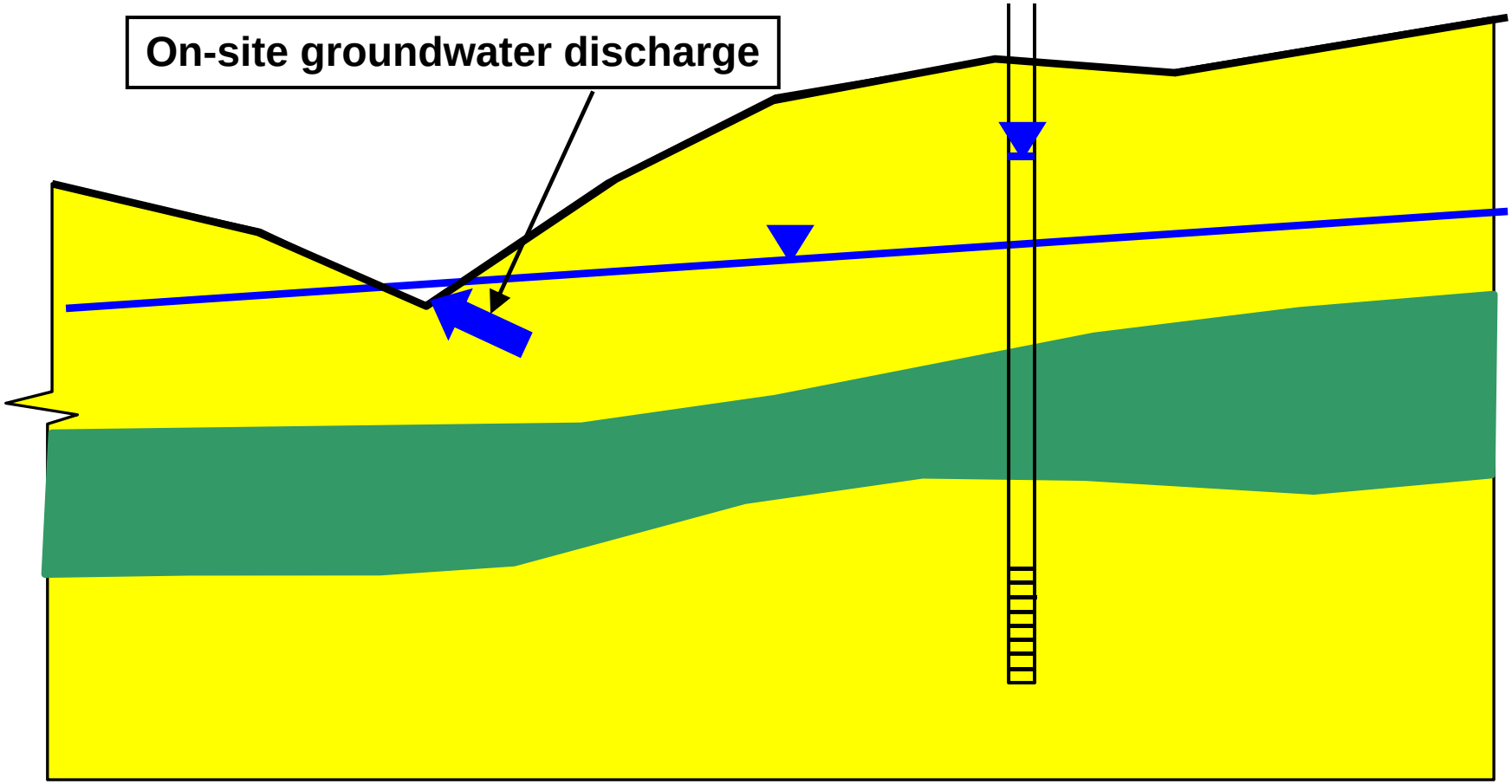


WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

Calibration targets: Off-site groundwater discharge



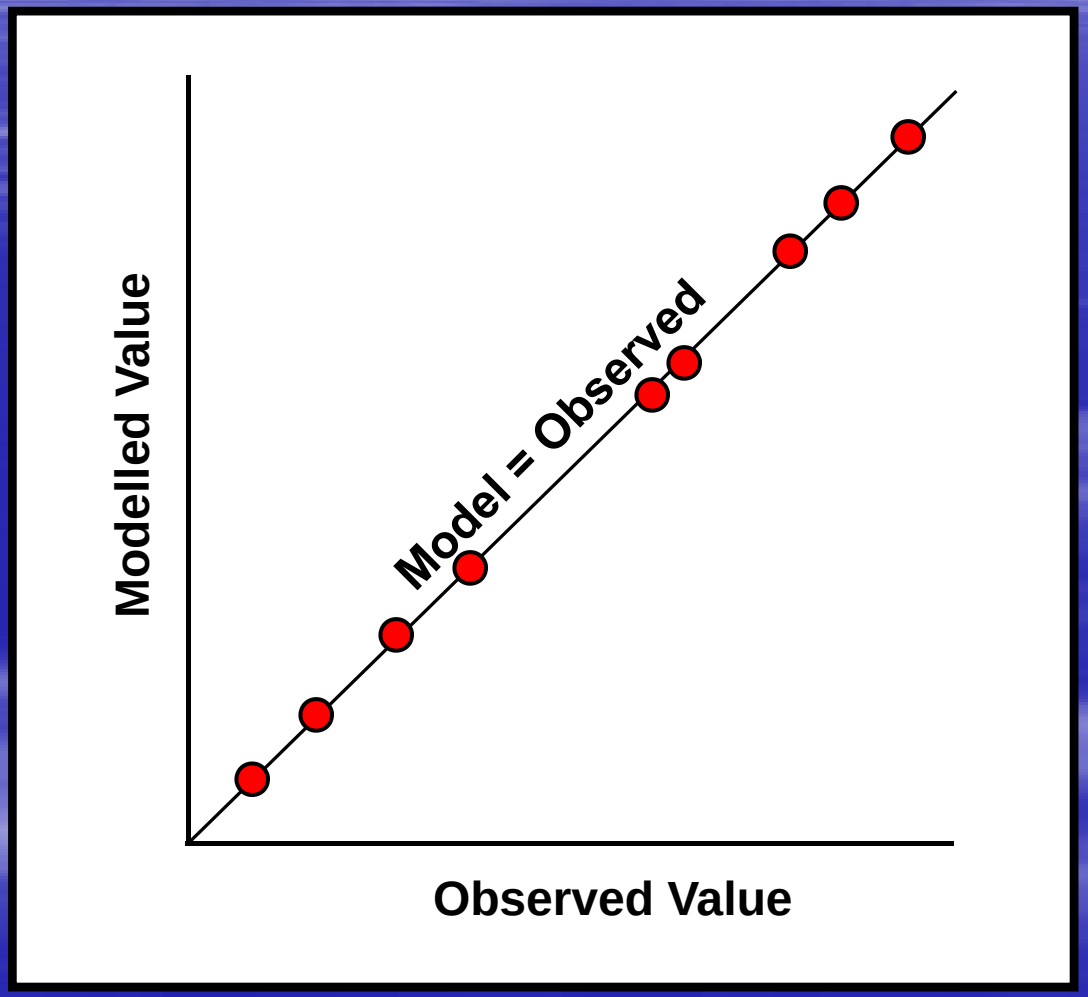
Calibration Targets: On-site groundwater discharge



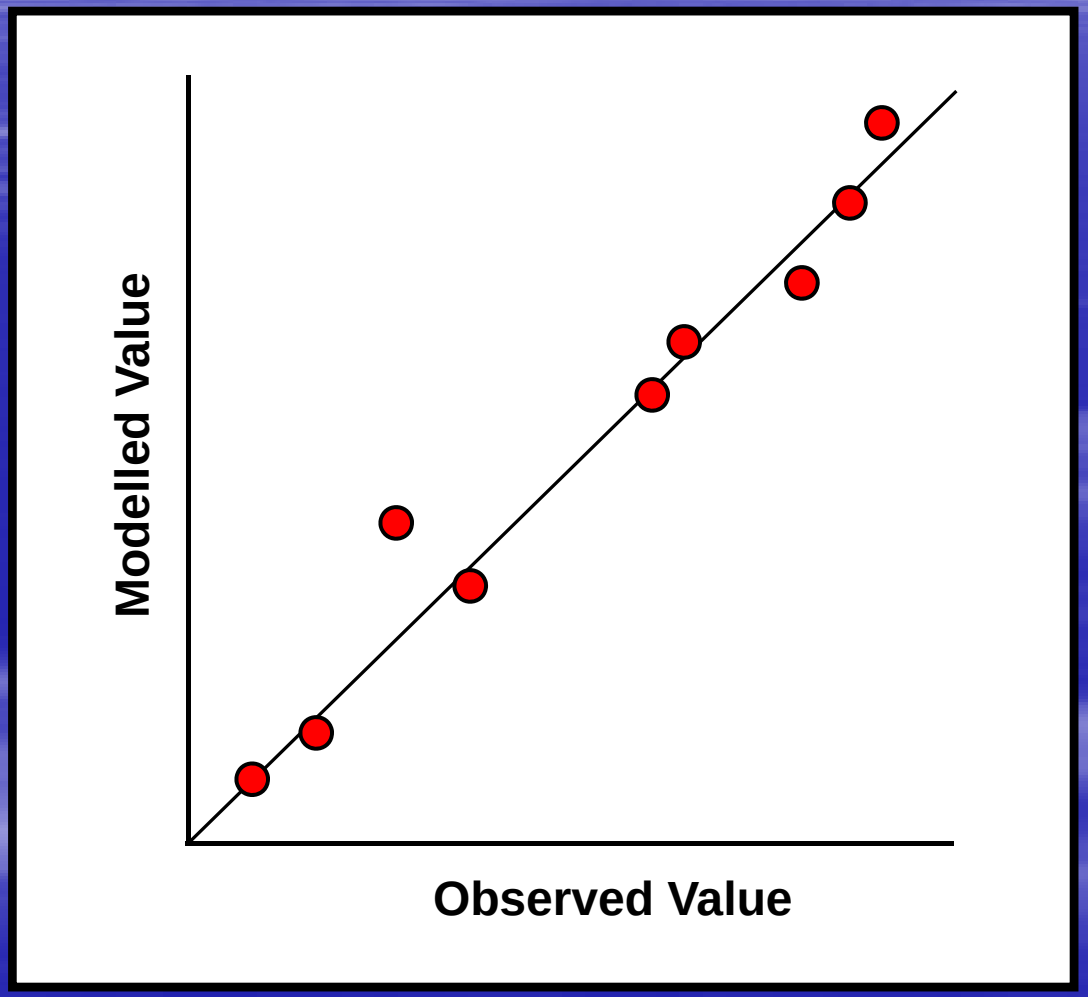
Calibration Targets: Summary

- >1,000 groundwater elevation measurements
- 144 off-site groundwater discharge estimates
- 144 on-site groundwater discharge estimates

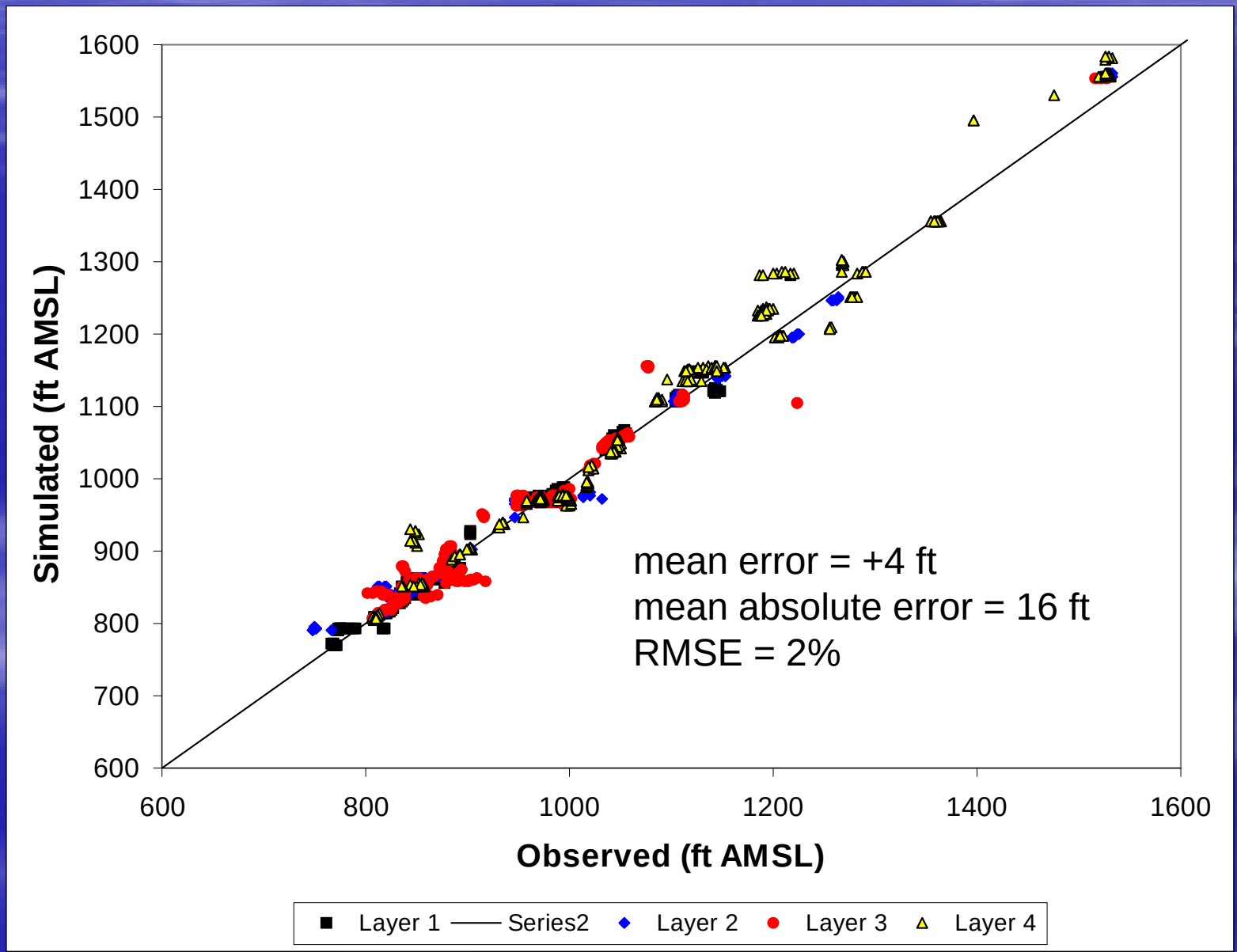
Perfect Calibration



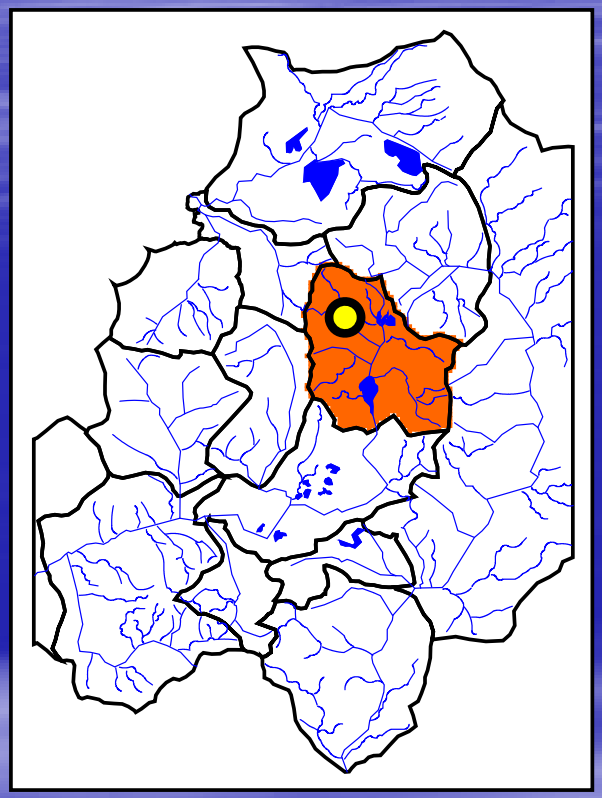
Normal Calibration

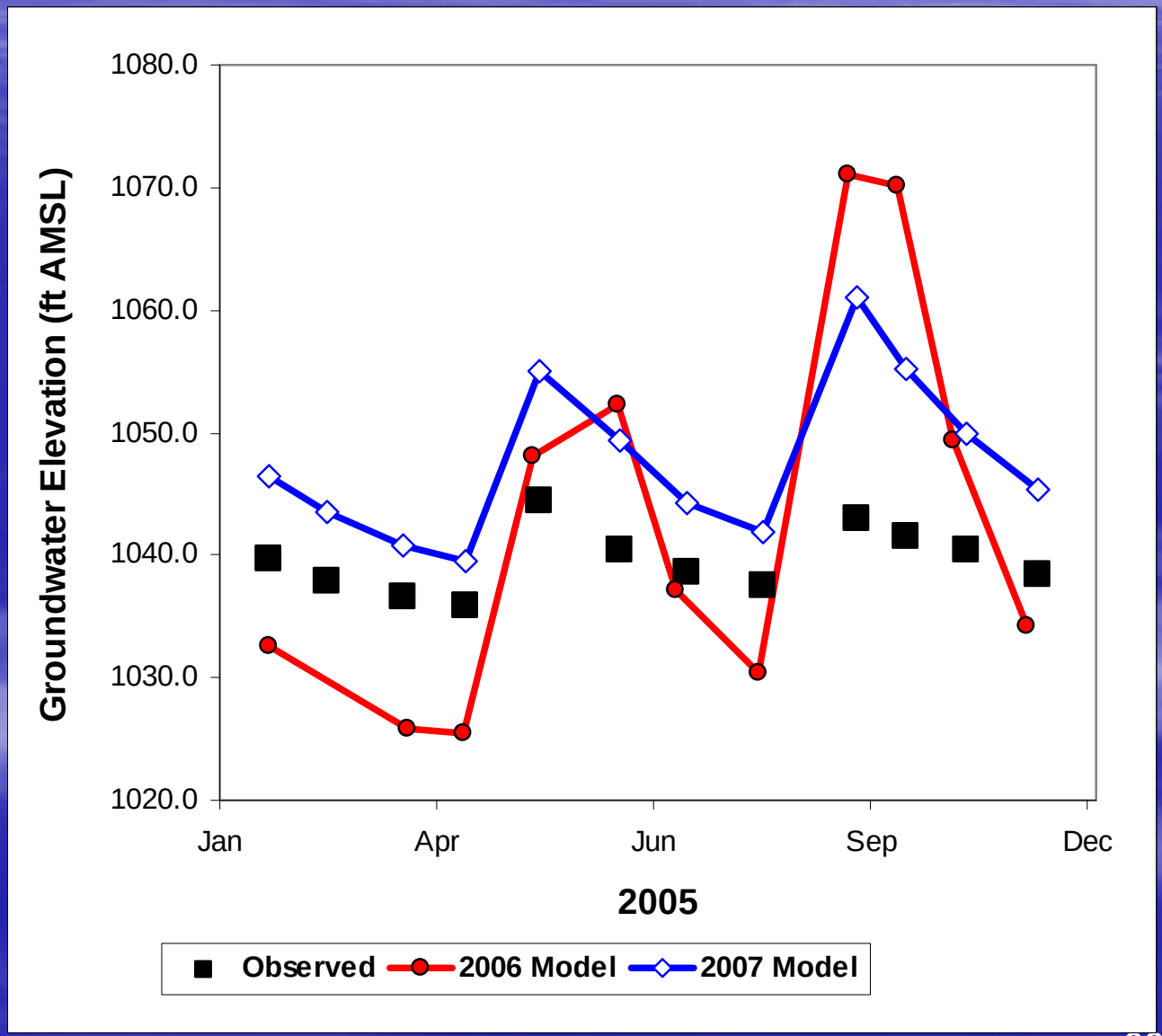


Head Calibration: Overburden and Bedrock All Areas

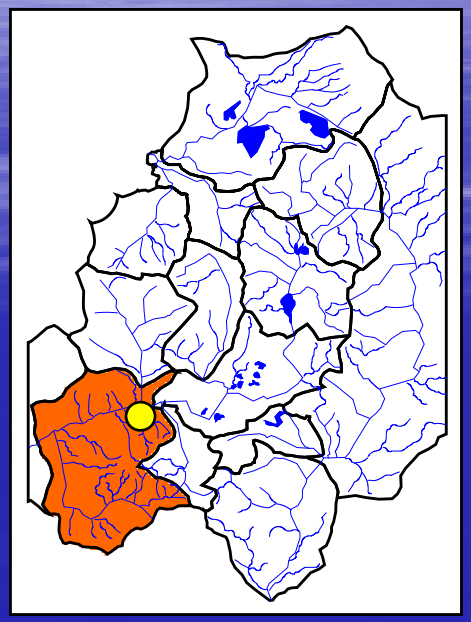


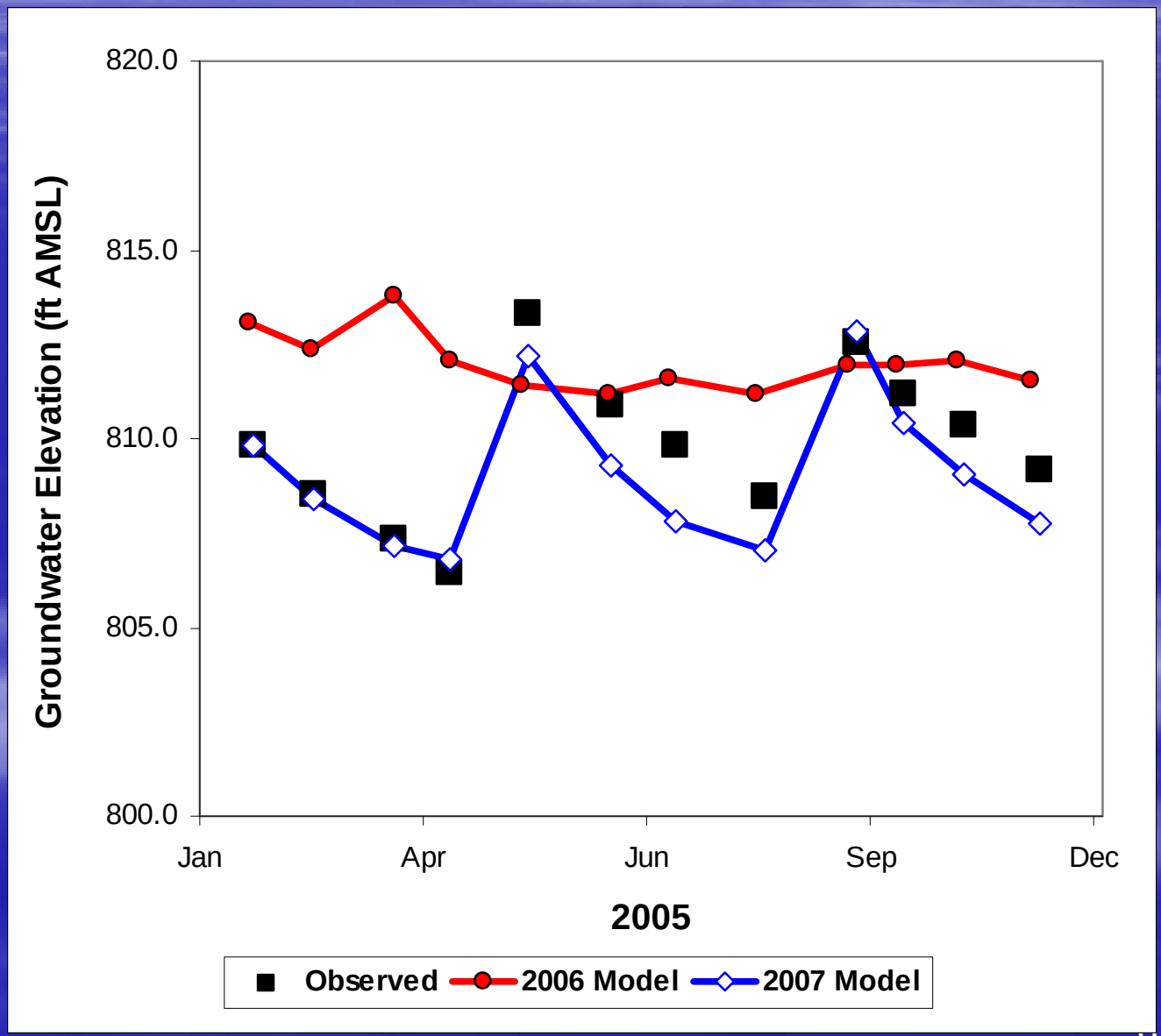
Head Calibration Time Series: KP-P3S (Area 3)





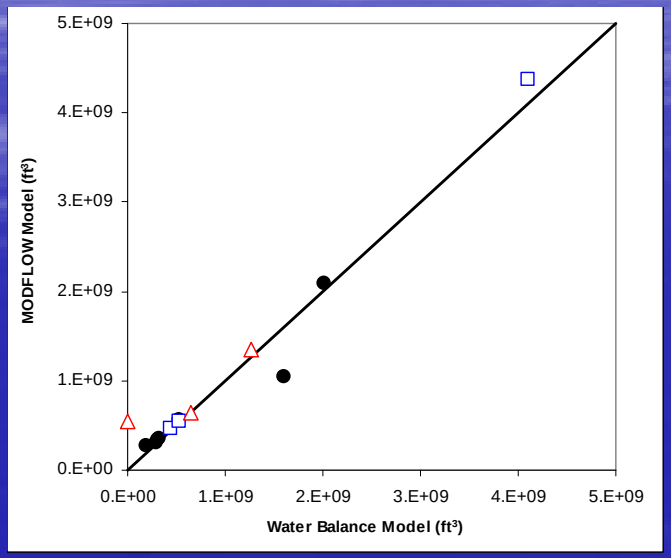
Head Calibration Time Series: MW-1S

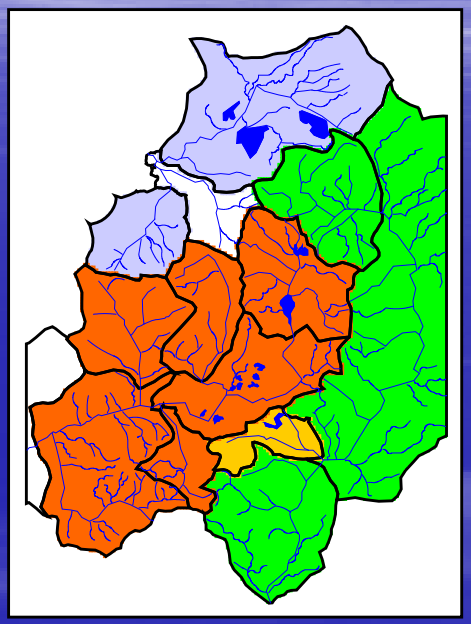




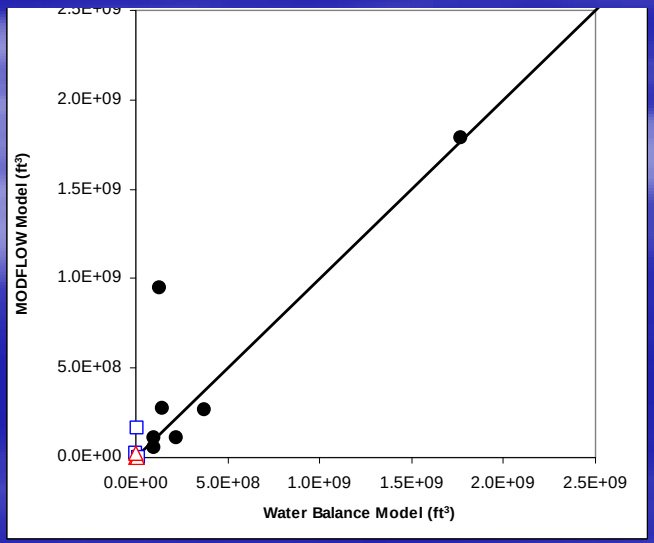
Flow Calibration (2007): Total Annual Flows

Recharge (ft^3)

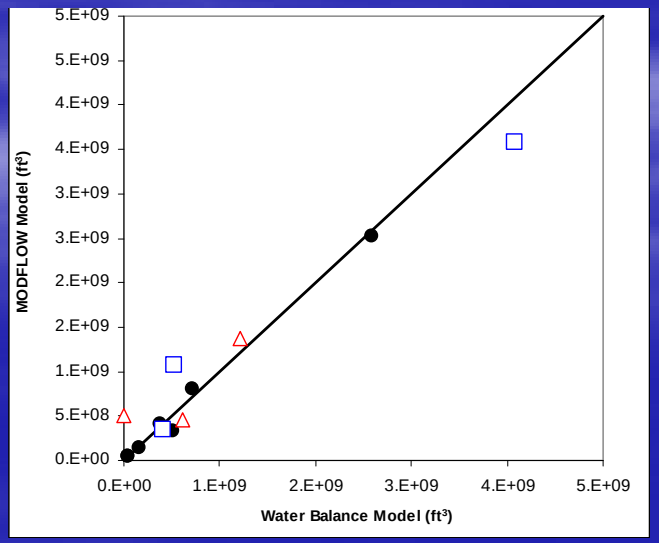




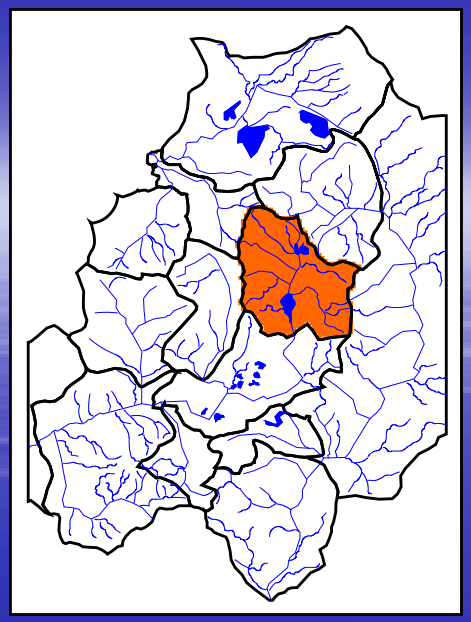
Discharge off site (ft^3)



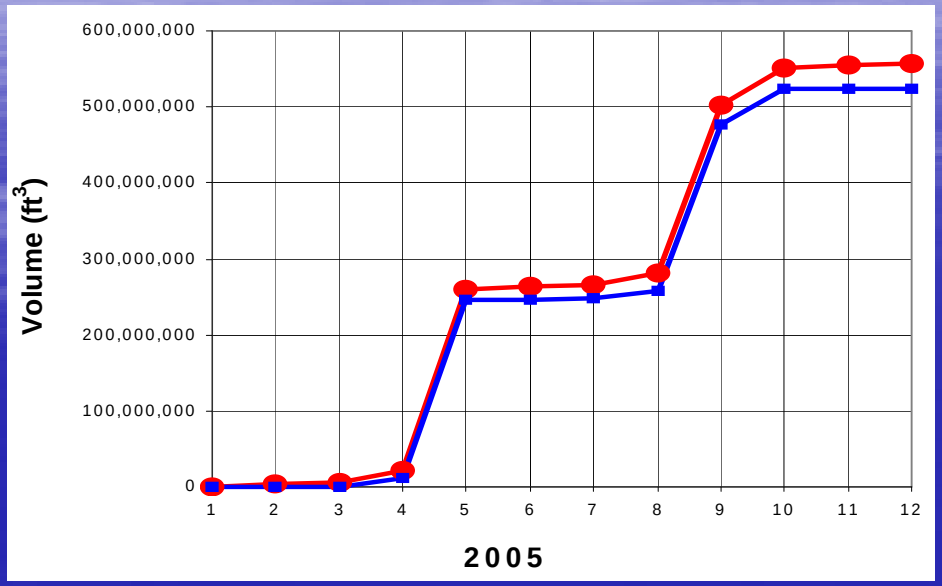
Discharge on site (ft^3)



Flow Calibration: Area 3



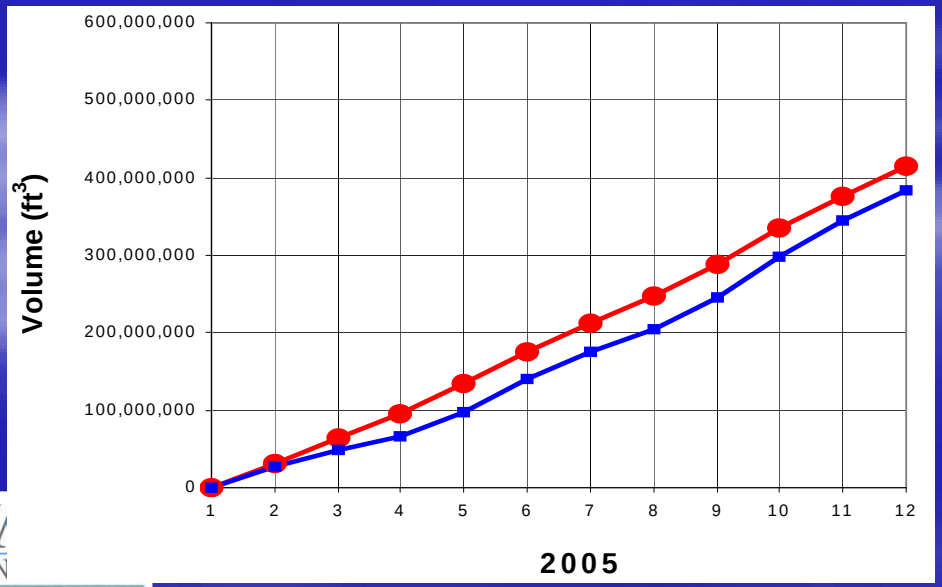
Recharge (ft^3/day)



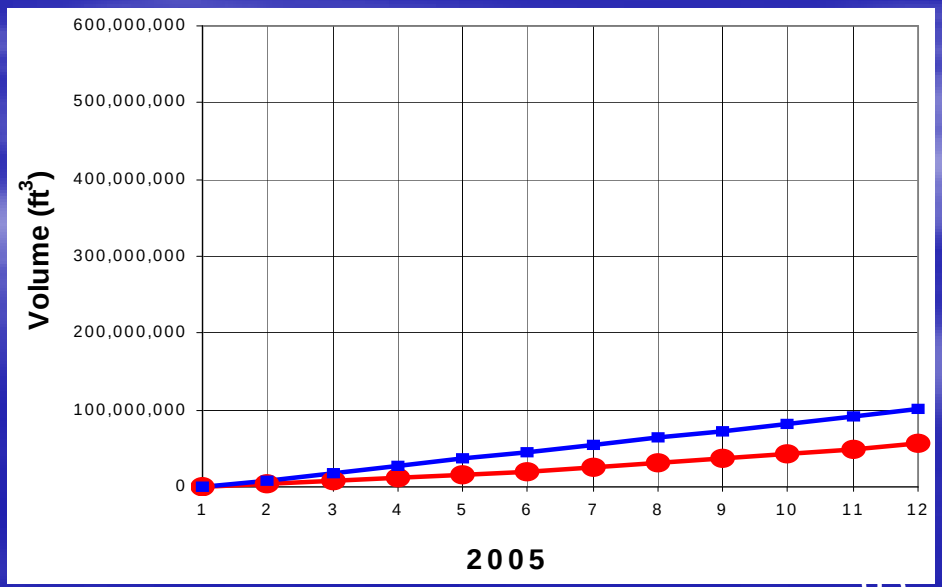
Water Balance Model

Groundwater Model

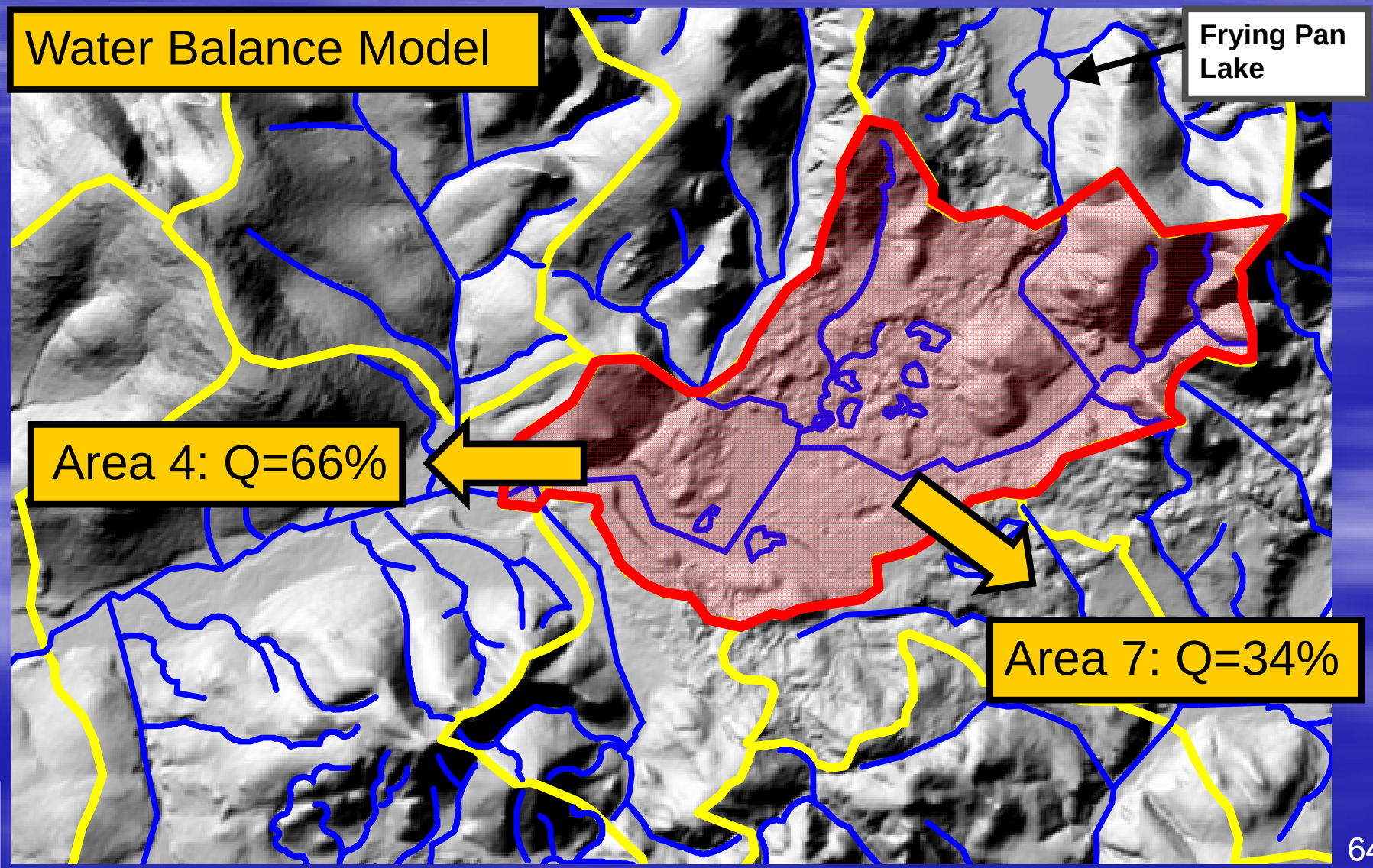
On-Site Discharge (ft^3/day)



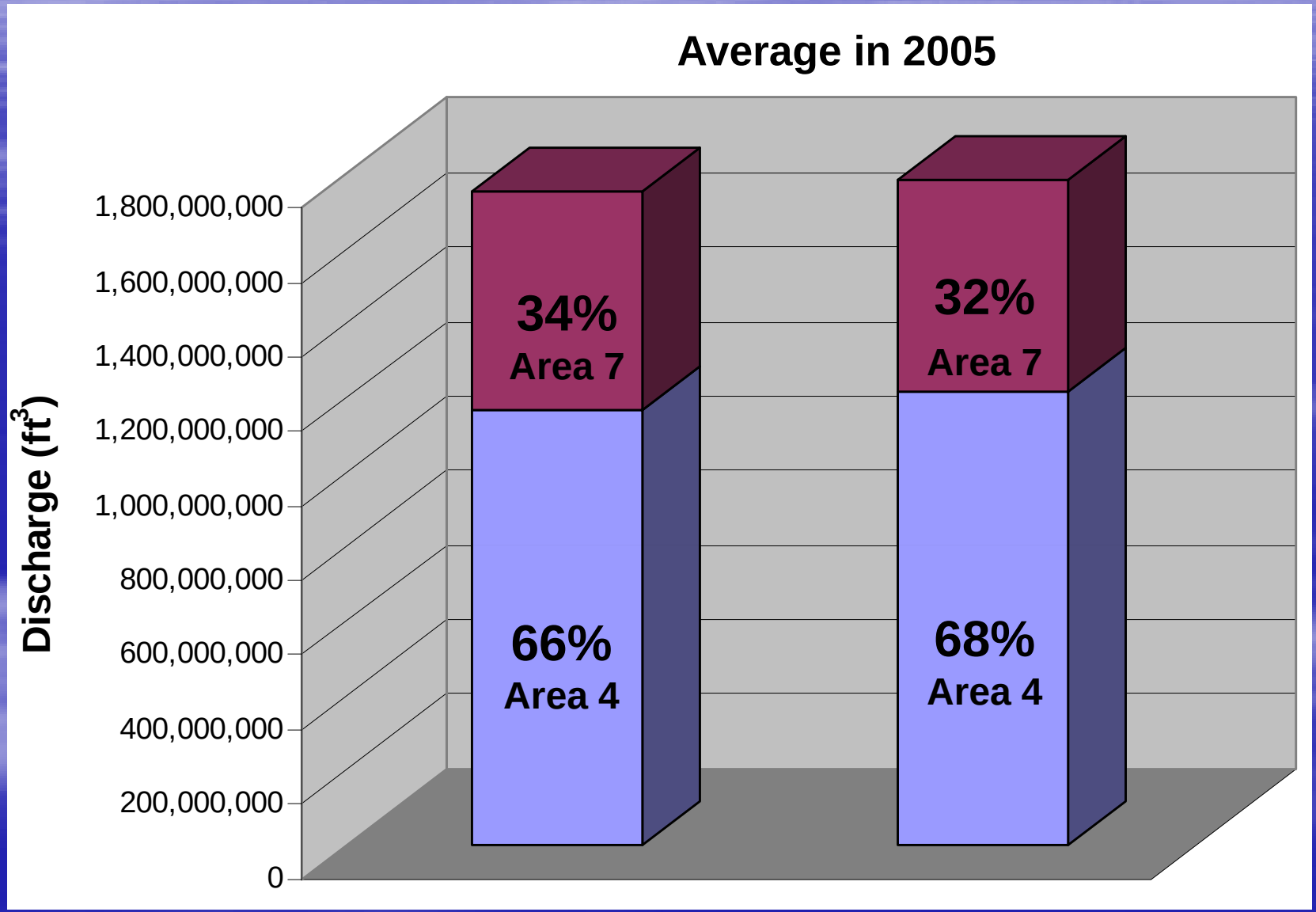
Off-Site Discharge (ft^3/day)



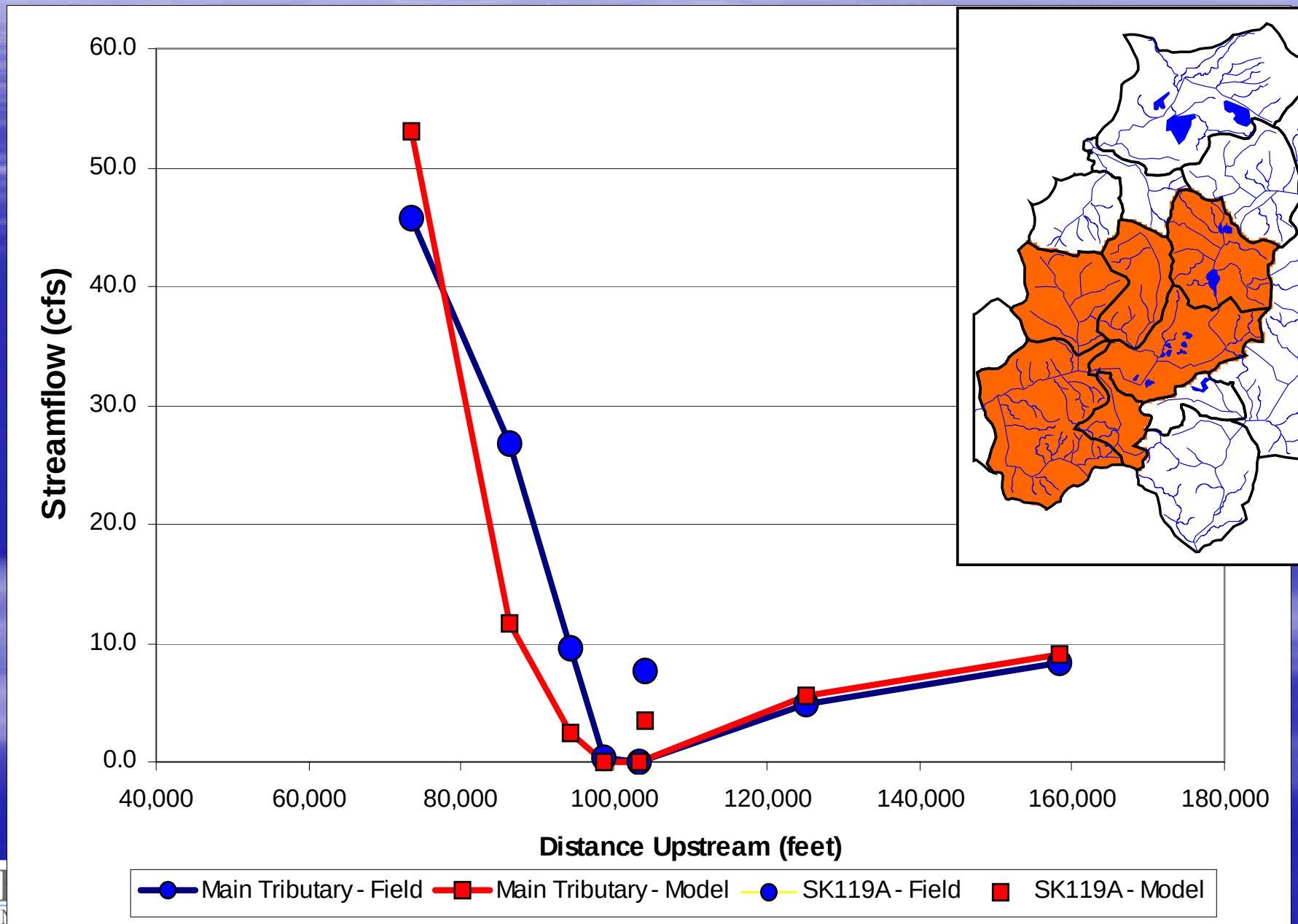
Area 5
Discharge to Area 4 vs. Area 7



Area 5 off-site discharge



Flow Calibration: SFK Low-Flow Streamflow

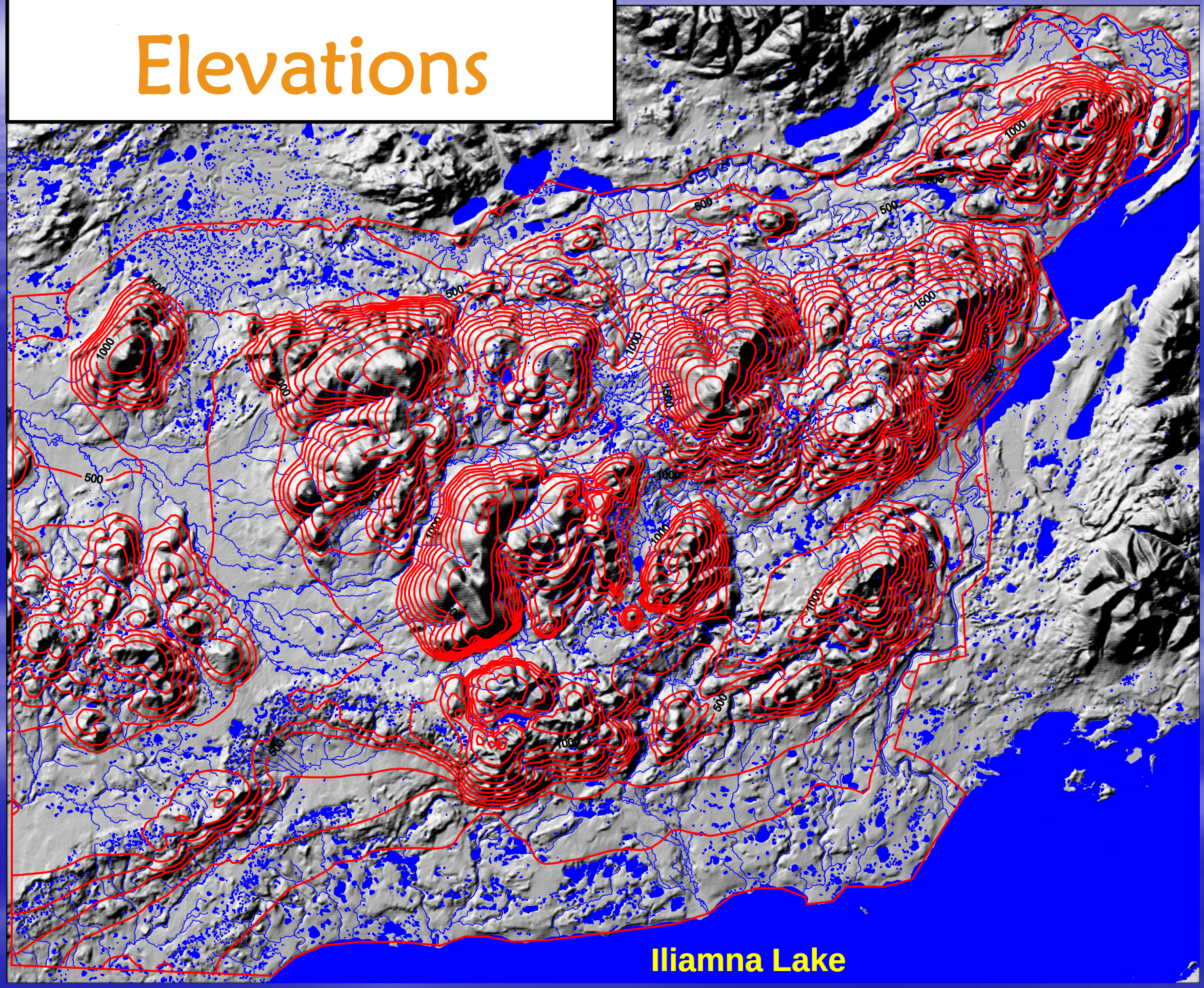


Model Output

- Groundwater Elevations
- Pathlines
- On-site groundwater discharge (discharge to rivers)

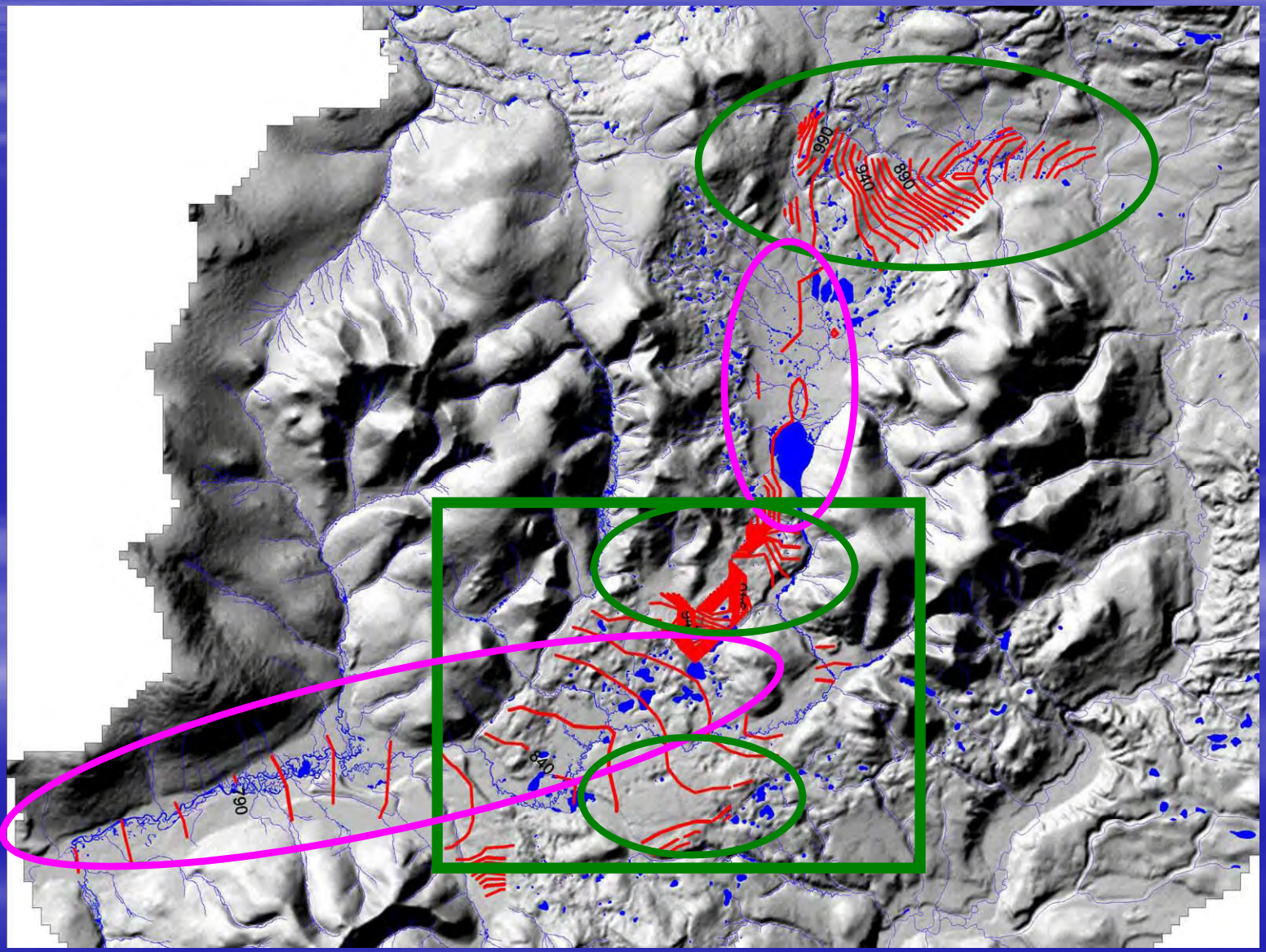
THE pebble PARTNERSHIP

Groundwater Elevations

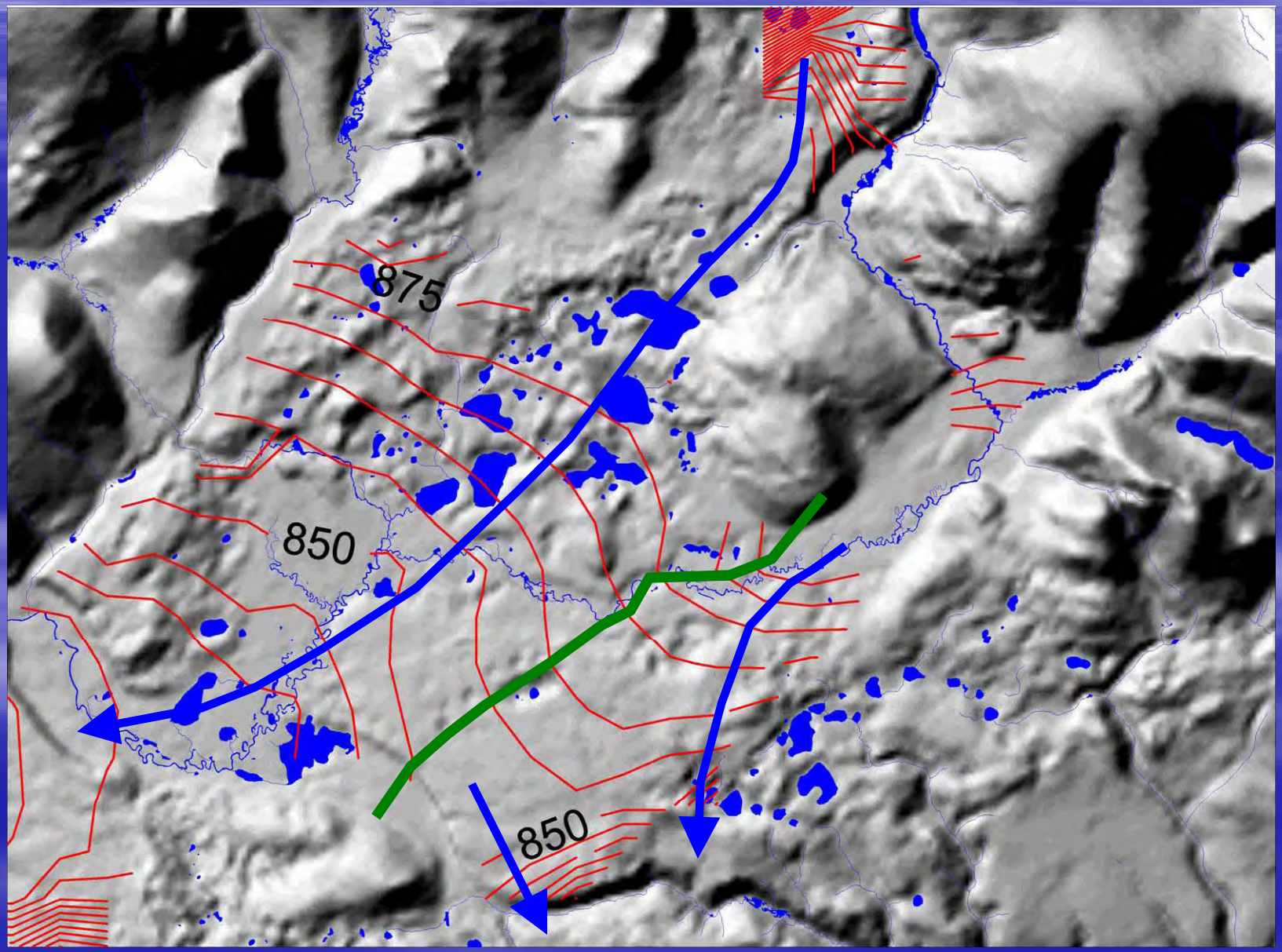


WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

Groundwater Elevations: South Fork Koktuli

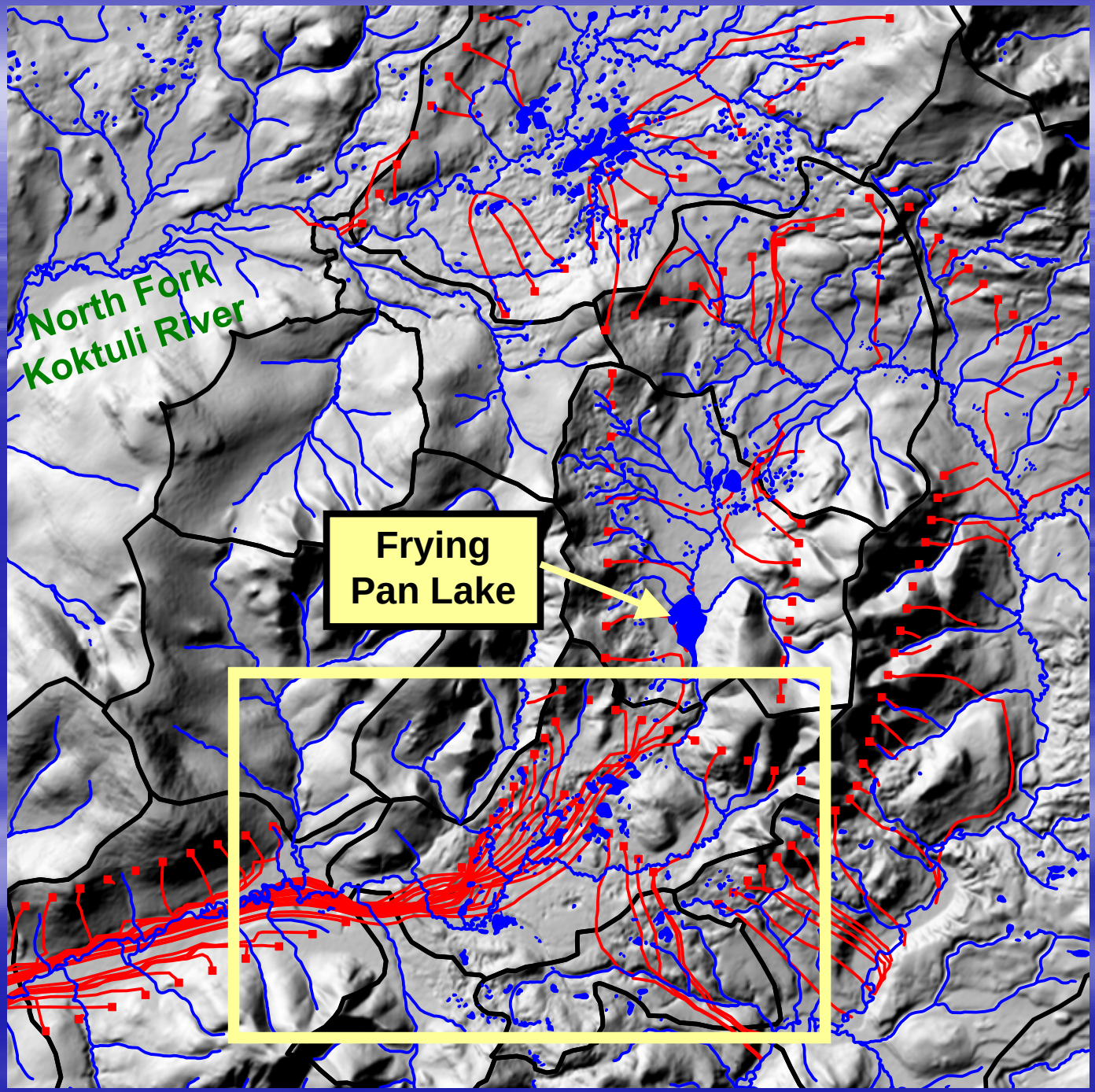


Groundwater Elevations: Groundwater Divide to UT1.190



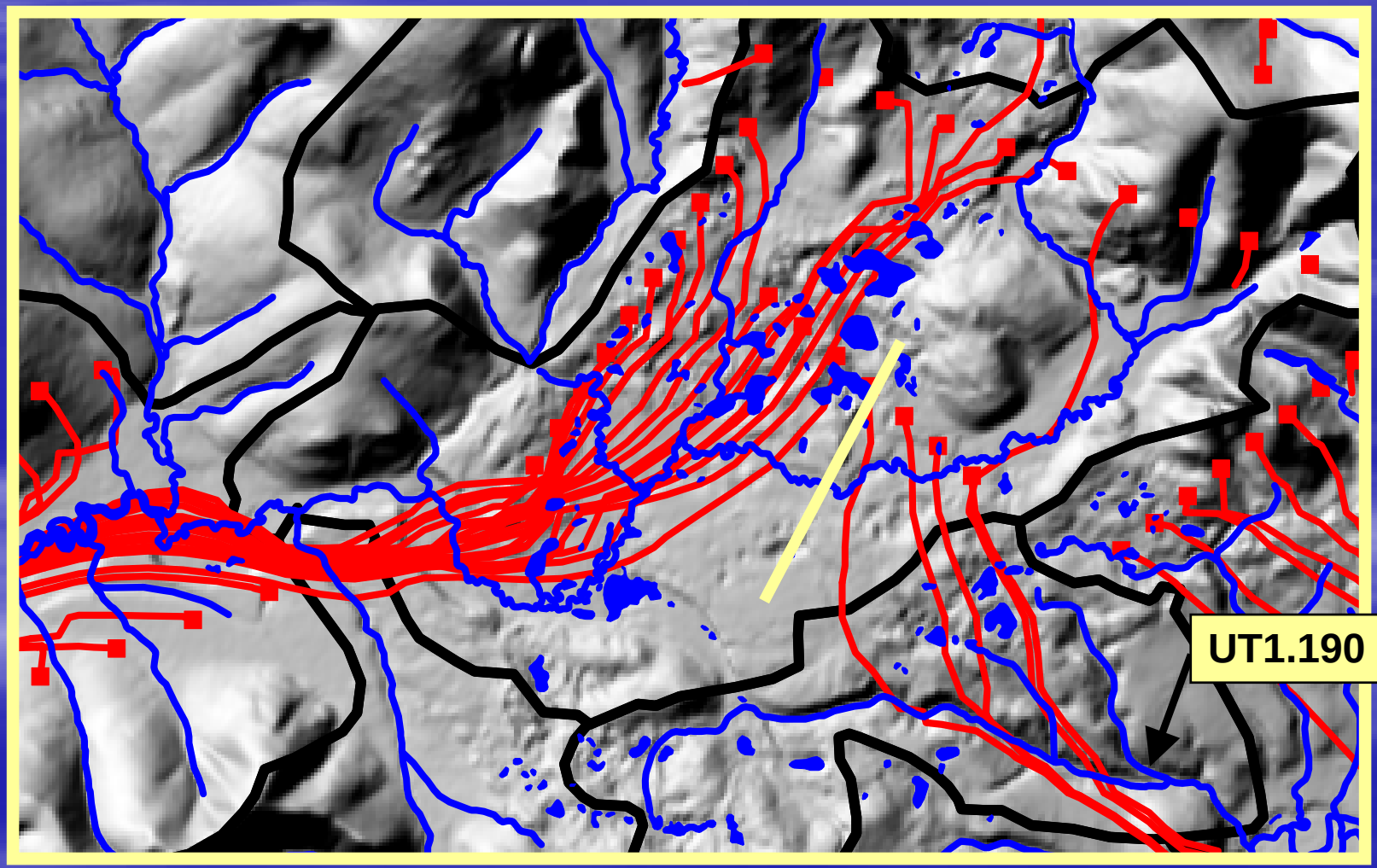
THE pebble PARTNERSHIP

Pathlines

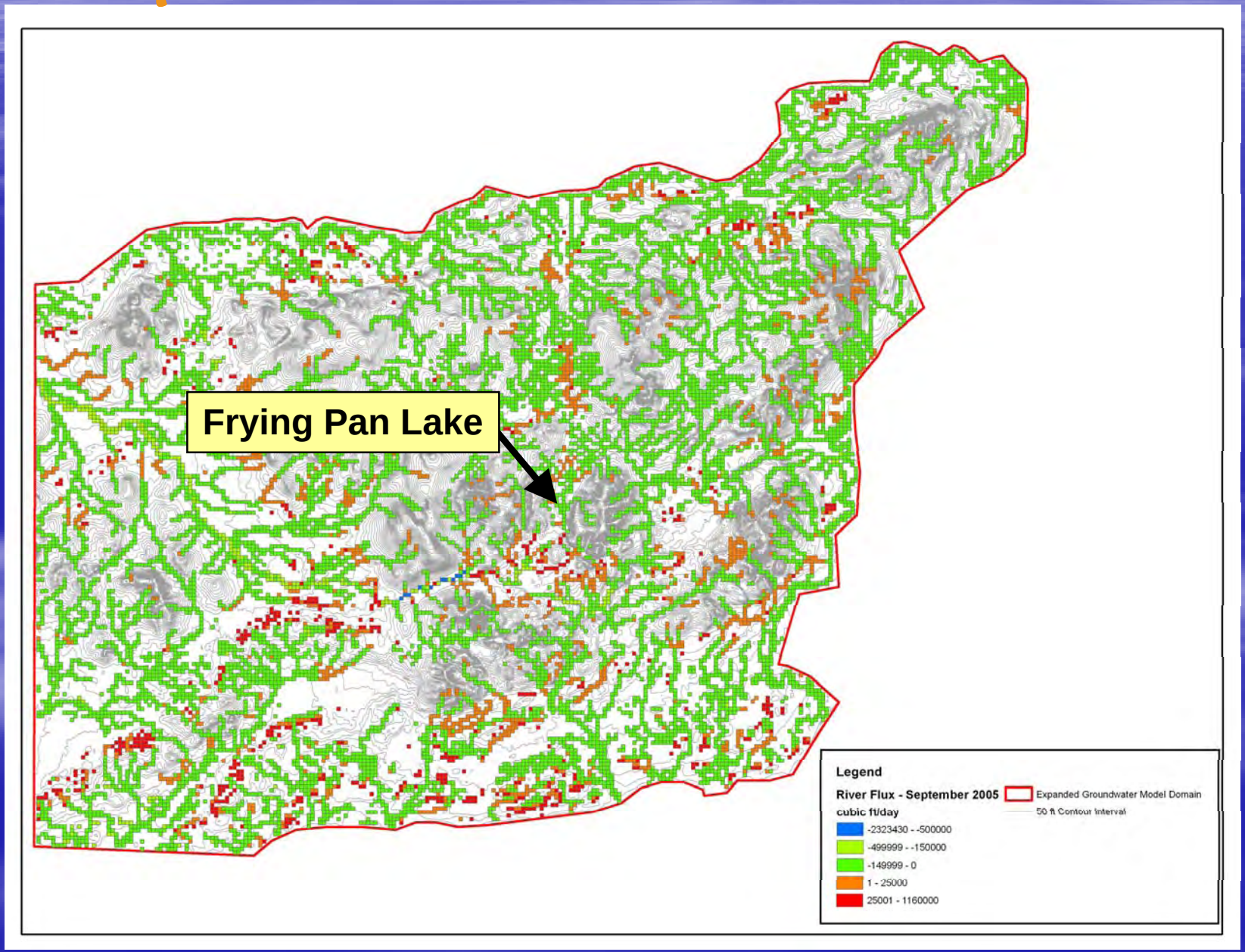


WATER MANAGEMENT CONSULTANTS
A Schlumberger Company

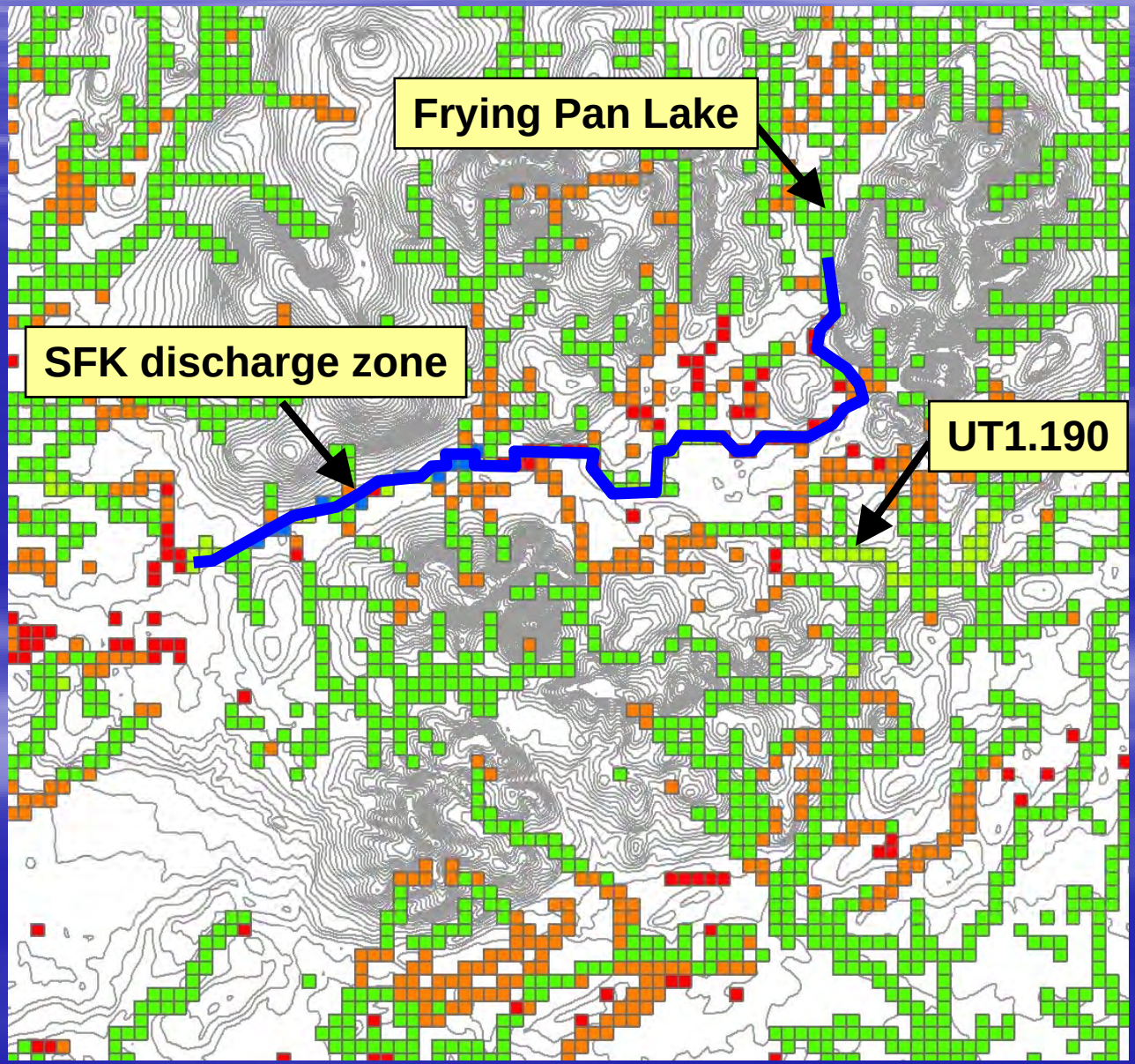
Pathlines: Divide to UT1.190 (Area 7)



Simulated discharge to rivers: Sept 05



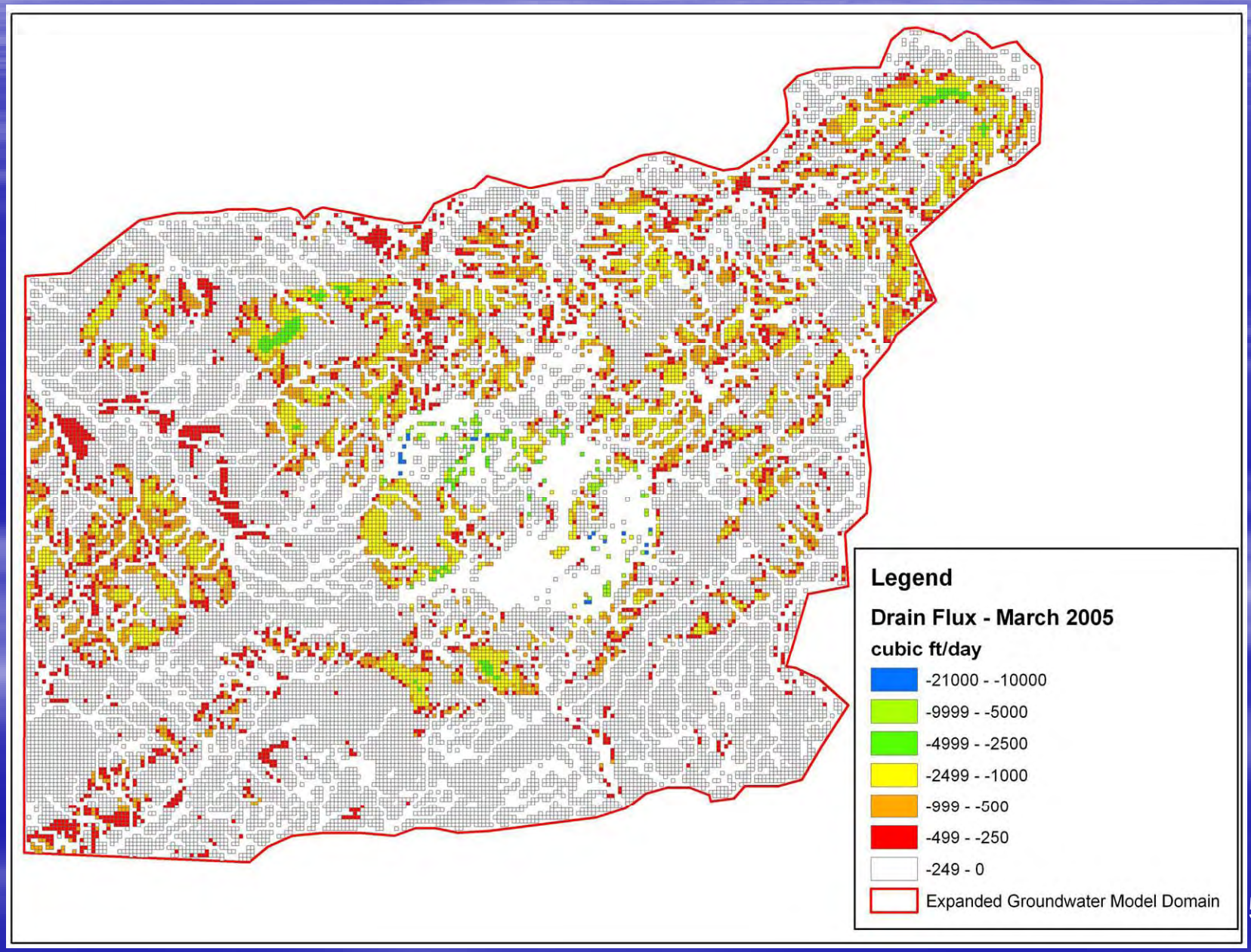
Simulated discharge to rivers: Sept 05 (SFK)



Legend

- Strong Discharge
- Moderate Discharge
- Moderate Recharge
- Strong Recharge

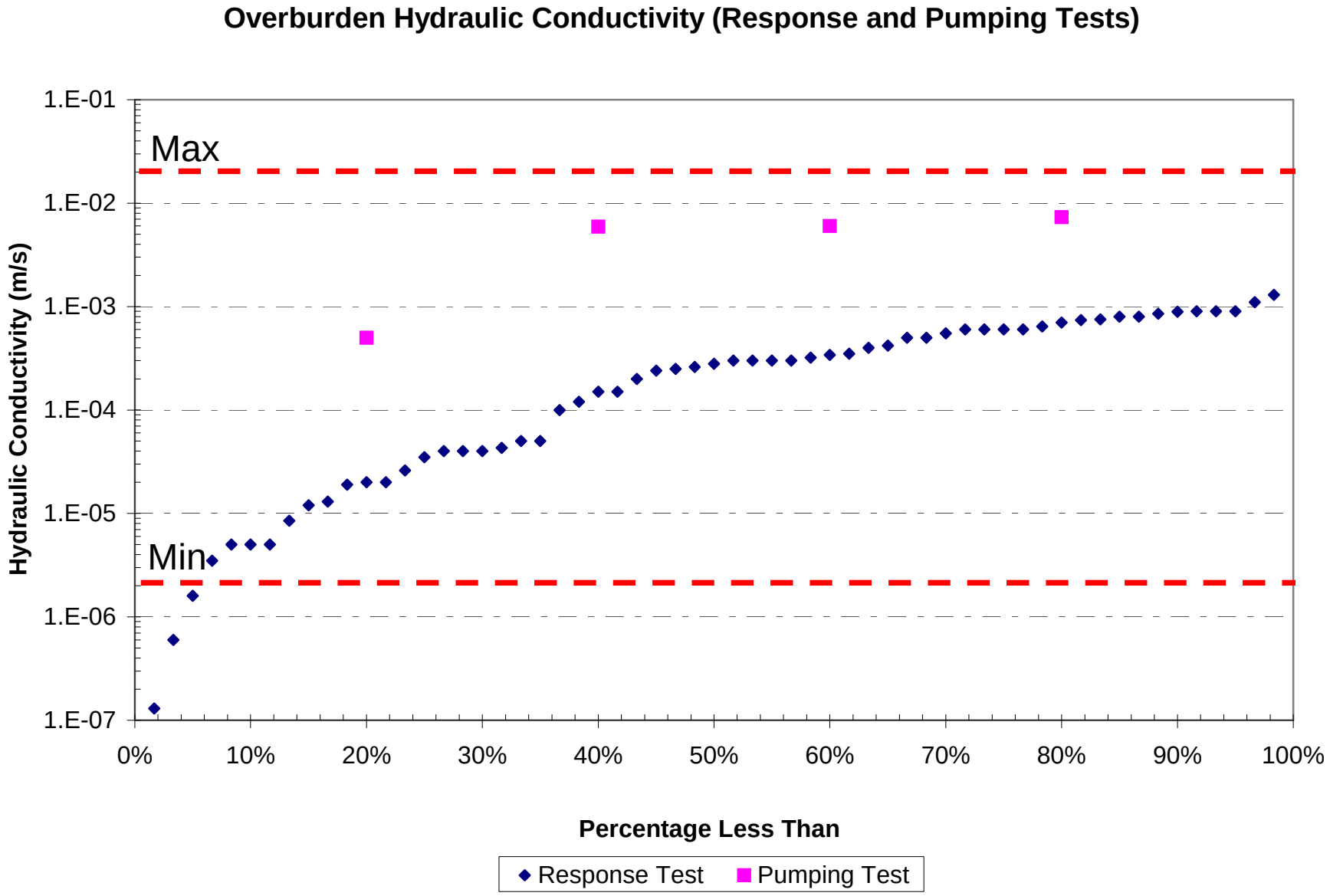
Simulated discharge to seeps: March 05



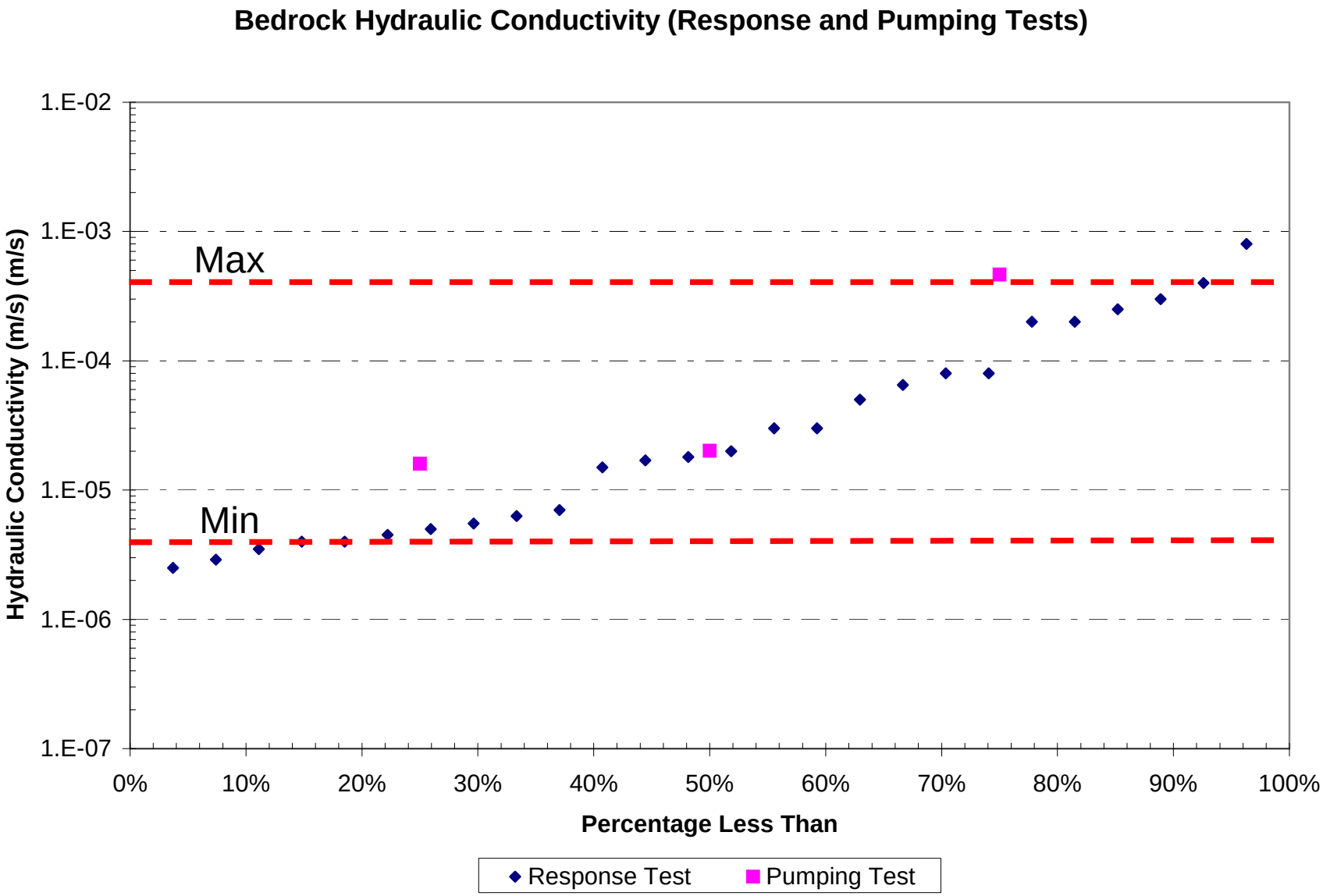
Agenda

1. Modelling Objectives
2. Conceptual Model
3. Integrated Modelling Approach
4. Input Parameters
5. Calibration Process
6. Model Assessment
7. Summary
8. Where we go from here!

Model Parameters vs. Field Measurements: Overburden



Model Parameters vs. Field Measurements: Bedrock



Agenda

1. Modelling Objectives
2. Conceptual Model
3. Integrated Modelling Approach
4. Input Parameters
5. Calibration Process
6. Model Assessment
7. Summary
8. Where we go from here!

Where we go from here

- Improve head calibration while maintaining flow calibration
- More iterations between groundwater model and water balance
- Simulate pumping tests
- Uncertainty analysis
- Data collection
  - Investigations in new areas


Questions …