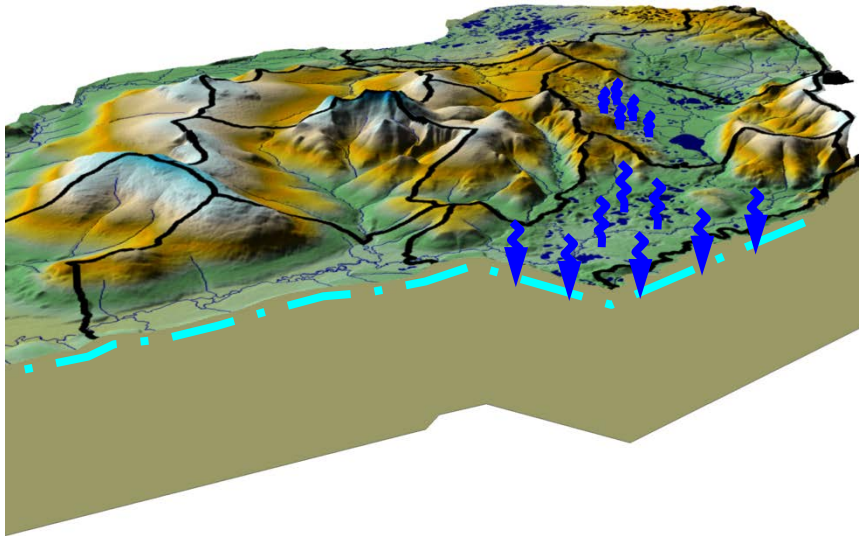


Groundwater Flow Model



Agency Meeting
January 31 – February 3, 2012

Hugh McCreadie (Piteau Associates)
Rengina Rahman (SWS)

Acknowledgements

- Rengina Rahman, Schlumberger Water Services

Agenda

1. Modeling Objectives
2. Conceptual Model
3. Integrated Modeling Approach
4. Calibration Process
5. Summary

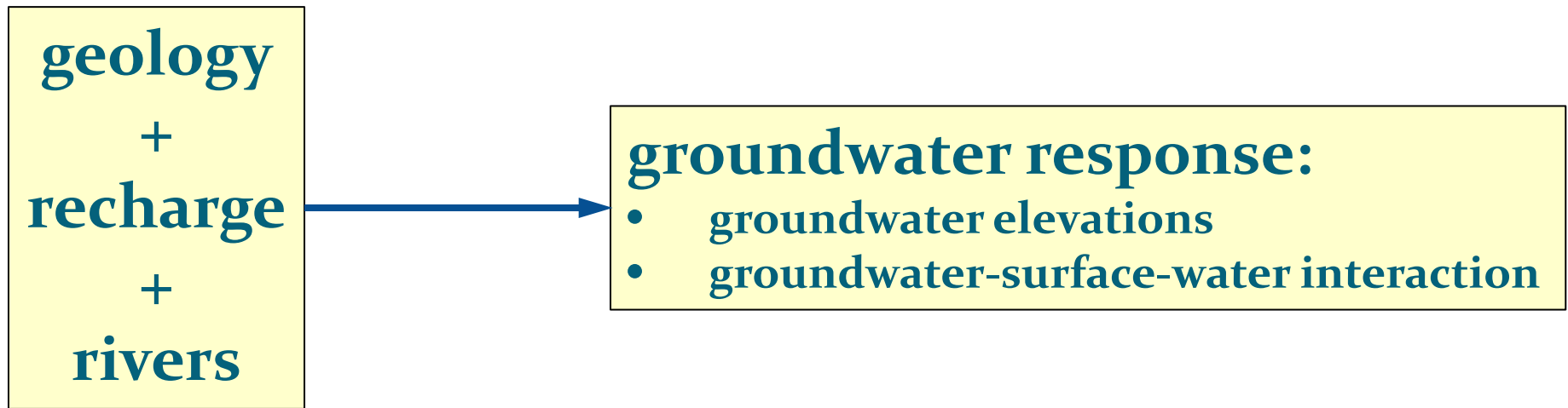
Objective of Modeling for EBD

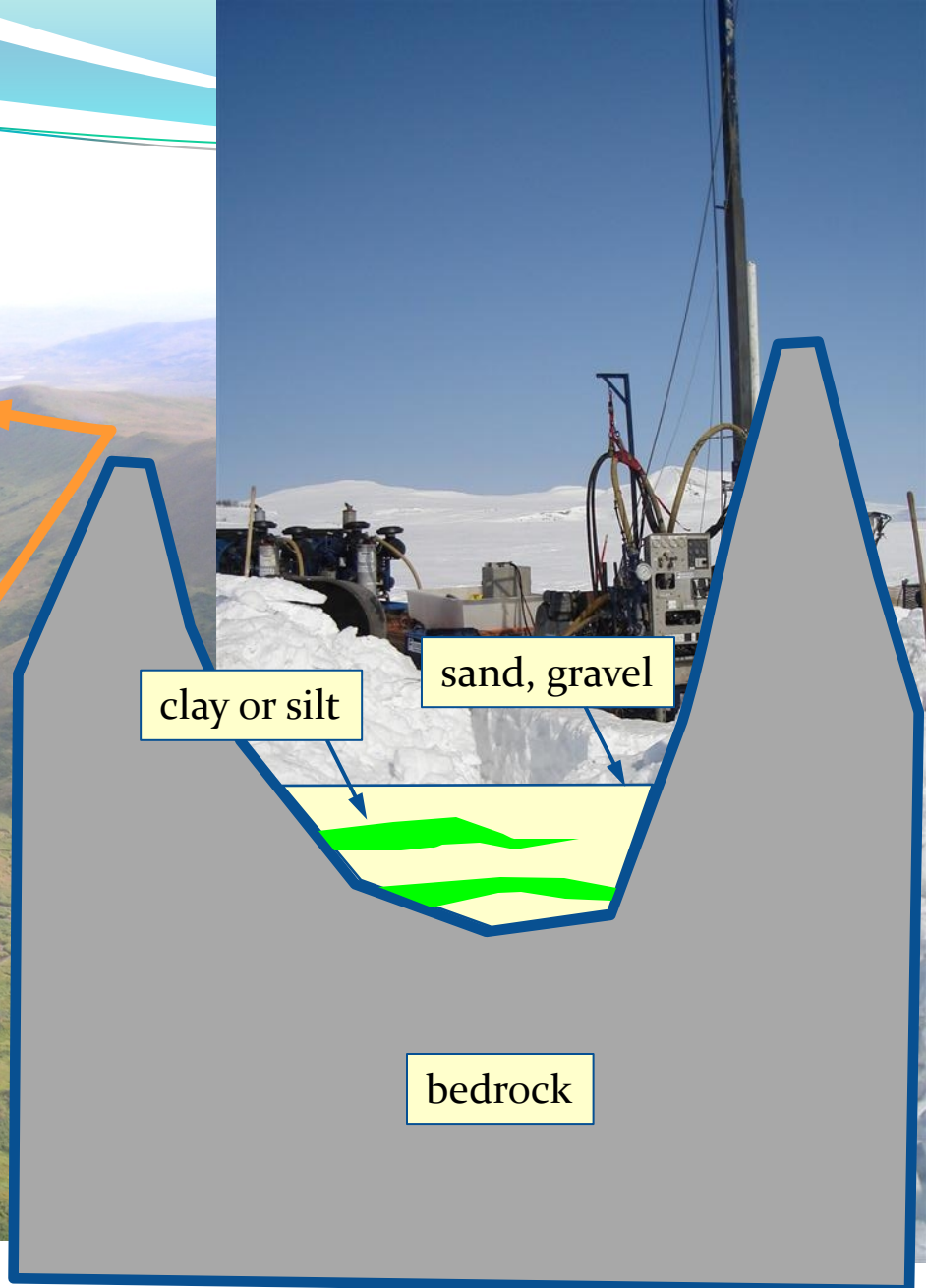
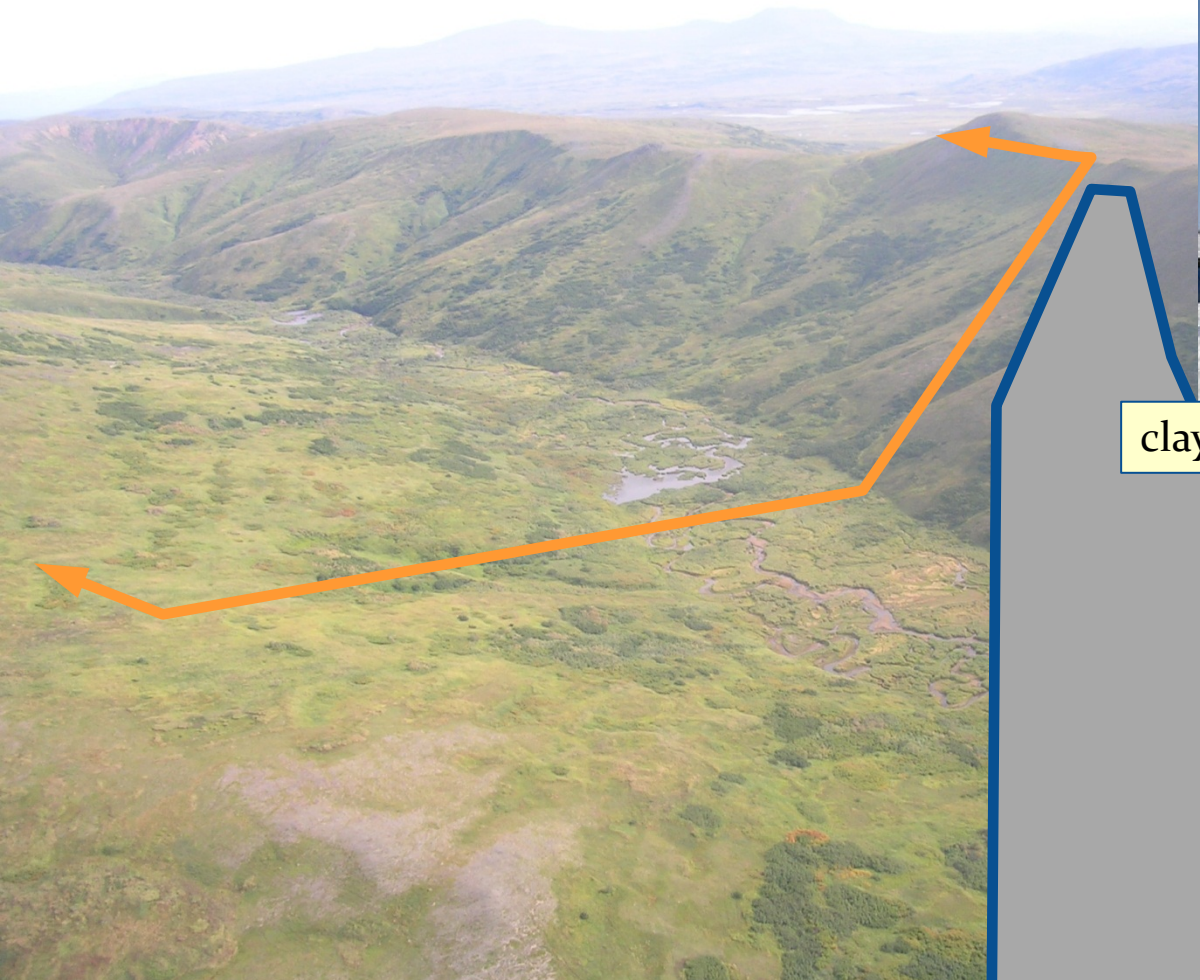
- Develop a model that simulates baseline conditions

Agenda

1. Modeling Objectives
2. Conceptual Model
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4. Calibration Process
5. Summary

What are we trying to represent with the model?

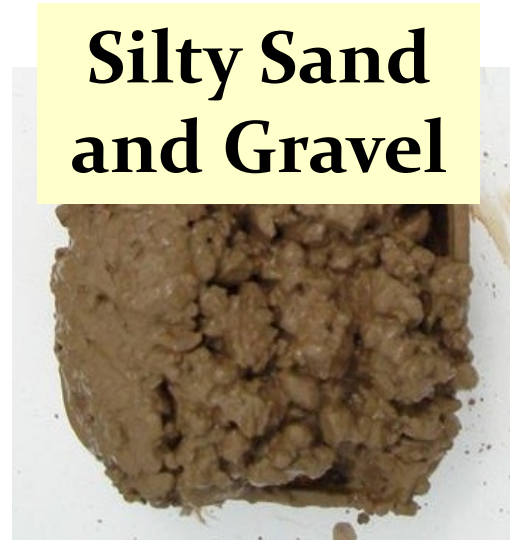




Geologic Materials



Fractured Bedrock



**Silty Sand
and Gravel**



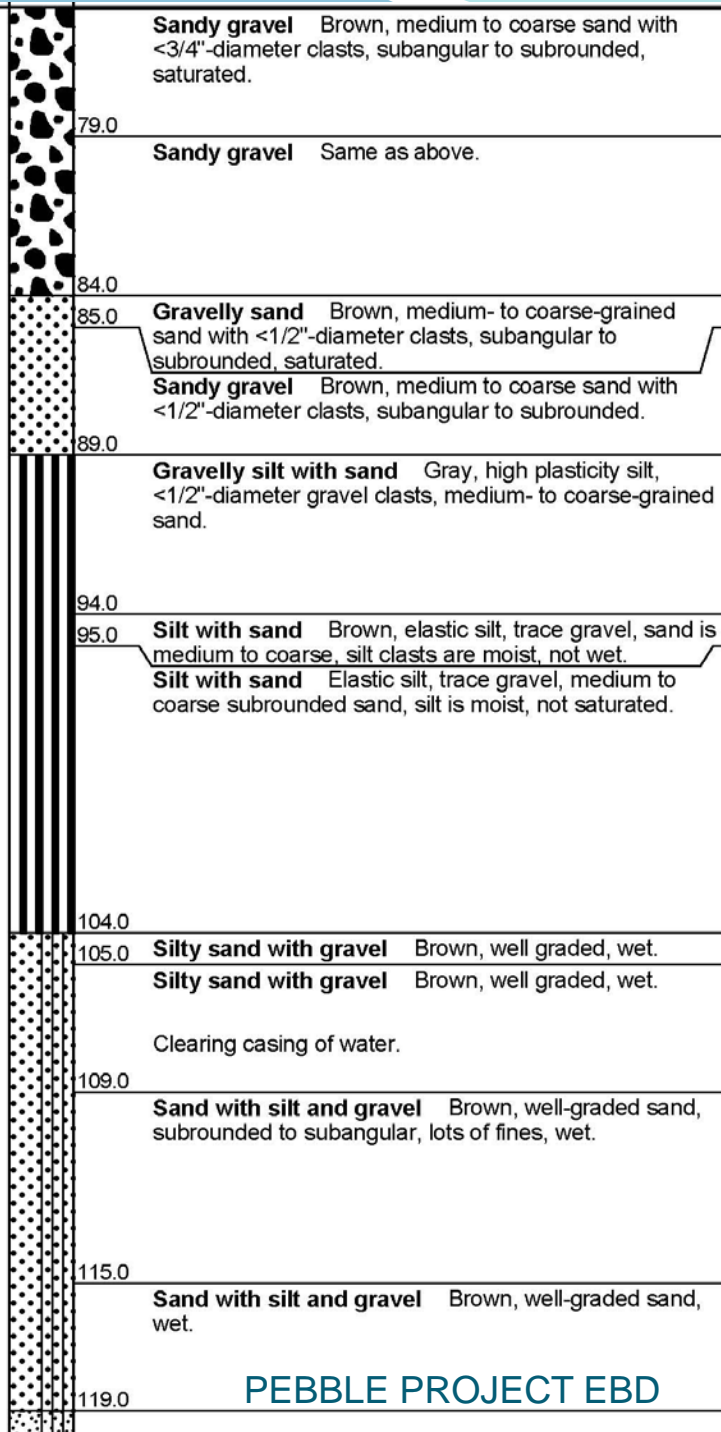
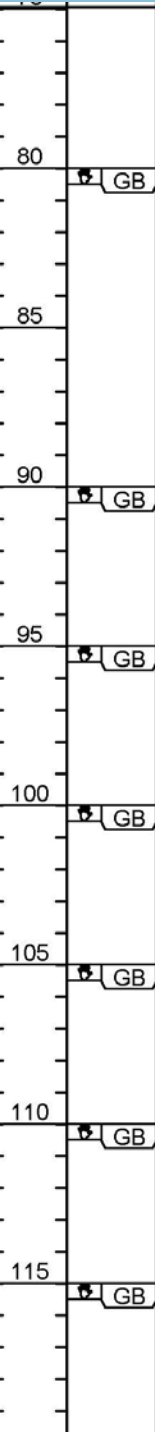
Sand



Competent Bedrock



PEBBLE2.GPJ PEBBLE2.GPJ 5/30/06



Sandy gravel Brown, medium to coarse sand with <3/4"-diameter clasts, subangular to subrounded, saturated.

79.0

Sandy gravel Same as above.

84.0

Gravelly sand Brown, medium- to coarse-grained sand with <1/2"-diameter clasts, subangular to subrounded, saturated.

Sandy gravel Brown, medium to coarse sand with <1/2"-diameter clasts, subangular to subrounded.

89.0

Gravelly silt with sand Gray, high plasticity silt, <1/2"-diameter gravel clasts, medium- to coarse-grained sand.

94.0

Silt with sand Brown, elastic silt, trace gravel, sand is medium to coarse, silt clasts are moist, not wet.

Silt with sand Elastic silt, trace gravel, medium to coarse subrounded sand, silt is moist, not saturated.

104.0

Silty sand with gravel Brown, well graded, wet.

Silty sand with gravel Brown, well graded, wet.

Clearing casing of water.

109.0

Sand with silt and gravel Brown, well-graded sand, subrounded to subangular, lots of fines, wet.

115.0

Sand with silt and gravel Brown, well-graded sand, wet.

119.0

PEBBLE PROJECT EBD

Geology Drill hole log

293 logs

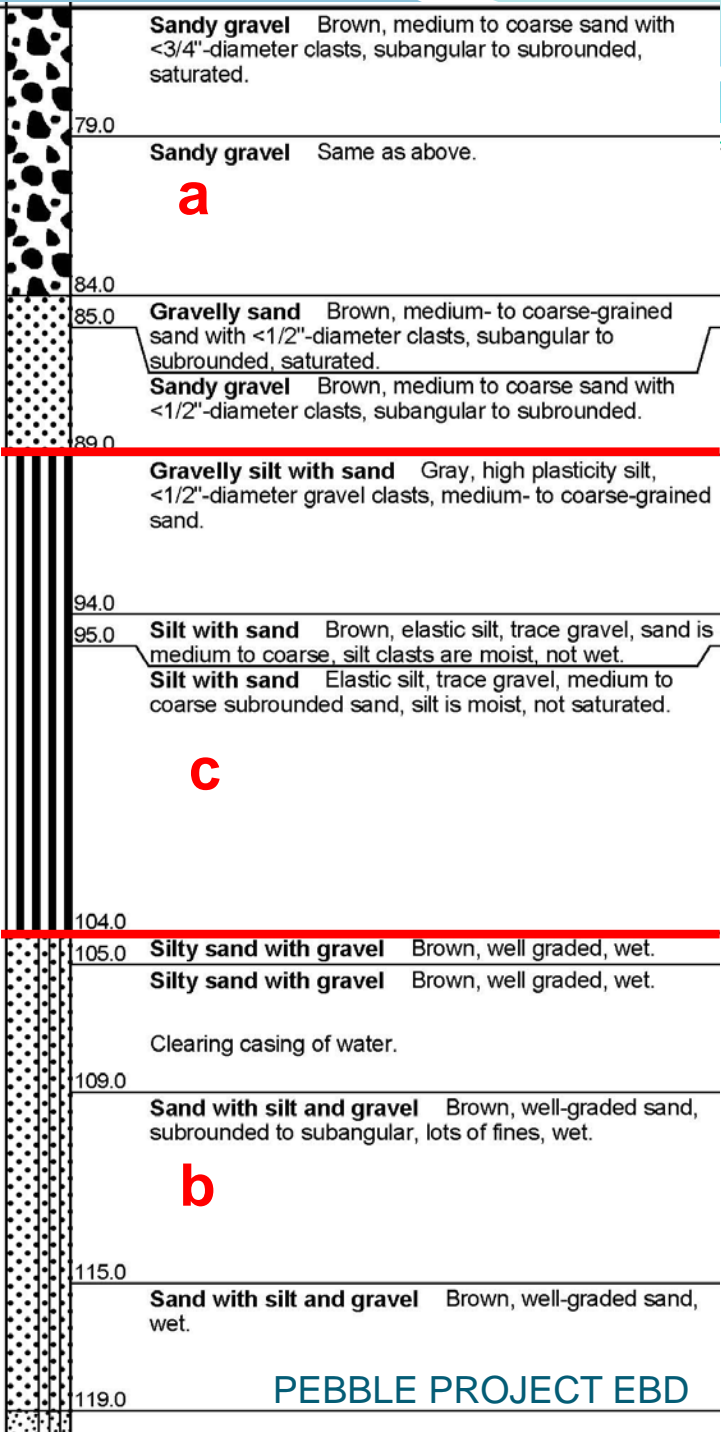
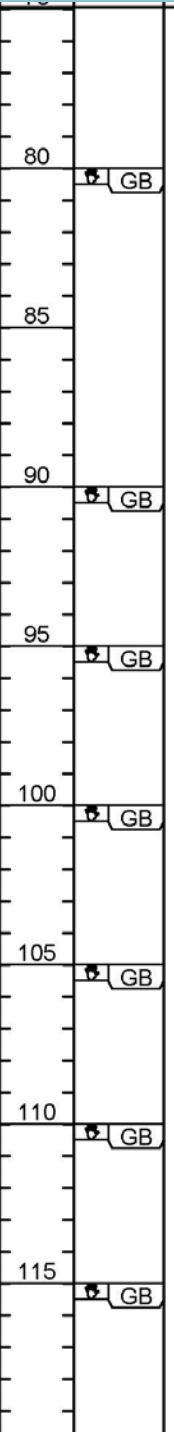


Geology simplification

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



IASTY_PEBBLE2.GPJ_PEBBLE2.GPJ 5/30/06



a

c

b

Geology

Drill hole log

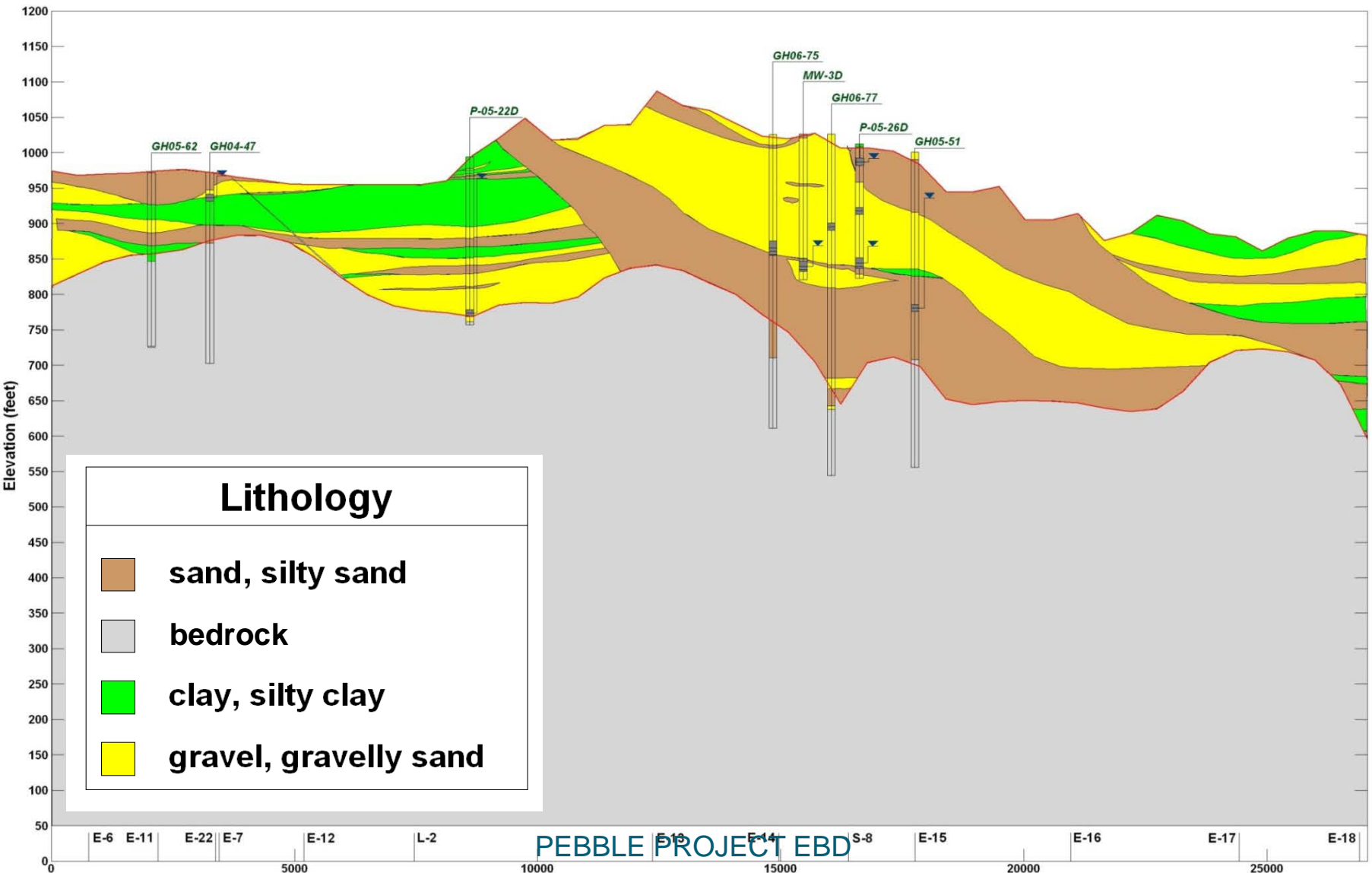
with classifications

Geologic Interpretation

NNE

Section L-1 Looking ESE

SSW



Lithology

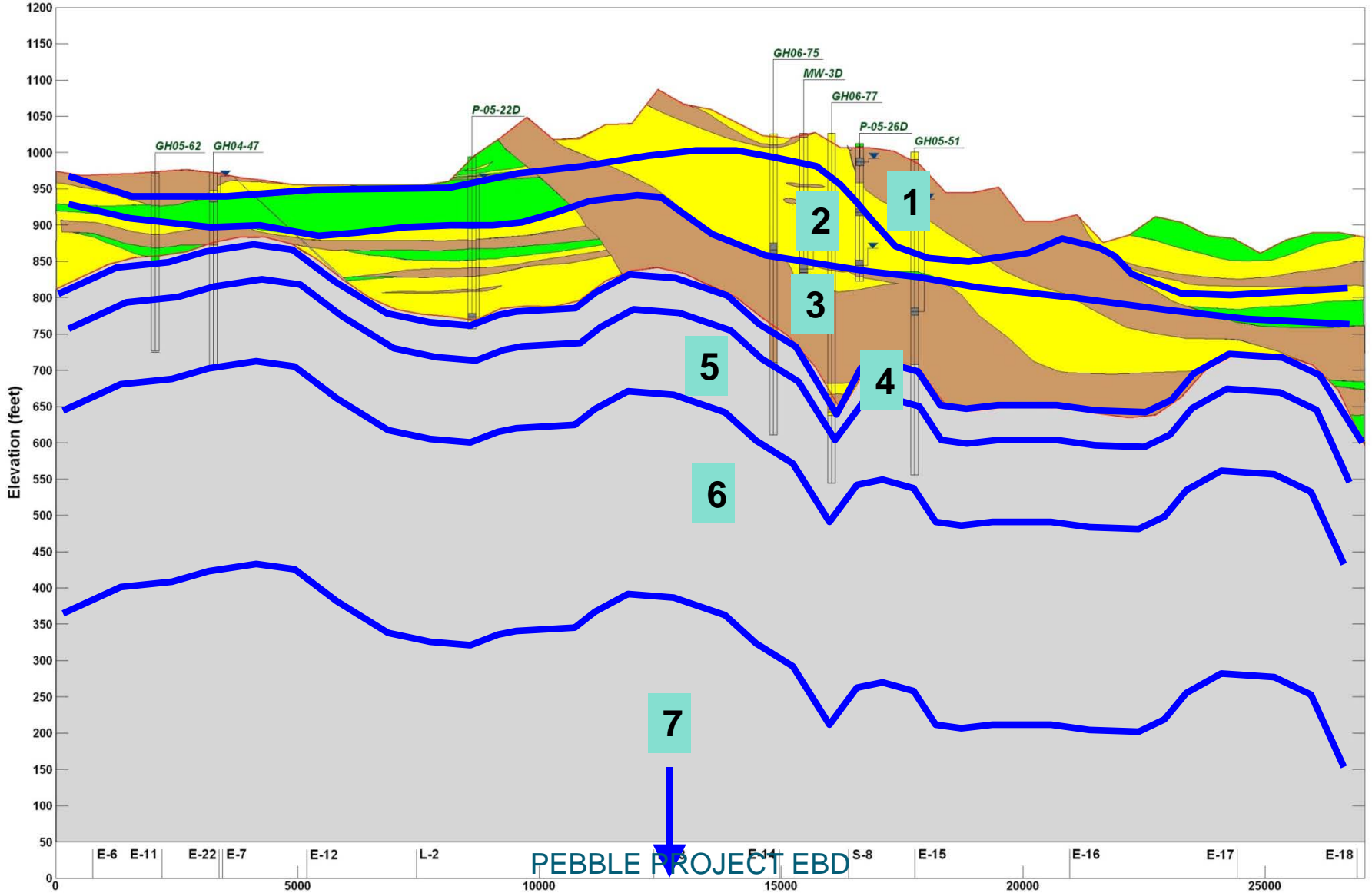
- sand, silty sand
- bedrock
- clay, silty clay
- gravel, gravelly sand

Model Layers

NNE

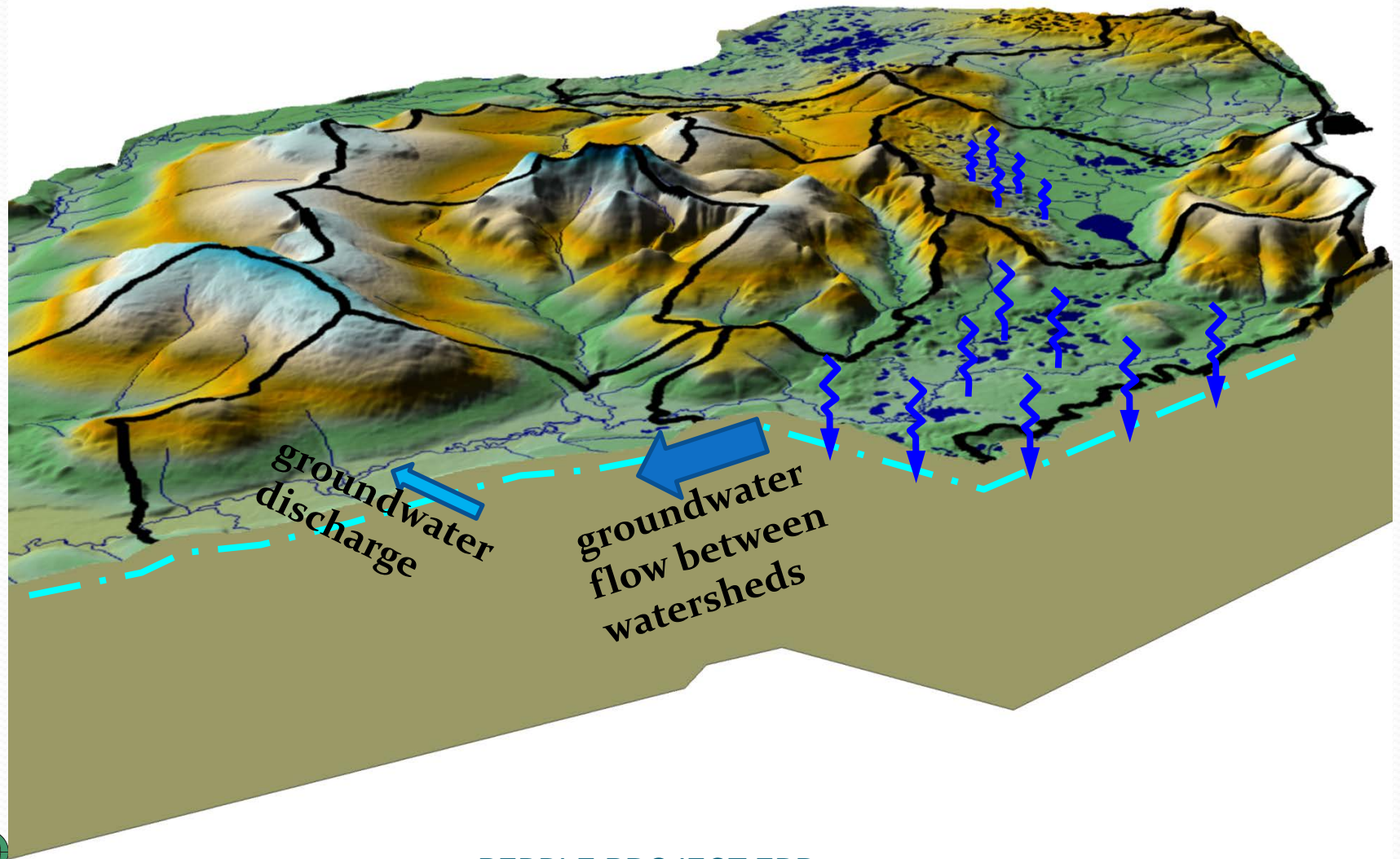
Section L-1 Looking ESE

SSW



What processes are we simulating?

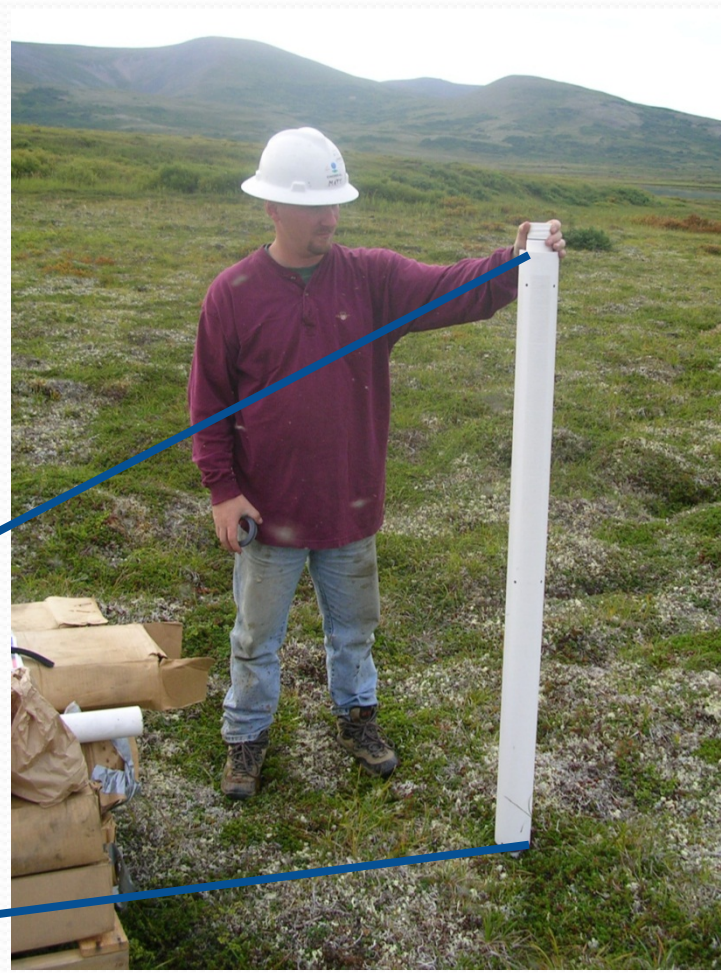
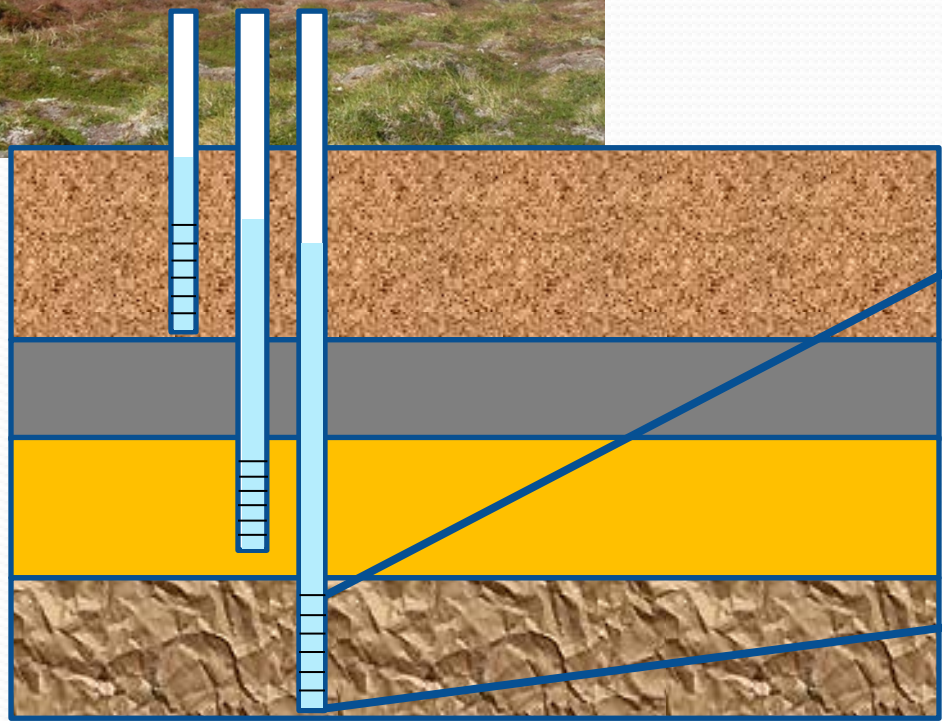
Conceptual model of flow



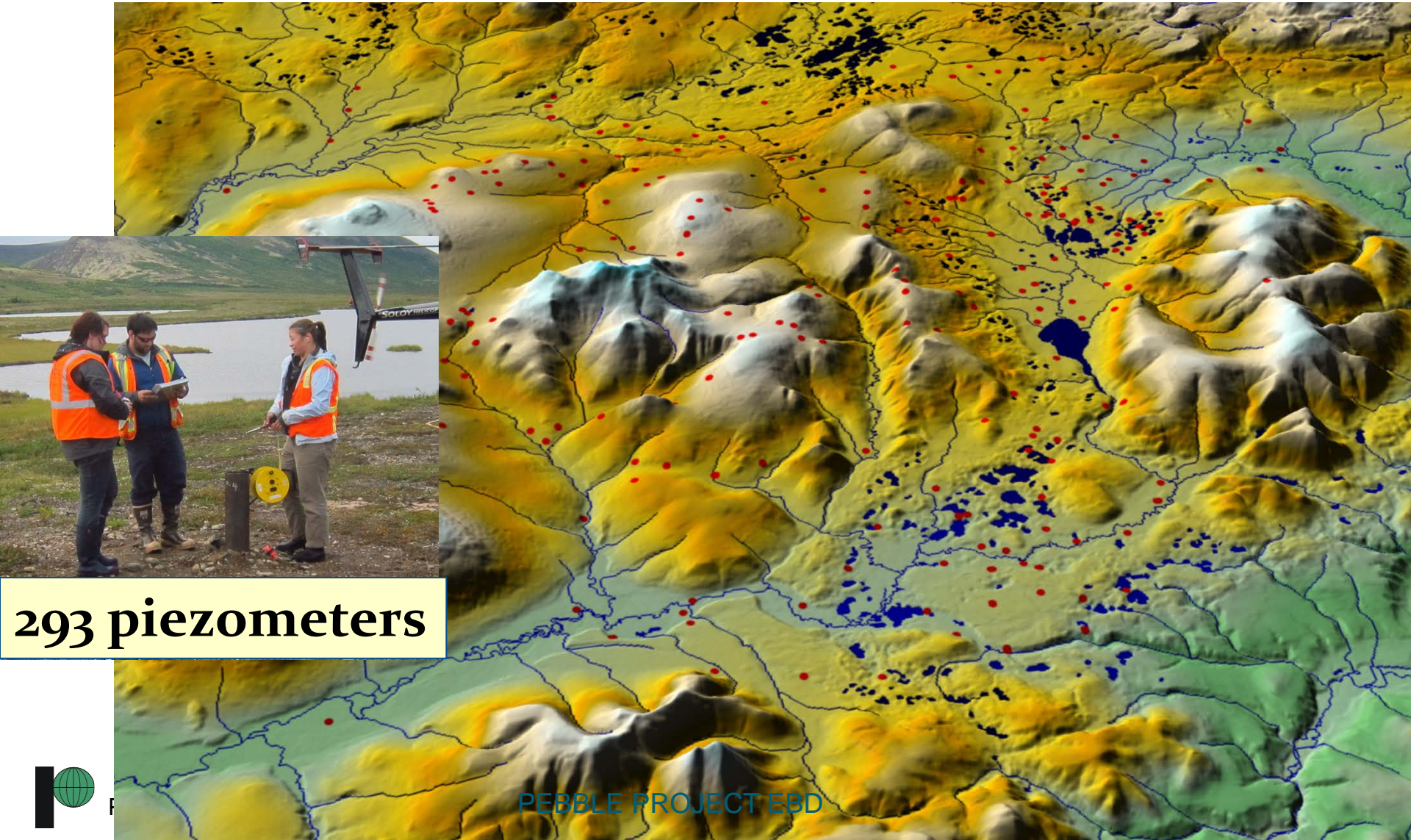
Groundwater Discharge



Groundwater Elevations



Groundwater elevations



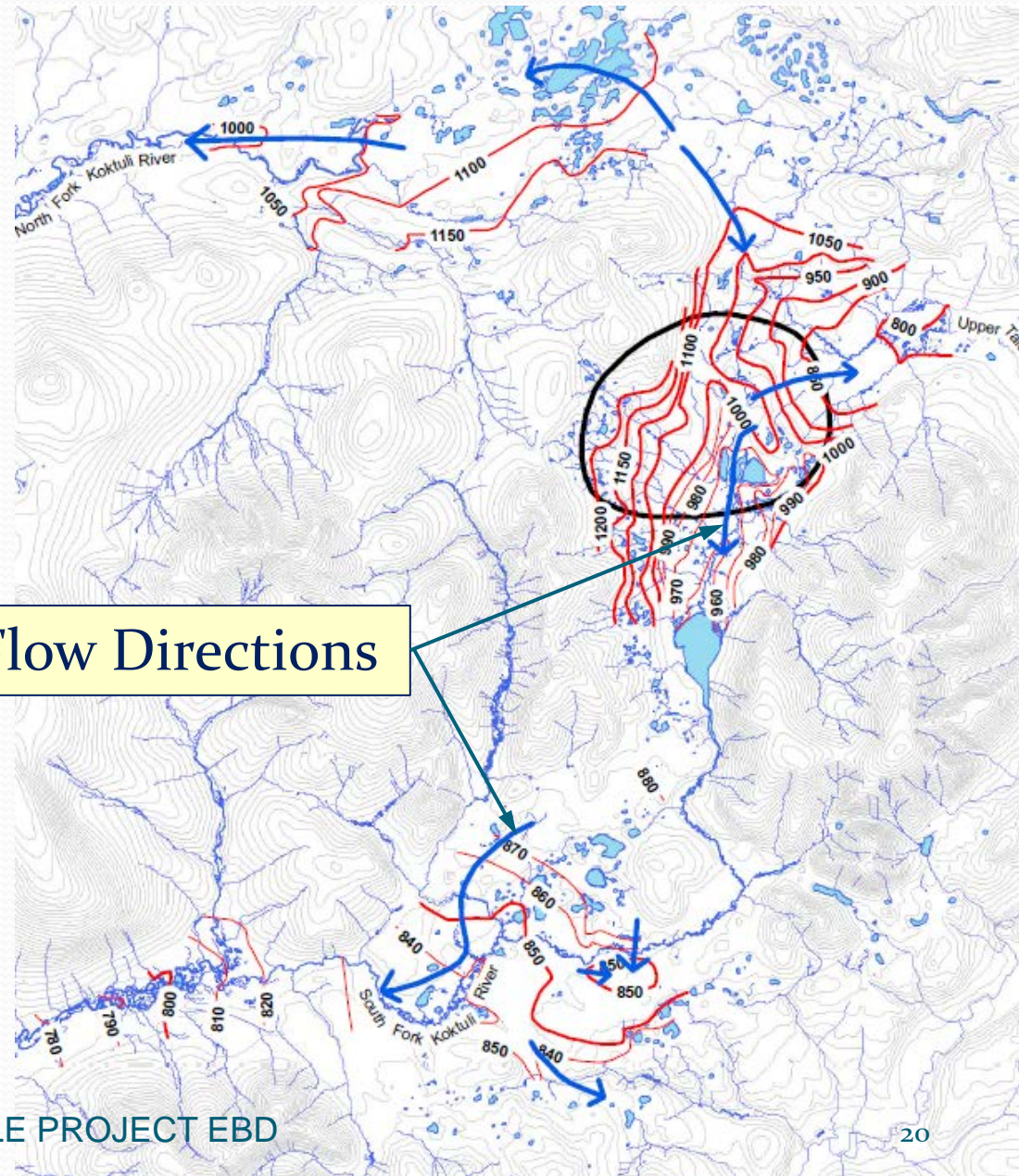
293 piezometers



Interpreting horizontal flow directions

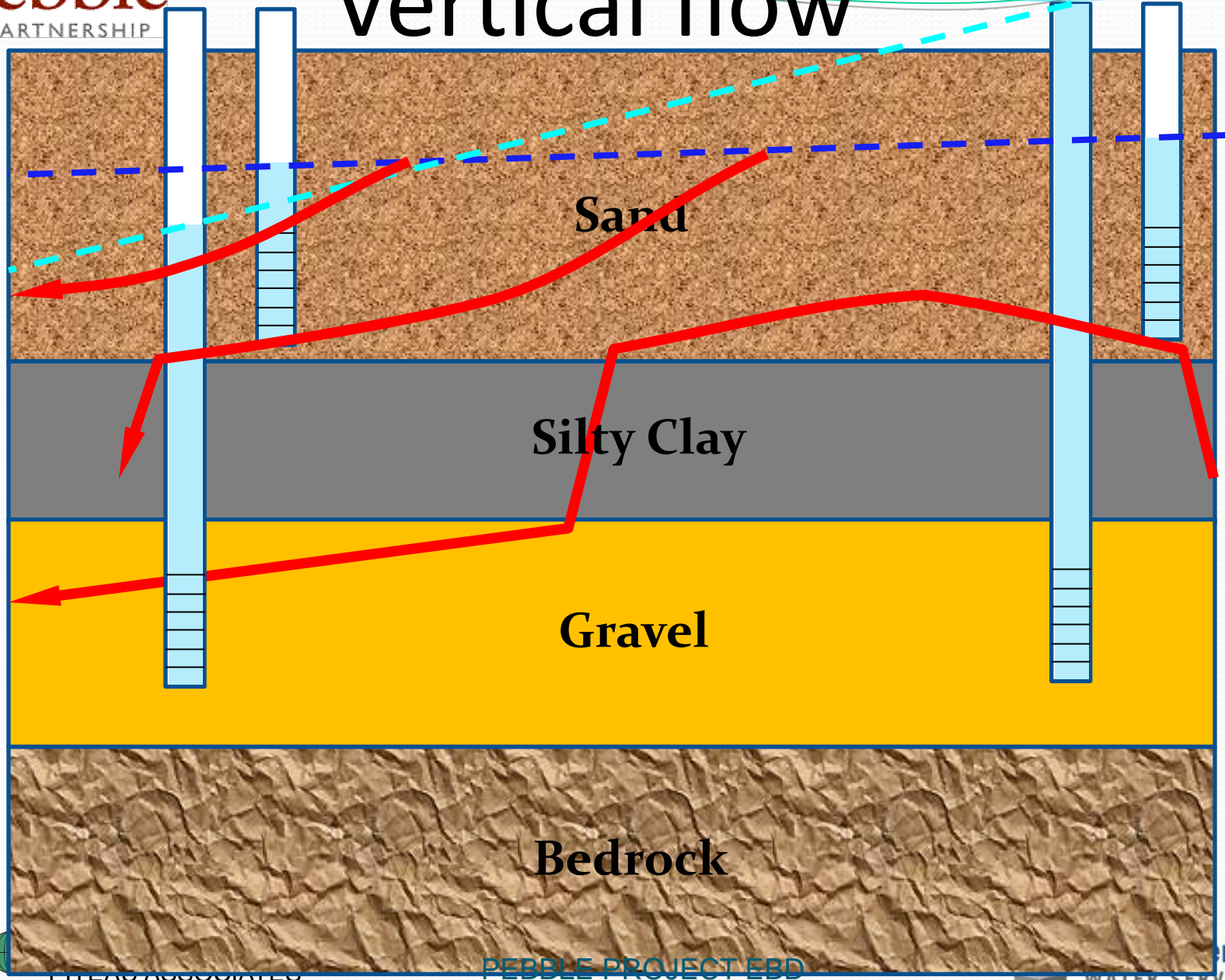


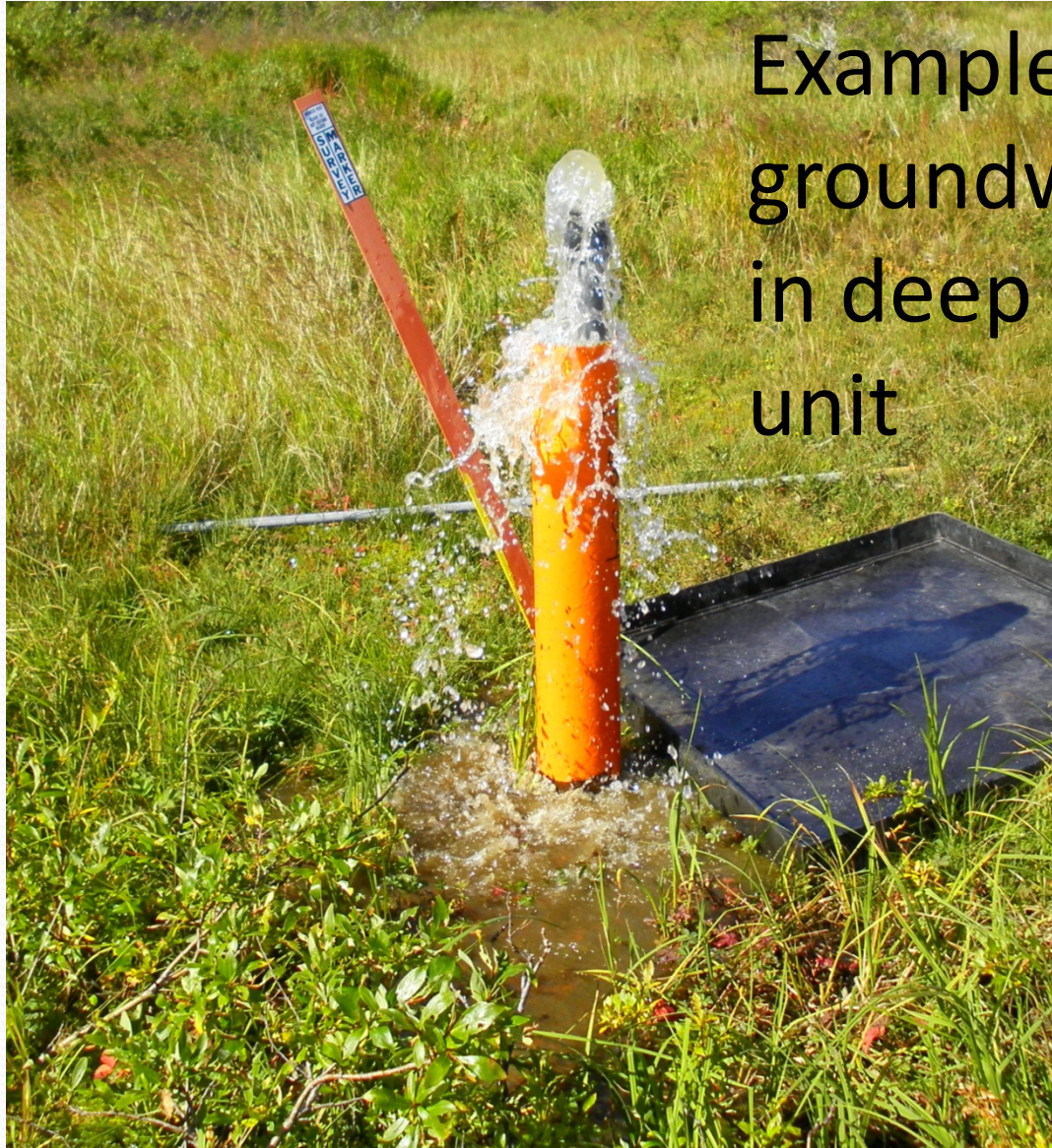
Groundwater Elevation Contours



Interpreted Flow Directions

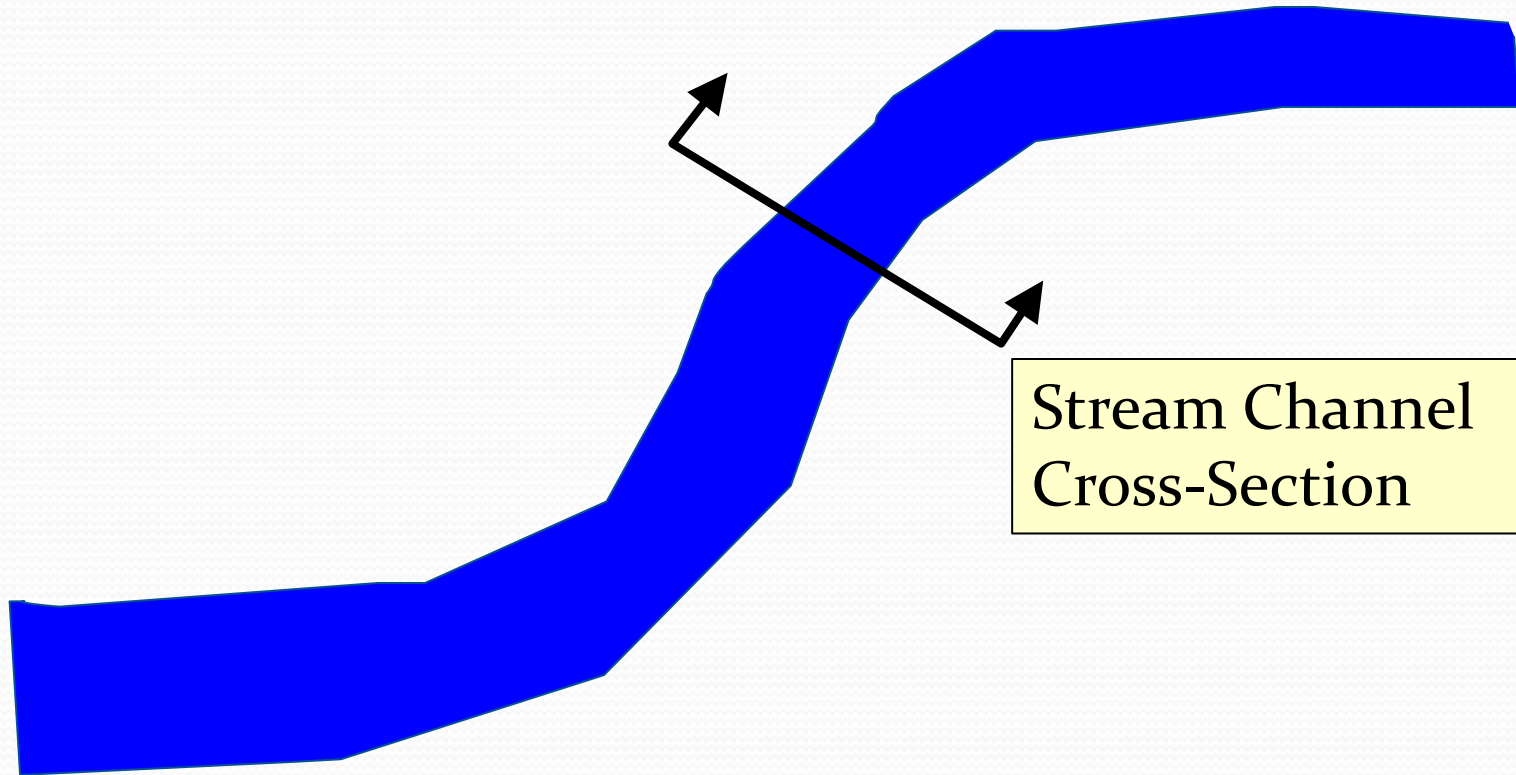
Vertical flow



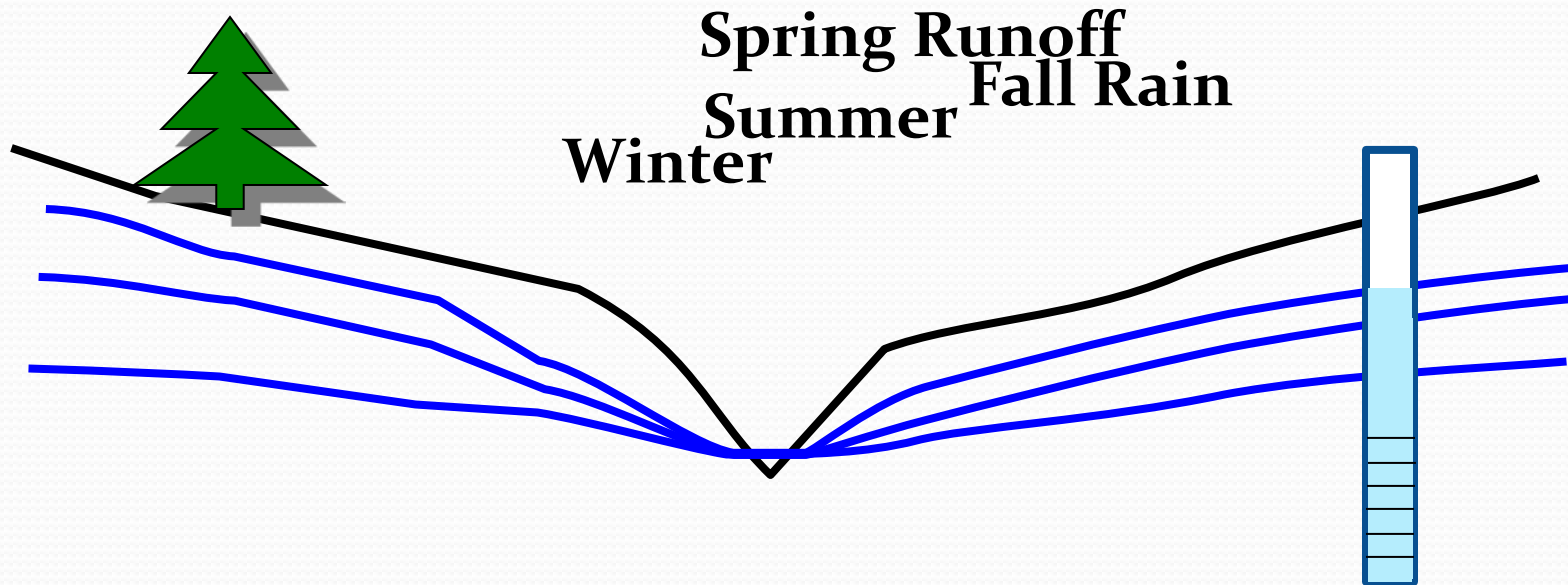


Example of high
groundwater elevation
in deep hydrogeologic
unit

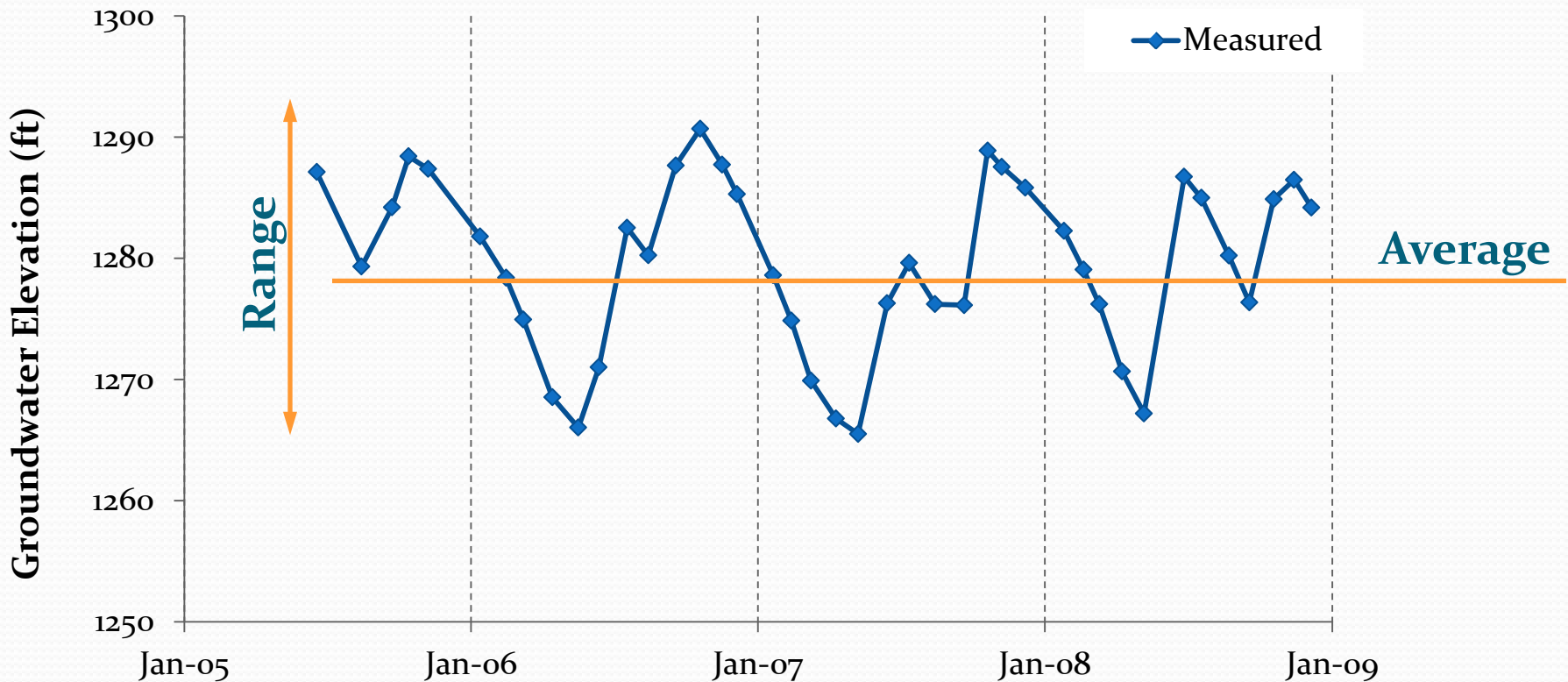
Seasonal Groundwater Elevations



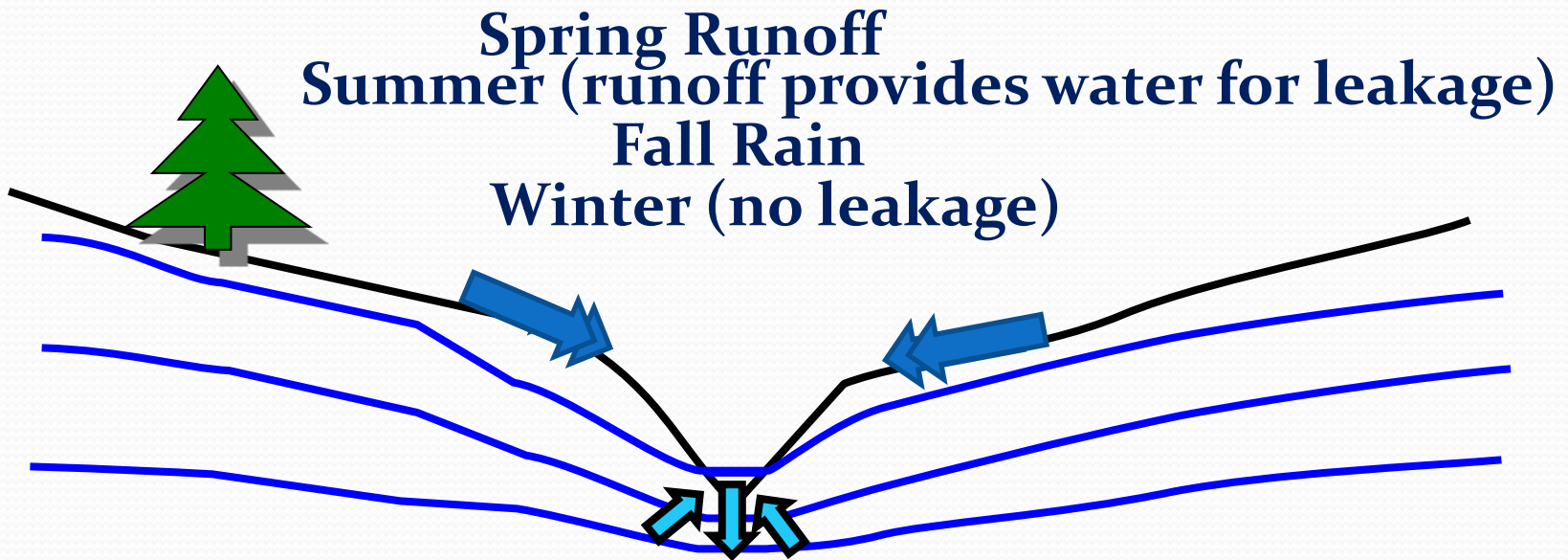
Seasonal groundwater elevations



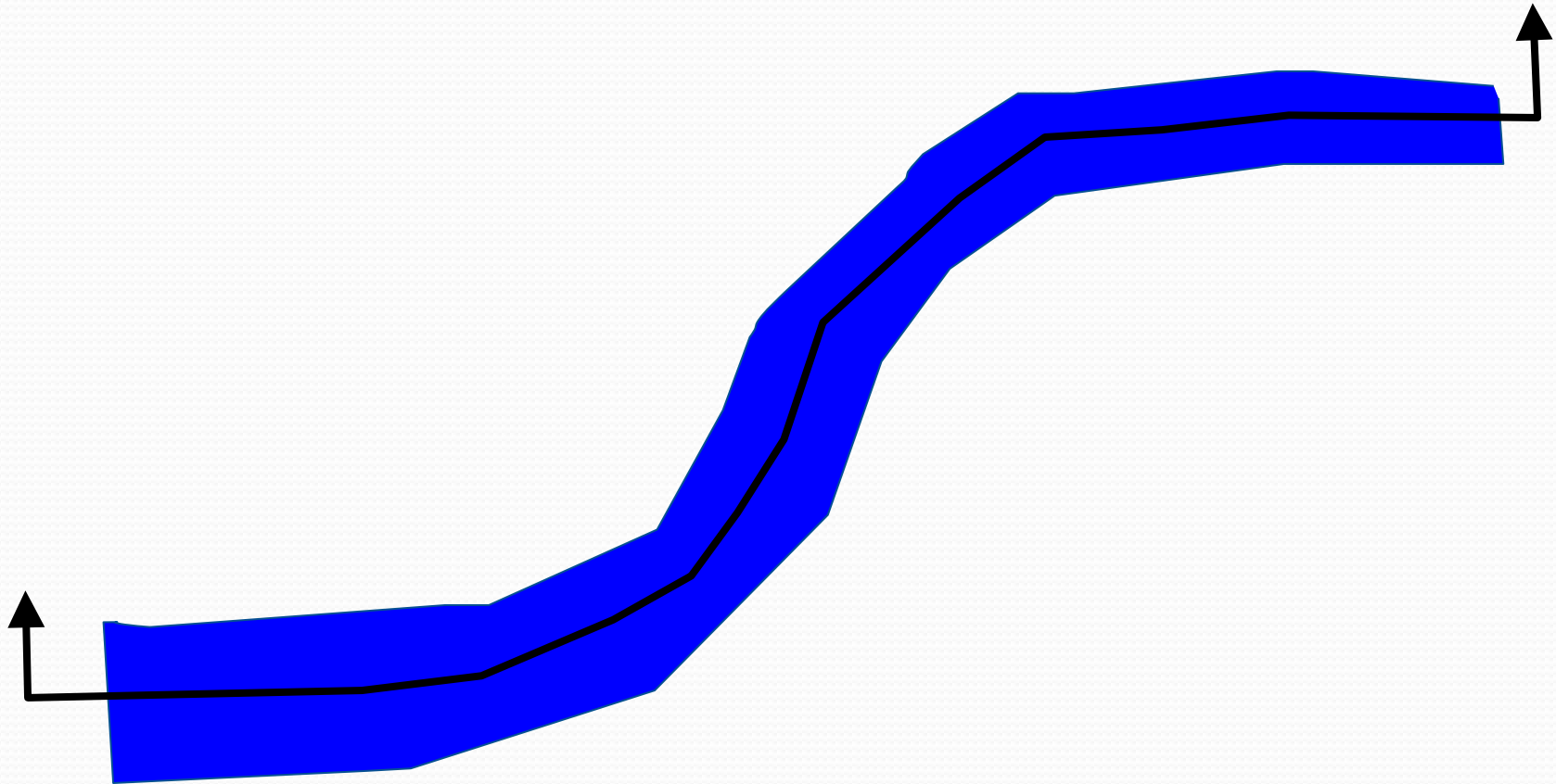
Groundwater Elevation vs. Time



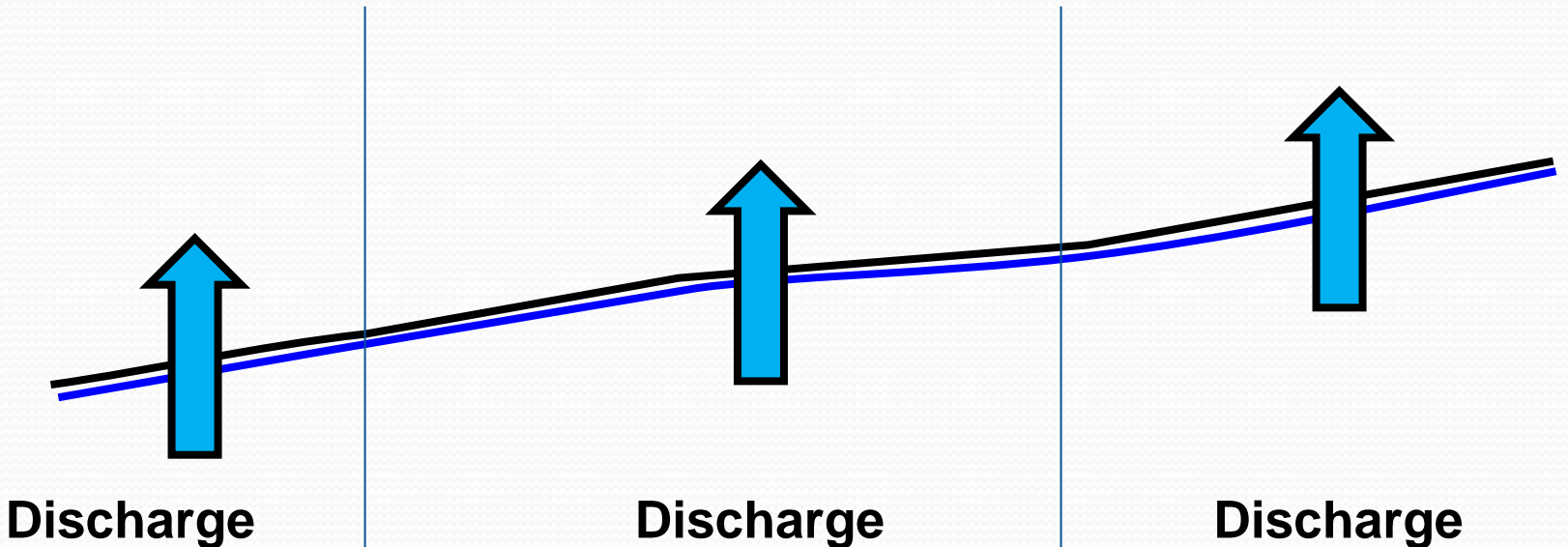
Potential pattern of seasonal surface-water-groundwater interaction



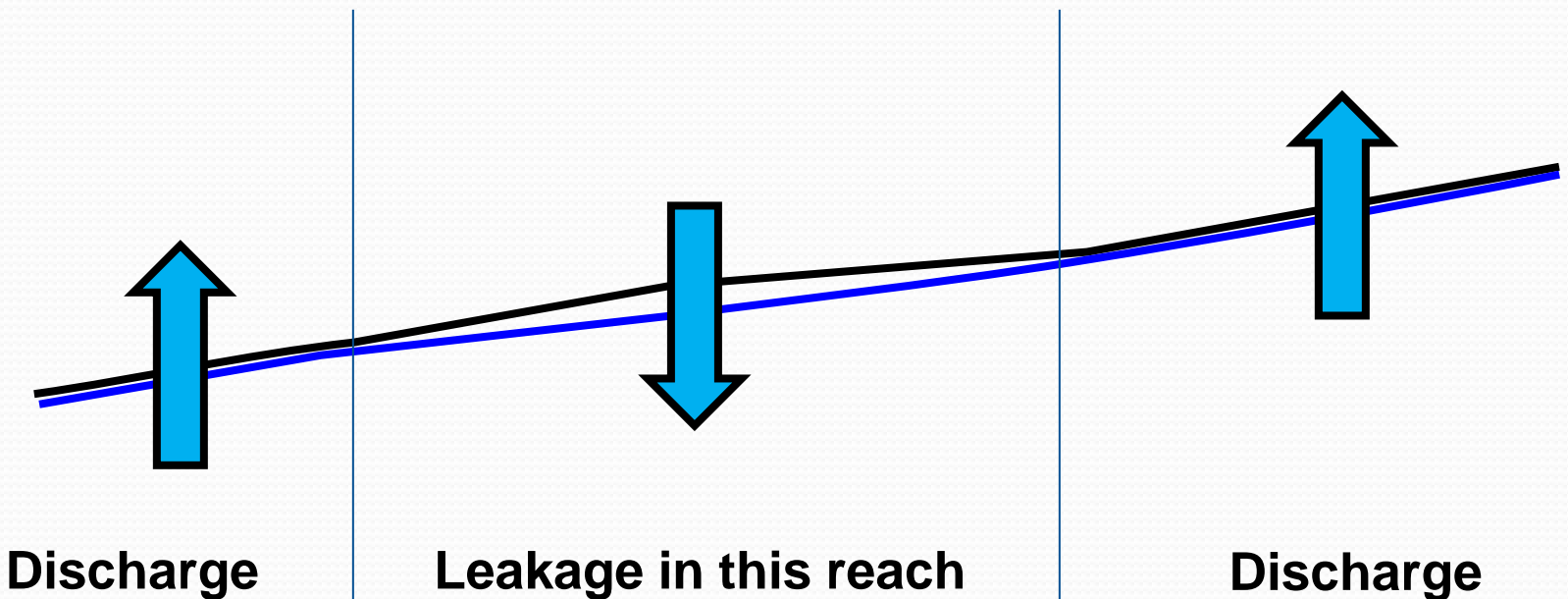
Stream Channel Longitudinal Section



High groundwater table



Low groundwater table



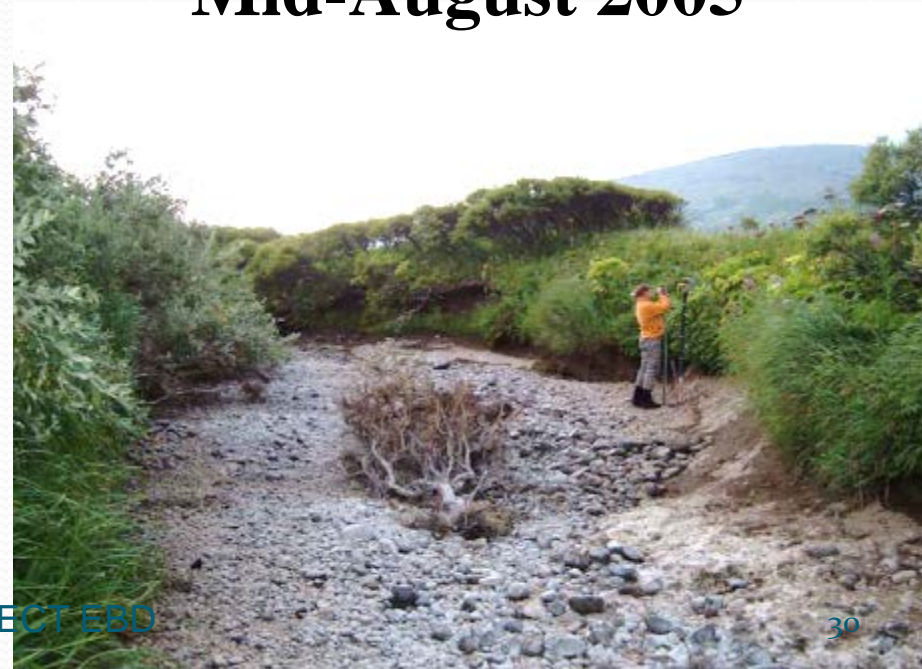
Groundwater Leakage South Fork Koktuli River

Early July 2005



Upstream of Springs

Mid-August 2005



South Fork Koktuli – dry section



South Fork Kuktuli – flow appearing due to groundwater discharge



Agenda

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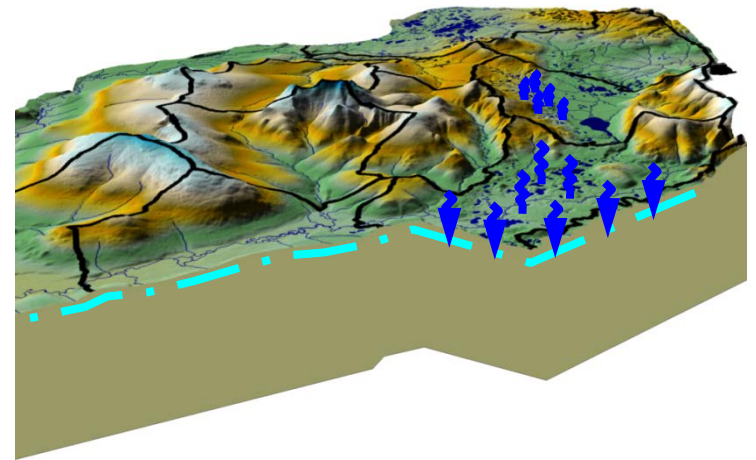
Integrated modeling approach

Water Balance



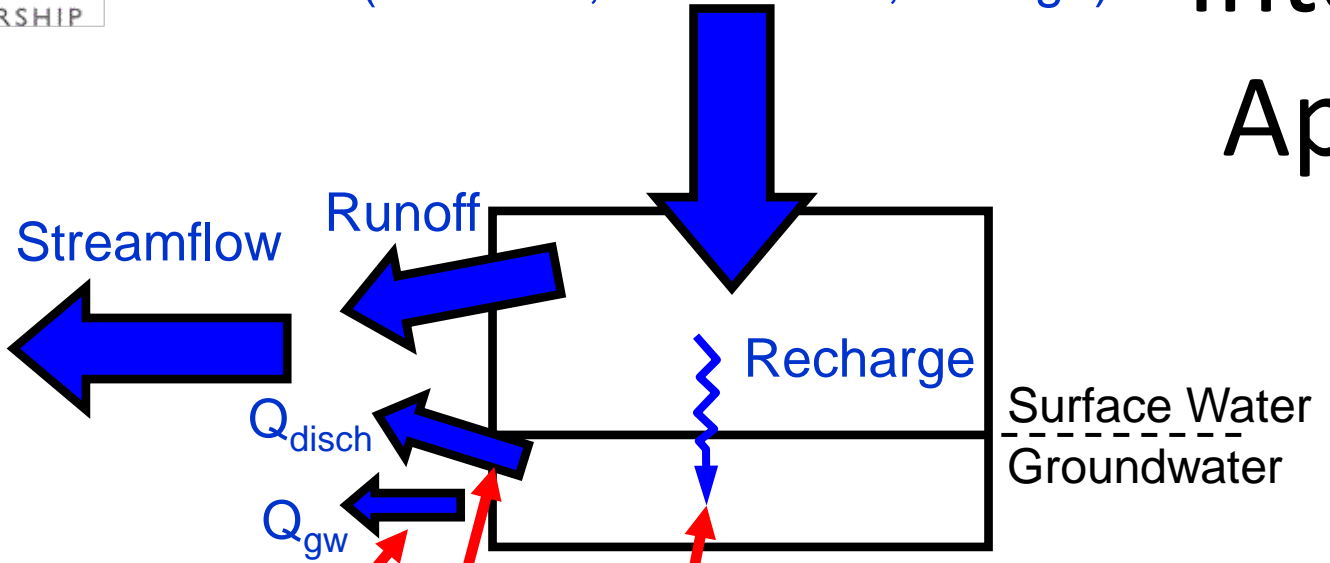
+

Groundwater Model

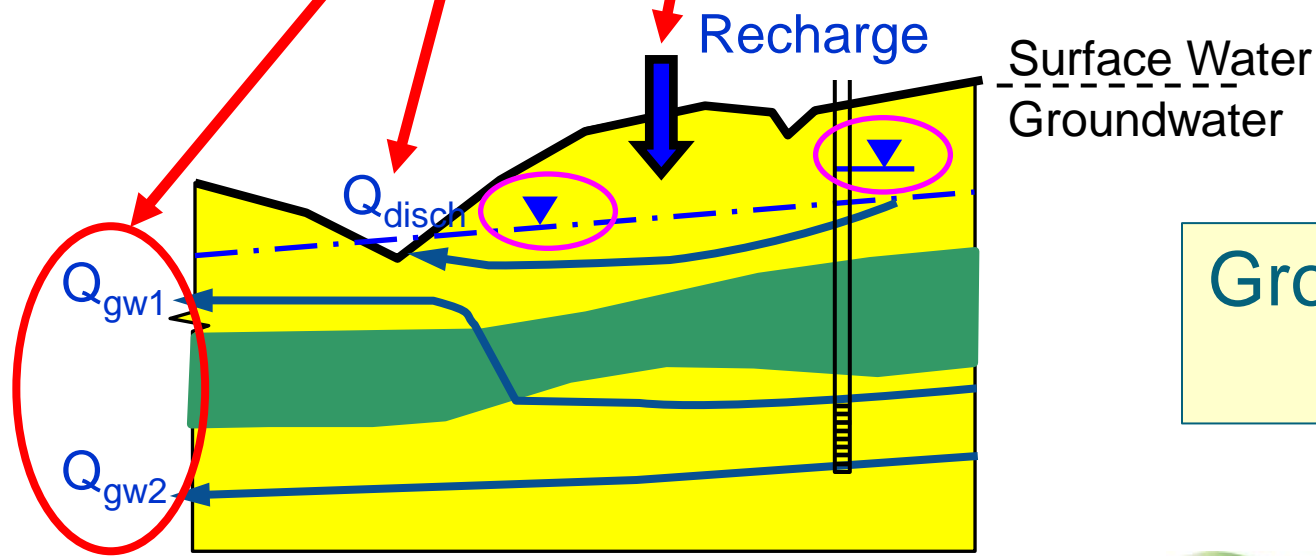


Precipitation
(net of ET, sublimation, storage)

Integrated Approach

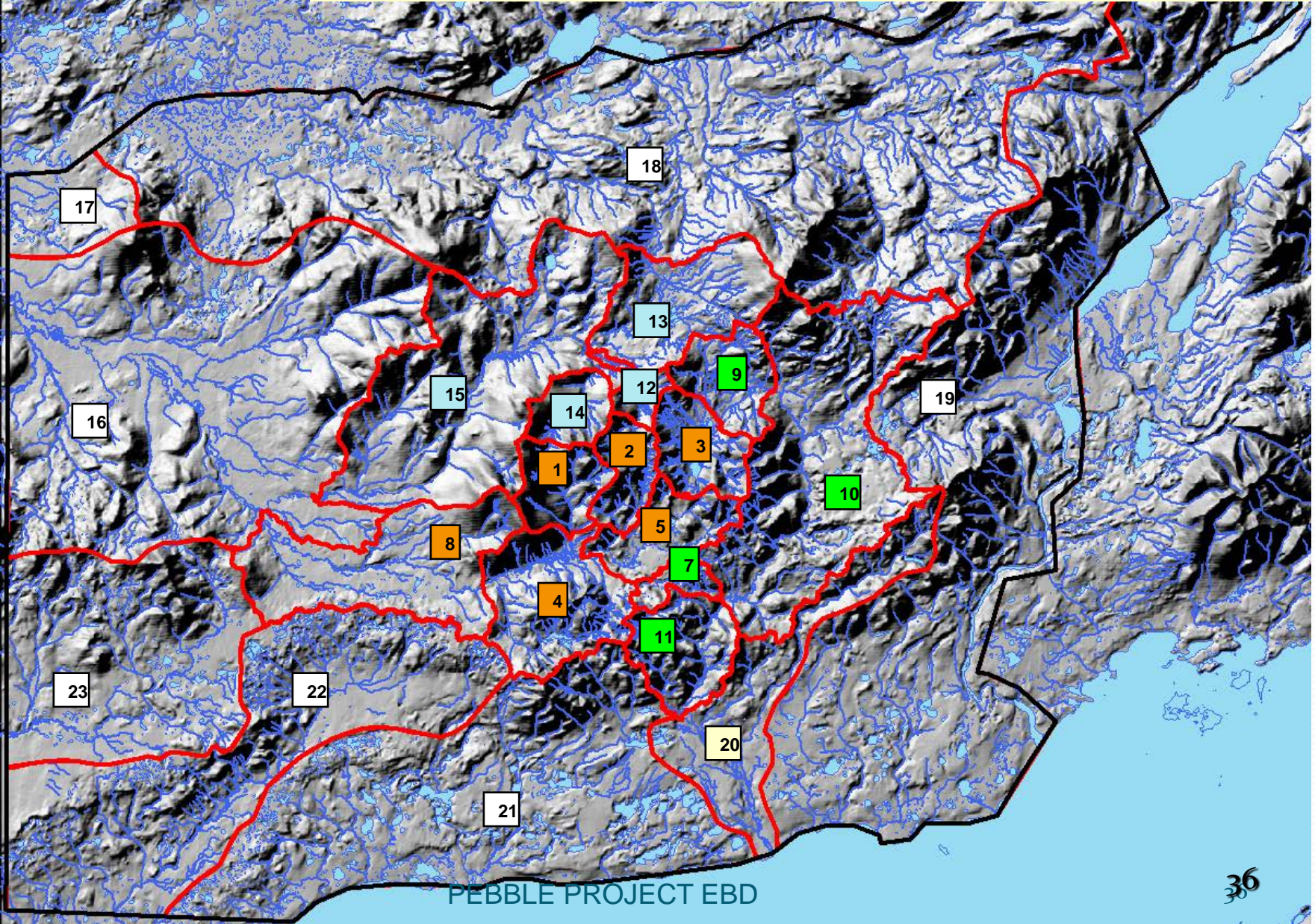


Water Balance

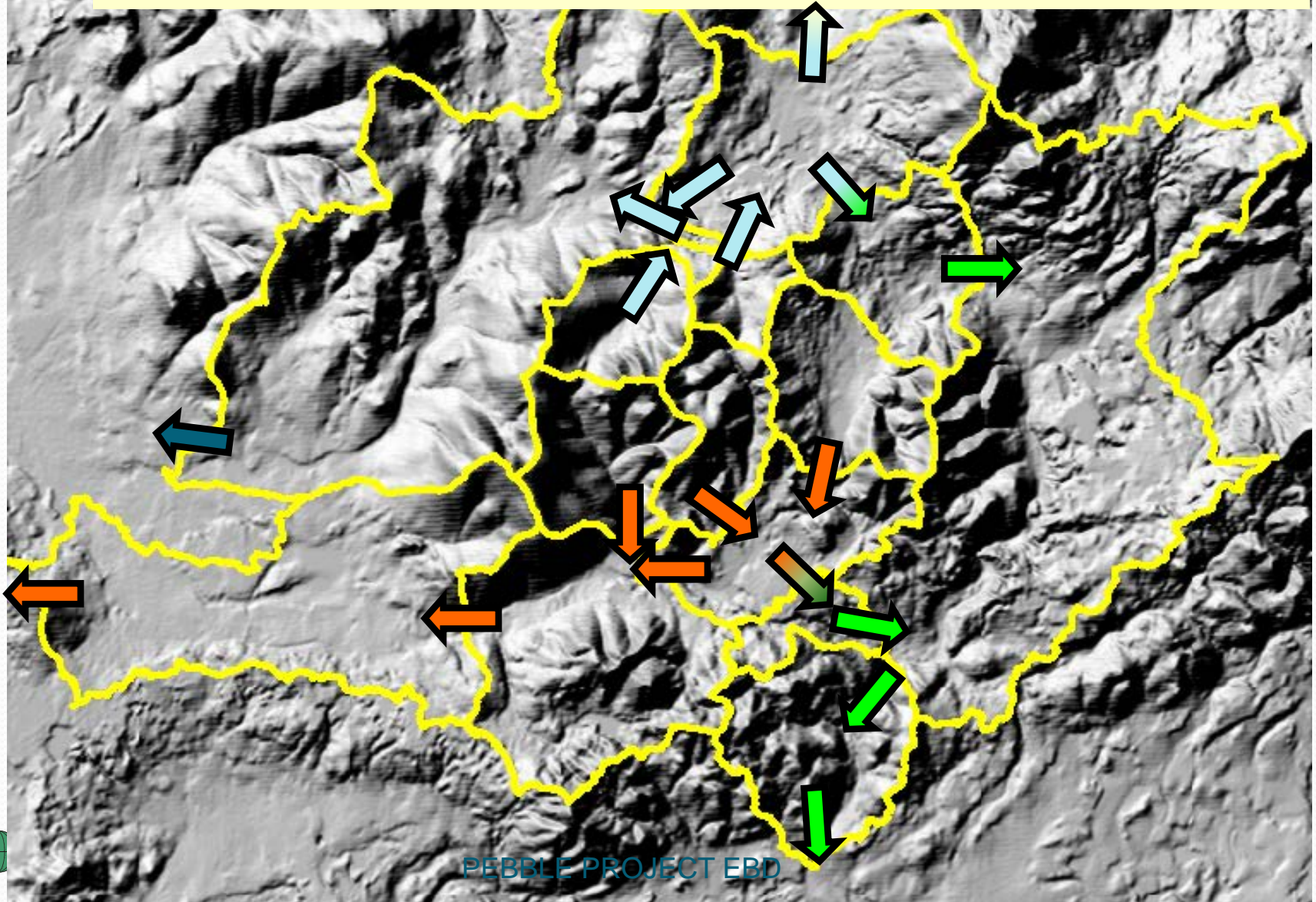


Groundwater Model

Watershed numbers



Inter-watershed groundwater flow assumed in water balance



Reasons for integrated Modeling

- 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

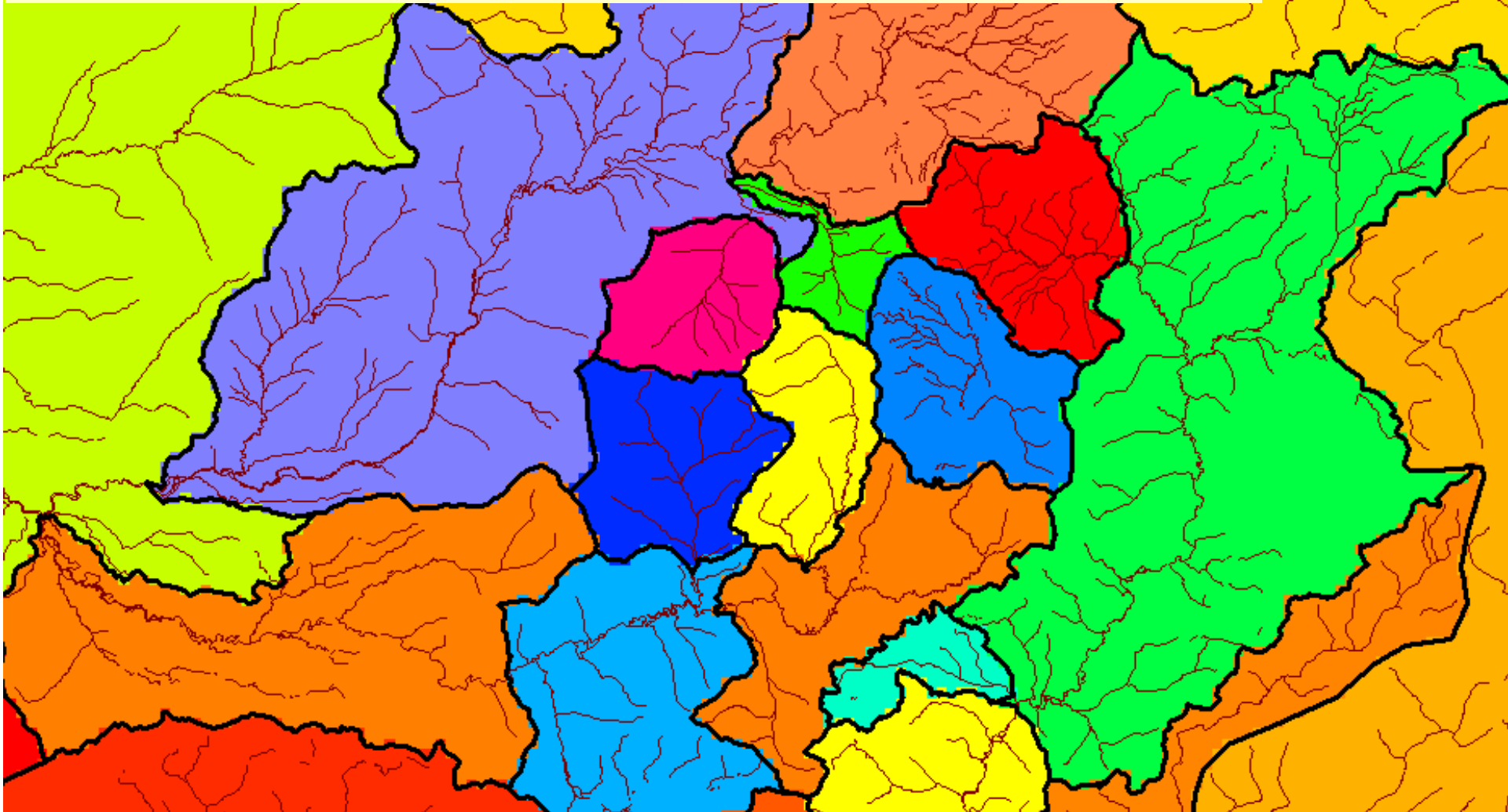
Water Balance Model

- analytical spreadsheet model
- considers total water volume by watershed
 - recharge
 - surface-water-groundwater interaction
- does not consider distribution within watershed
- calibrated to monthly streamflow
- calibration focused on low flows

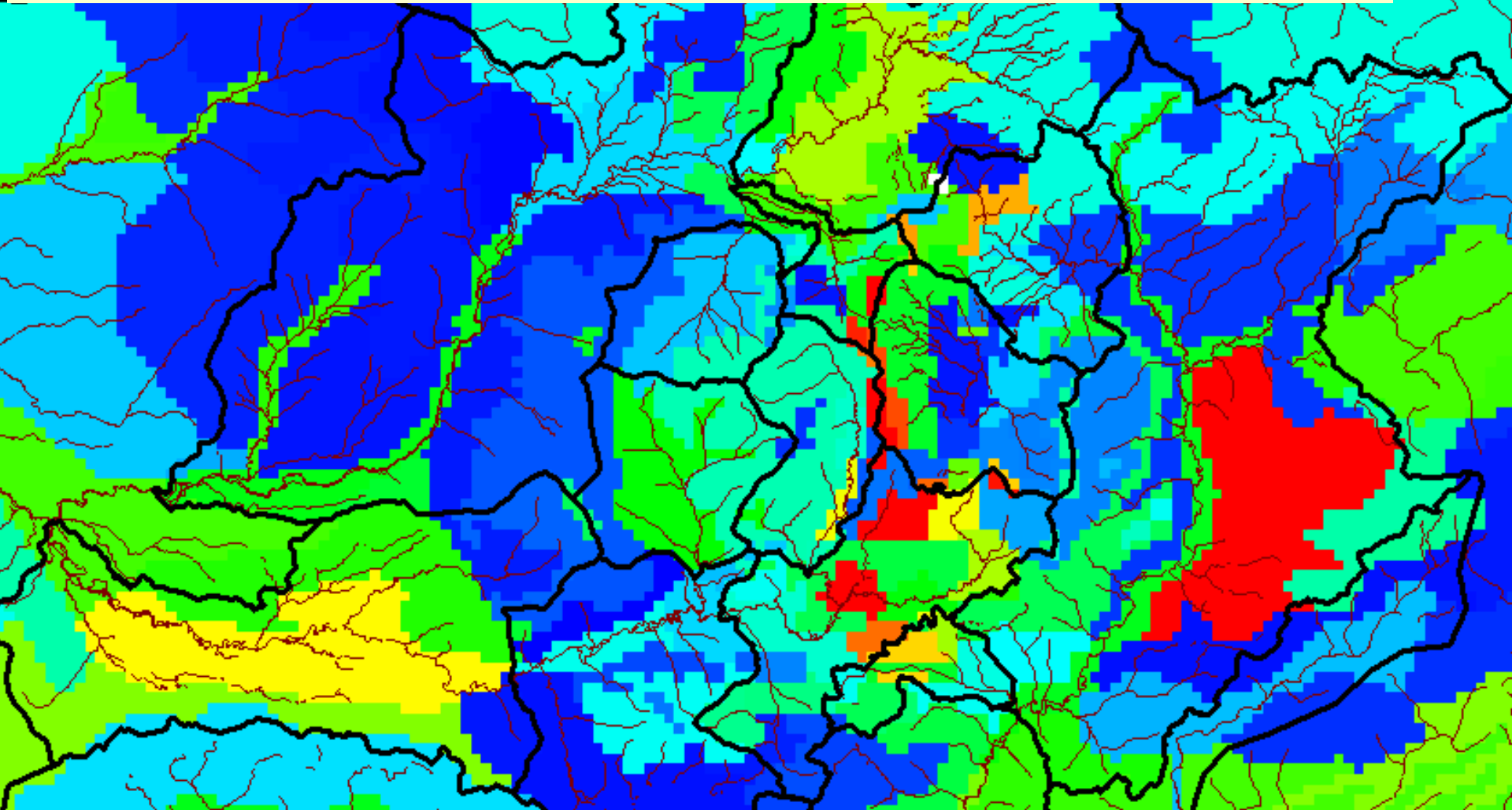
Groundwater Model

- Numerical finite difference model (MODFLOW-SURFACT)
- considers total water volumes within each watershed
- also considers the **distribution** of recharge and surface-water-groundwater interaction within each watershed
- Calibration targets
 - observed monthly groundwater elevations
 - monthly flows from water balance
 - field measurements of low-flow streamflows

Water balance recharge applied as total volume to each watershed

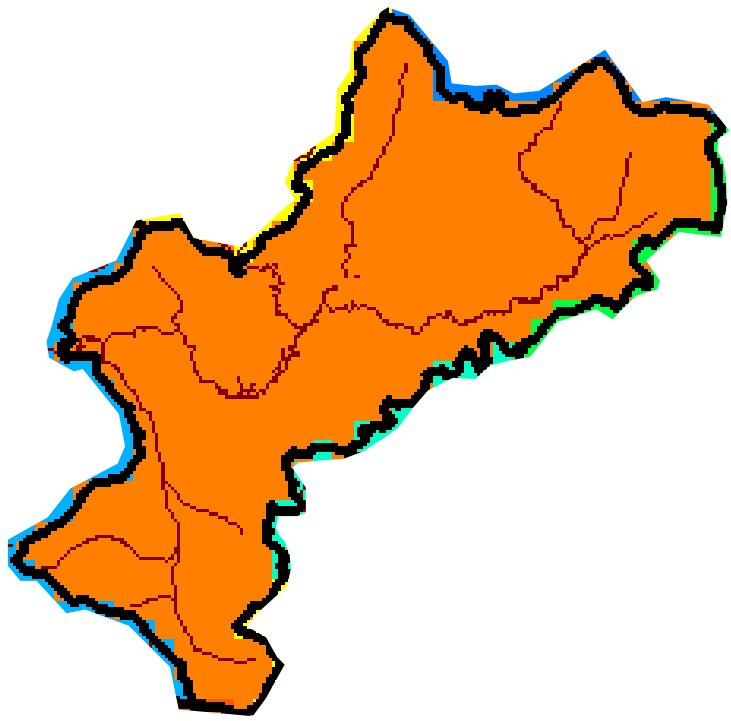


Groundwater model recharge distributed throughout each watershed

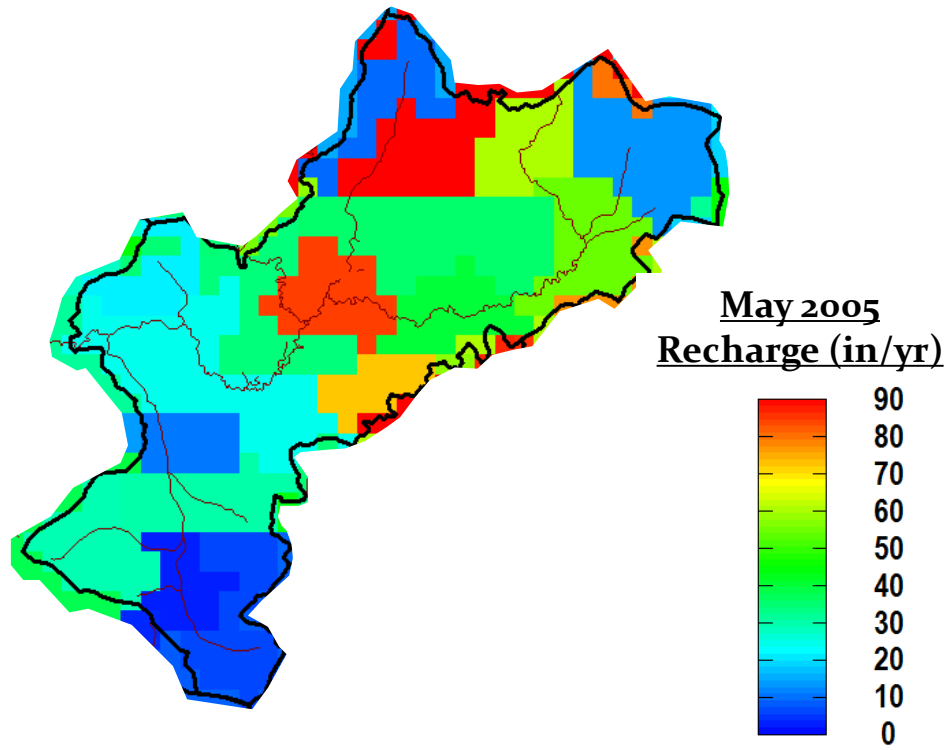


Water balance recharge compared to groundwater model

Water Balance
Total Volume



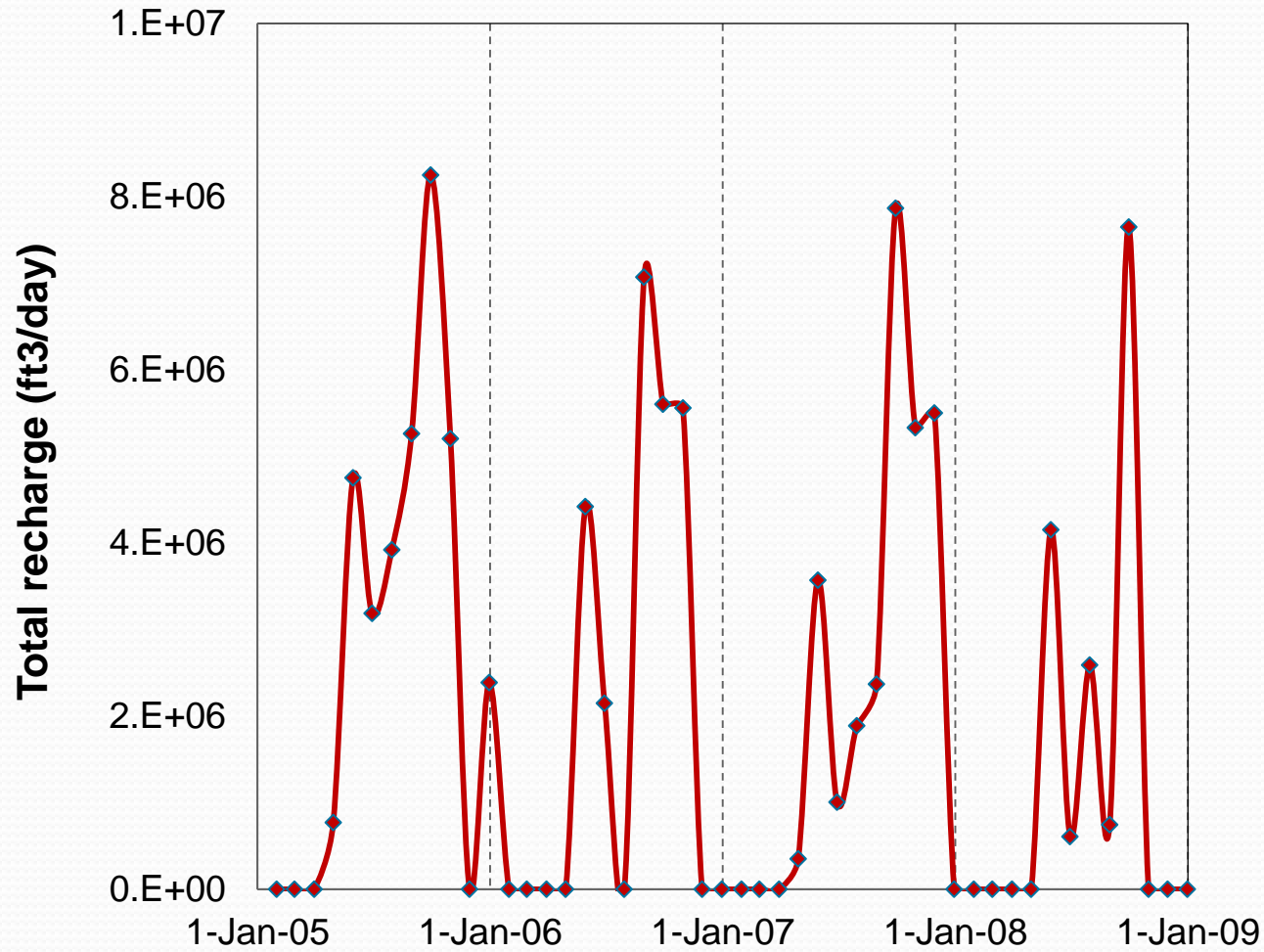
Groundwater Model
Same total volume
Distributed within watershed



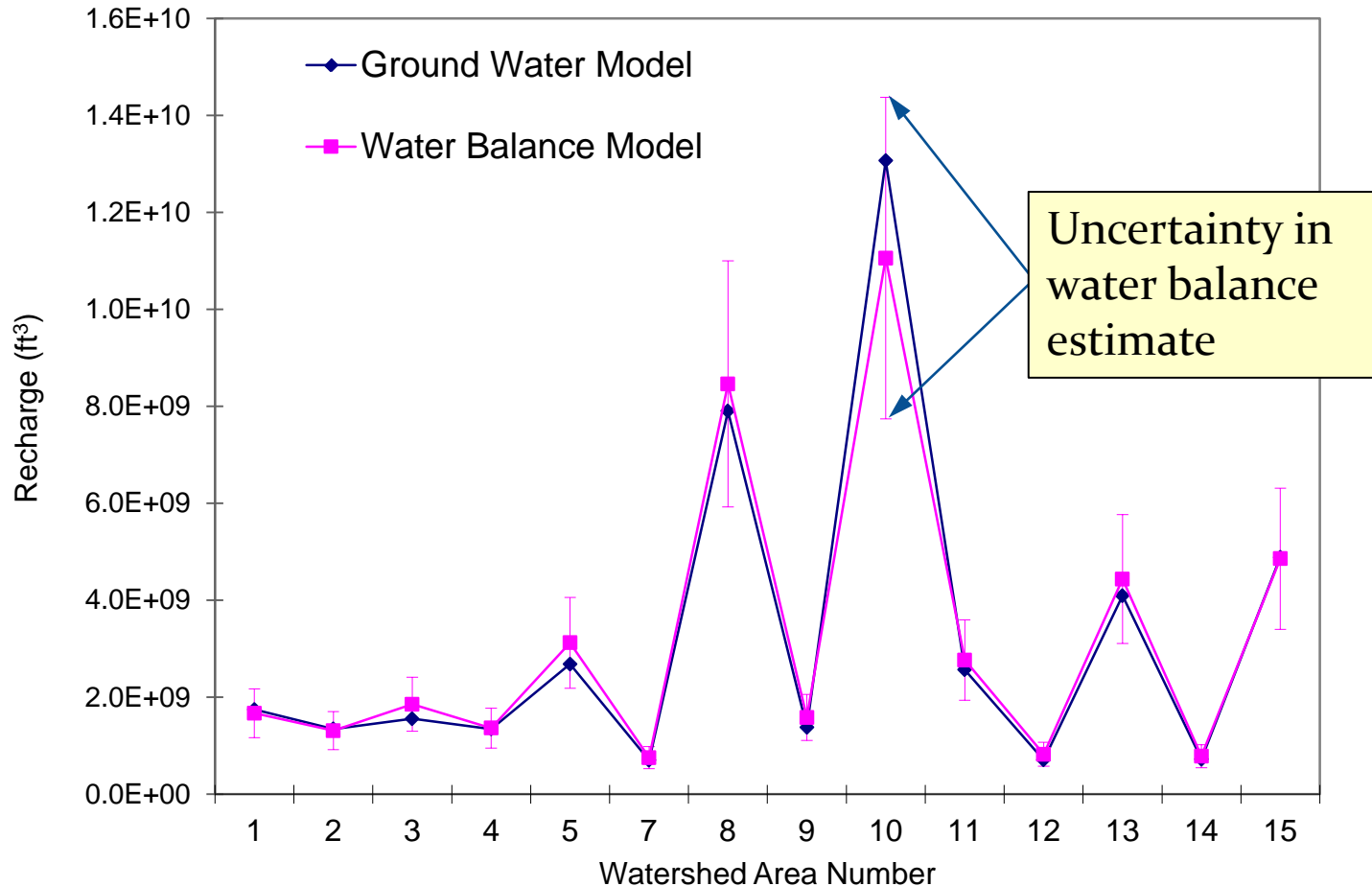
Modeling Time Period

- Water Balance Model
 - Inputs: January 1942 – December 2008
 - Calibration: July 2004 – December 2008
 - divided into monthly periods
- Groundwater Model:
 - Inputs and calibration: 2005-2008
 - divided into monthly periods

Transient Monthly Recharge



Total recharge volume (2005-2008)



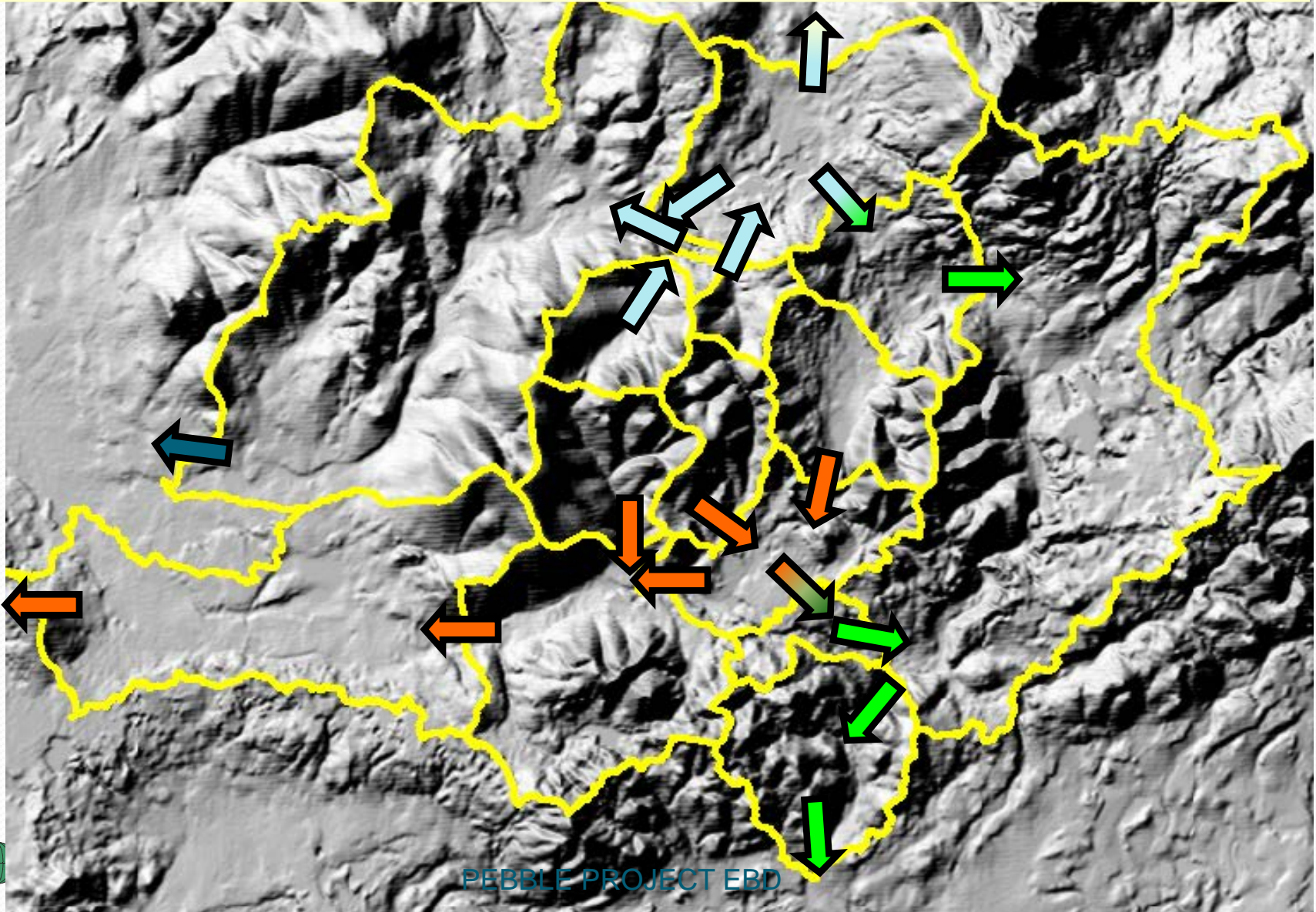
Agenda

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Calibration Targets

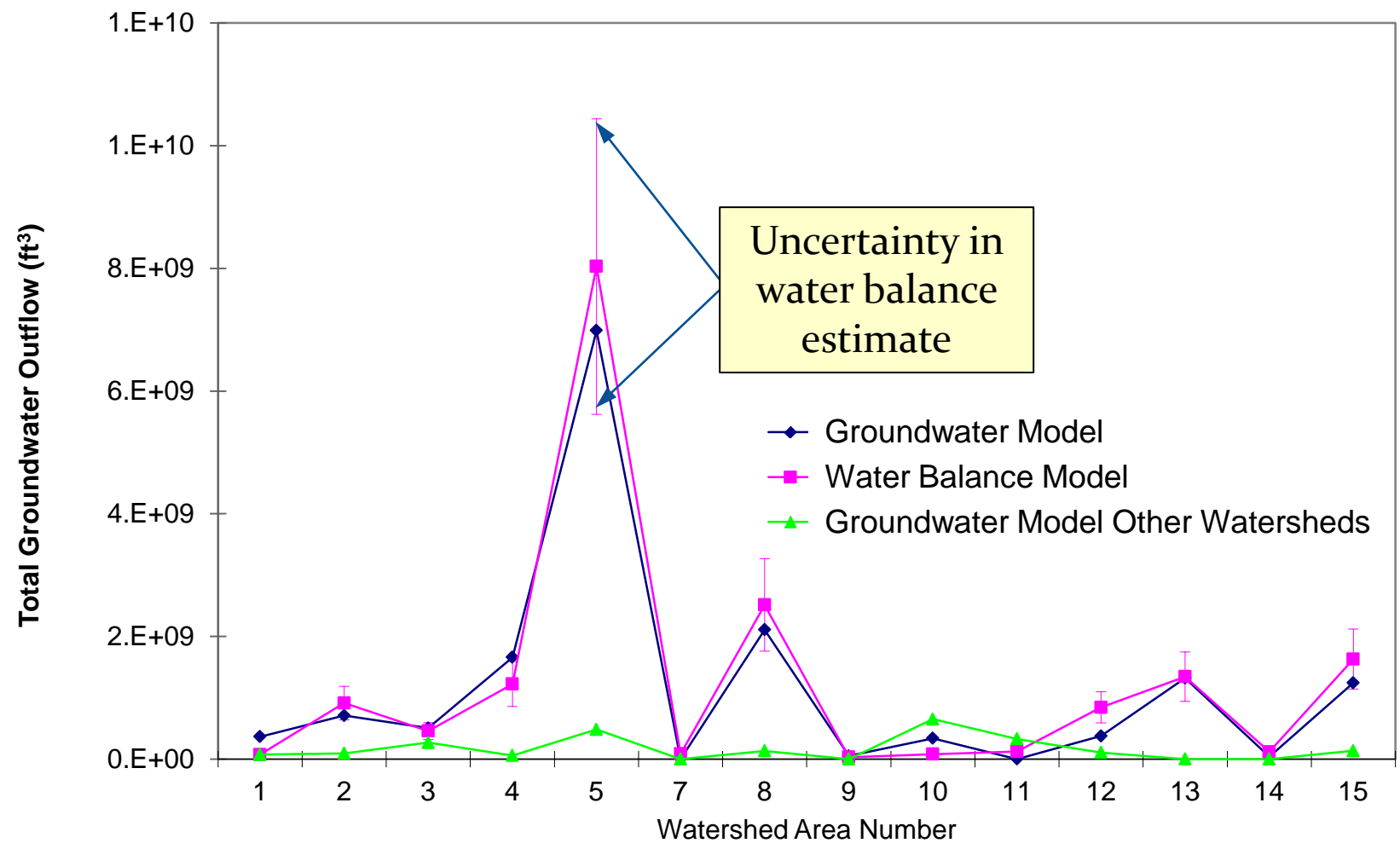
- Groundwater Flows:
 - inter-watershed groundwater flows
 - monthly net groundwater discharge (water balance)
 - late winter net groundwater discharge (field meas.)
- Groundwater Elevations (monthly field meas.)
- Calibrating to both heads *and* flows increases model uniqueness

Inter-watershed groundwater flow calibration targets (Estimated from water balance , one per watershed)



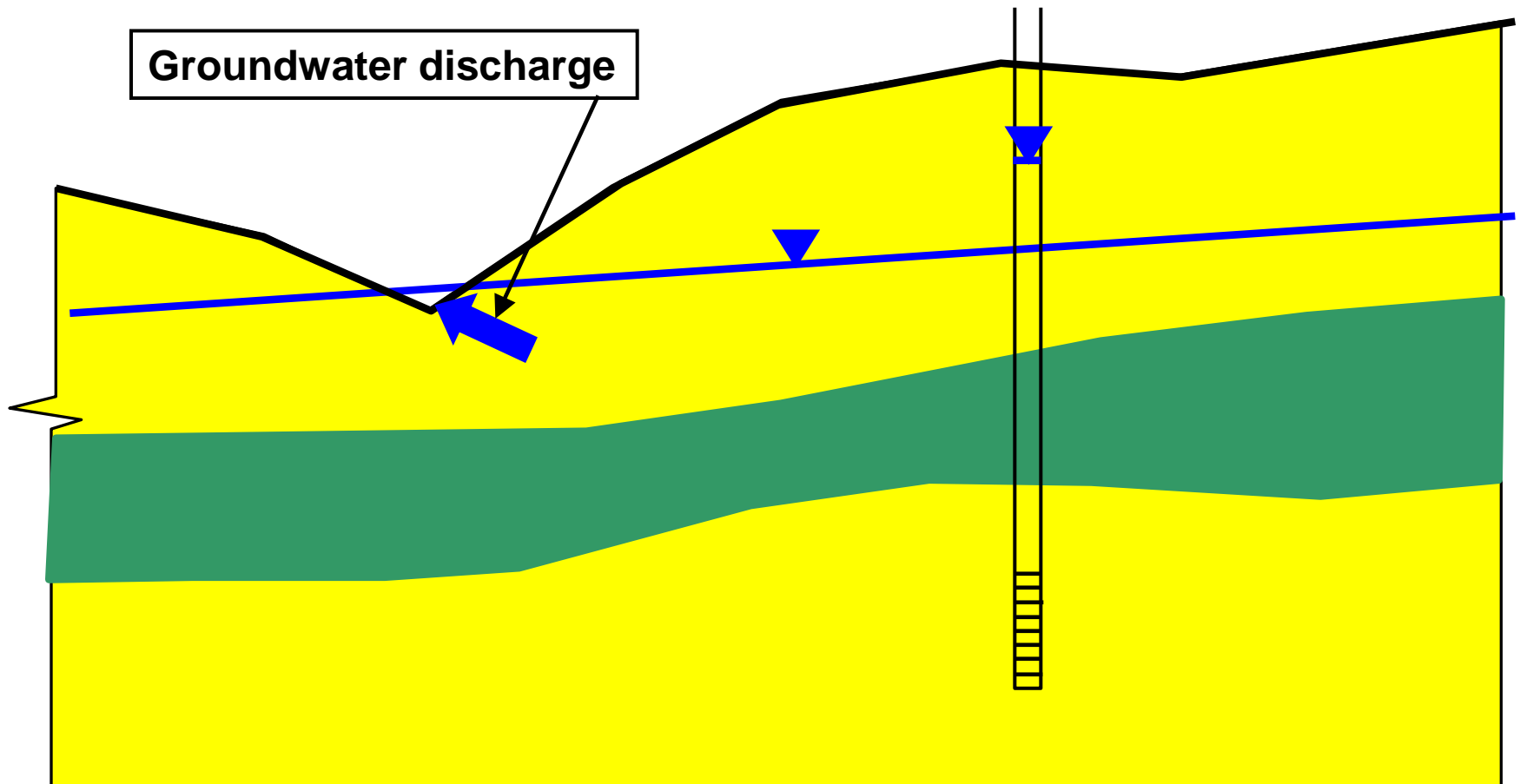
Results for inter-watershed groundwater flow calibration targets (one per watershed)

Total Groundwater Outflow to Adjacent Watersheds (ft³)



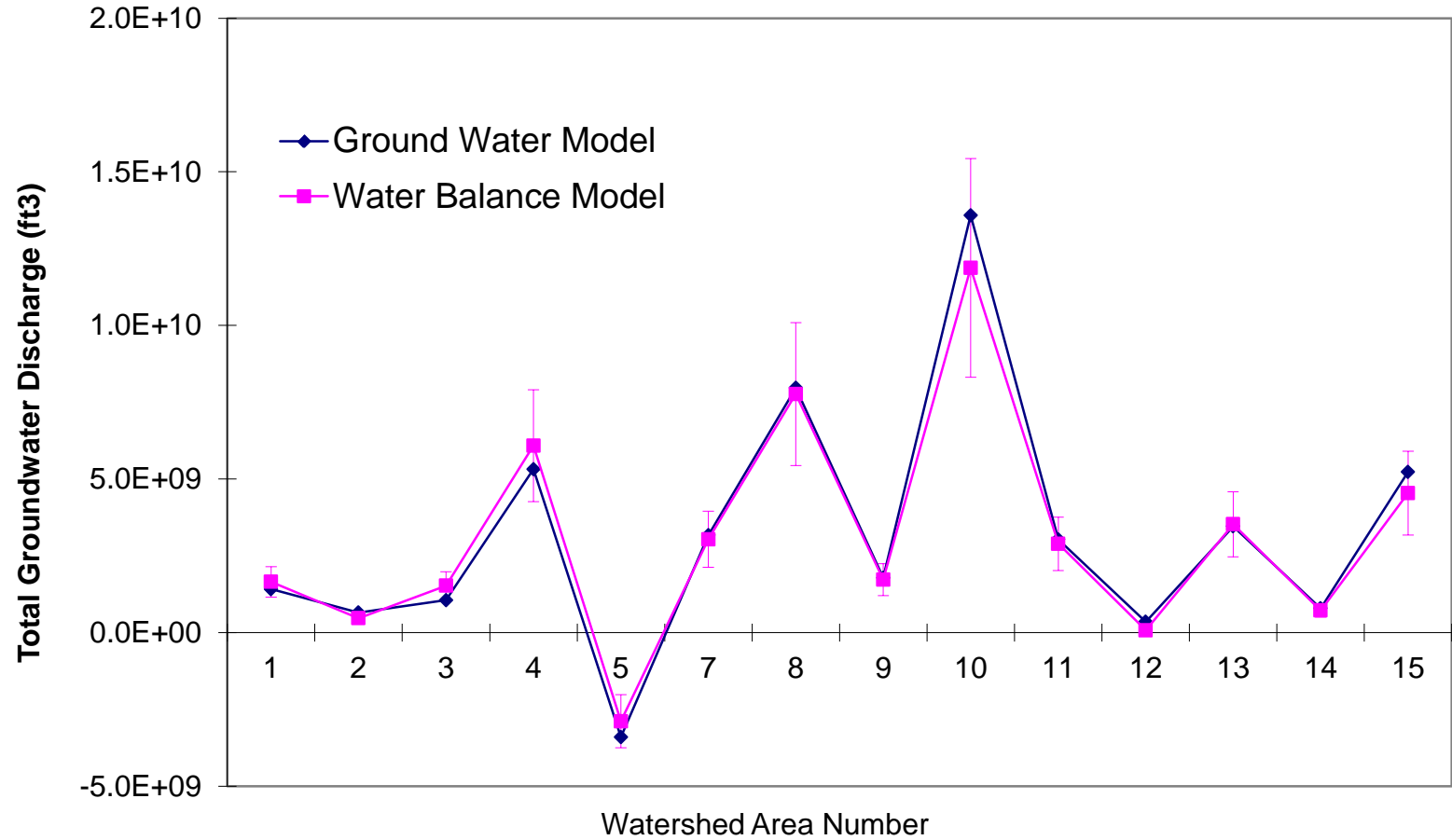
Groundwater discharge flow calibration targets

(Estimated from water balance, one per watershed)



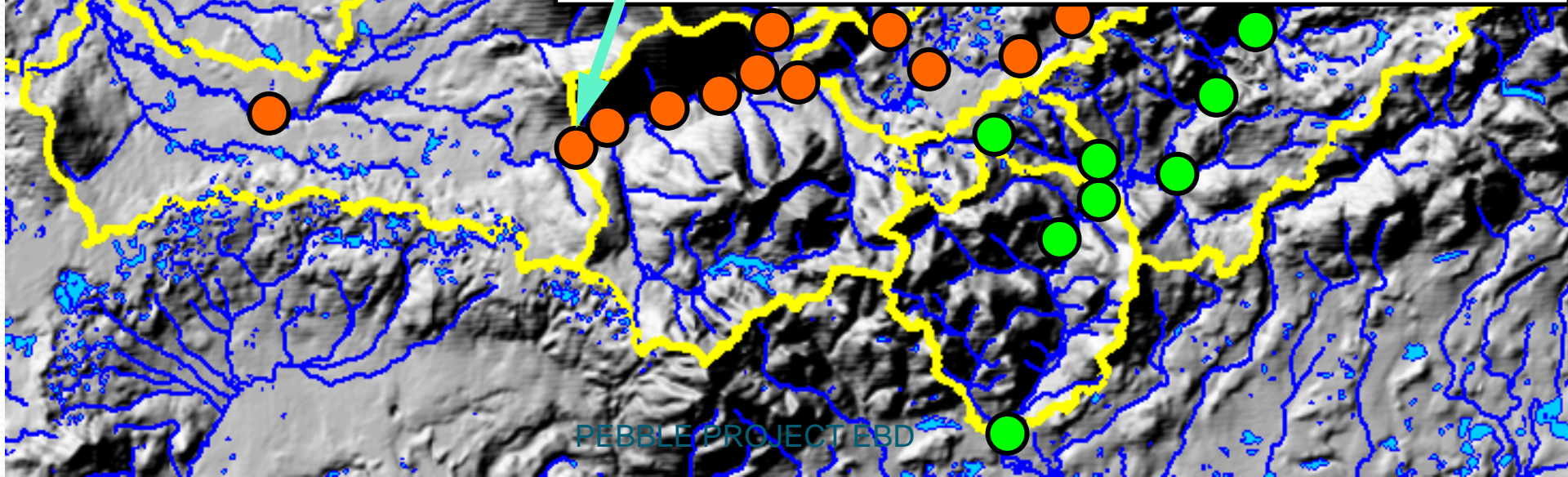
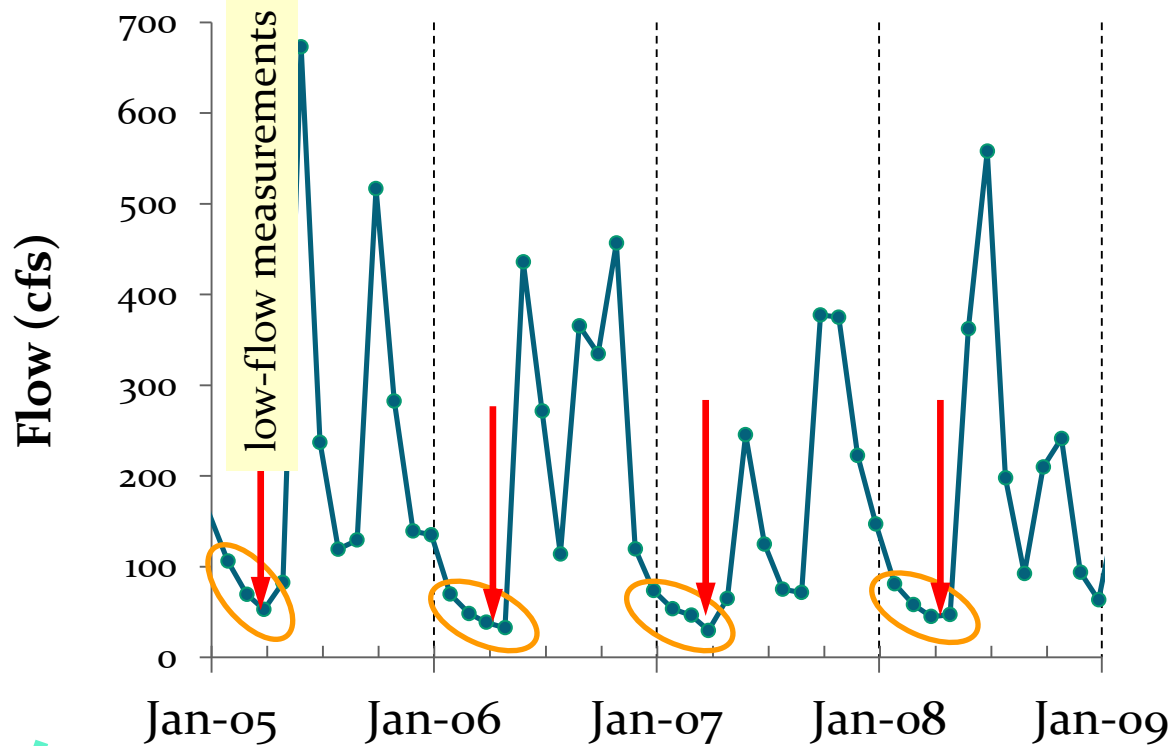
Results for groundwater discharge flow calibration targets from water balance (one per watershed)

Total Groundwater Discharge by Watershed (ft³)



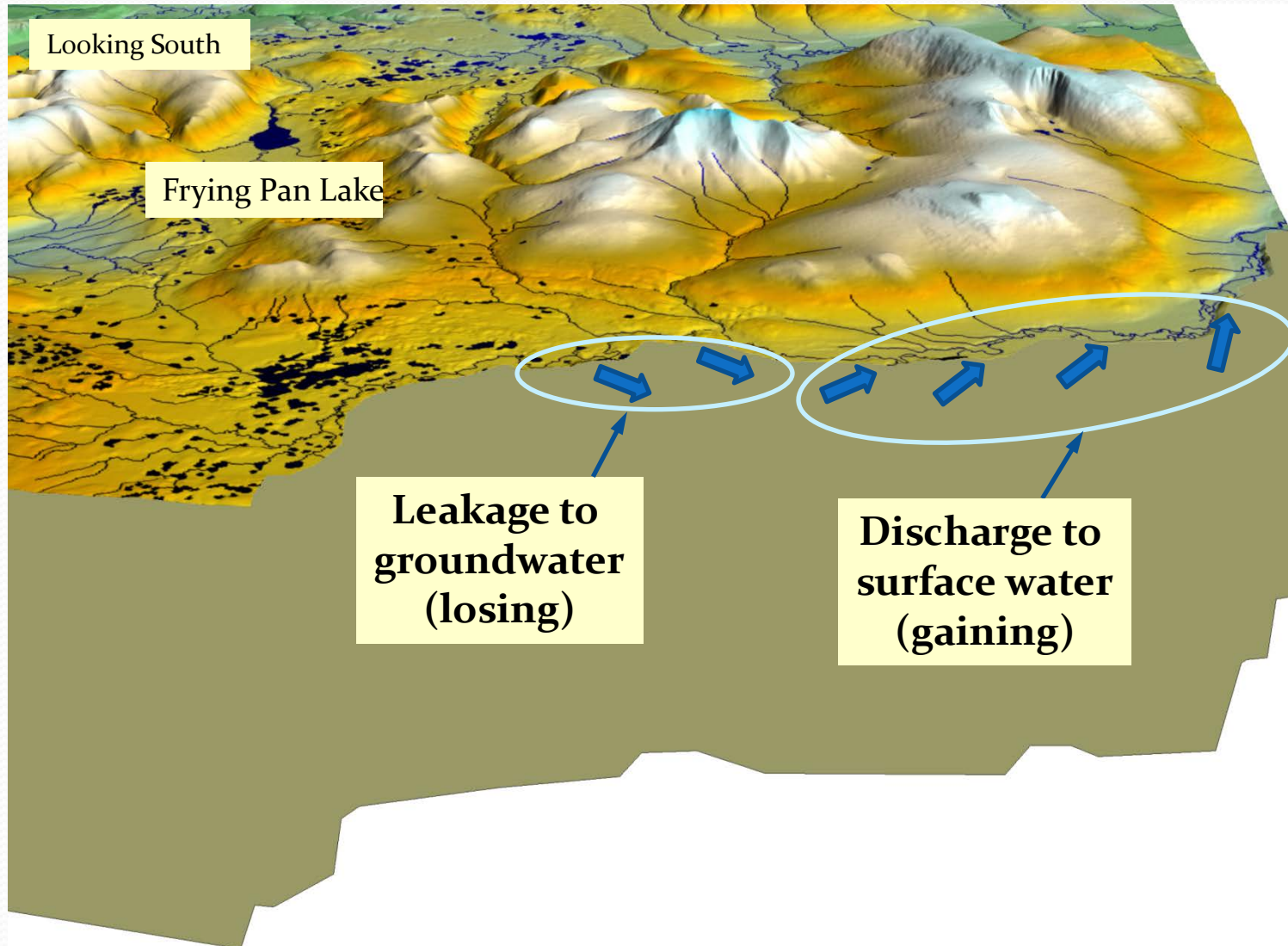
Low-flow groundwater
(Late winter field m

Average Monthly Streamflow SK100B

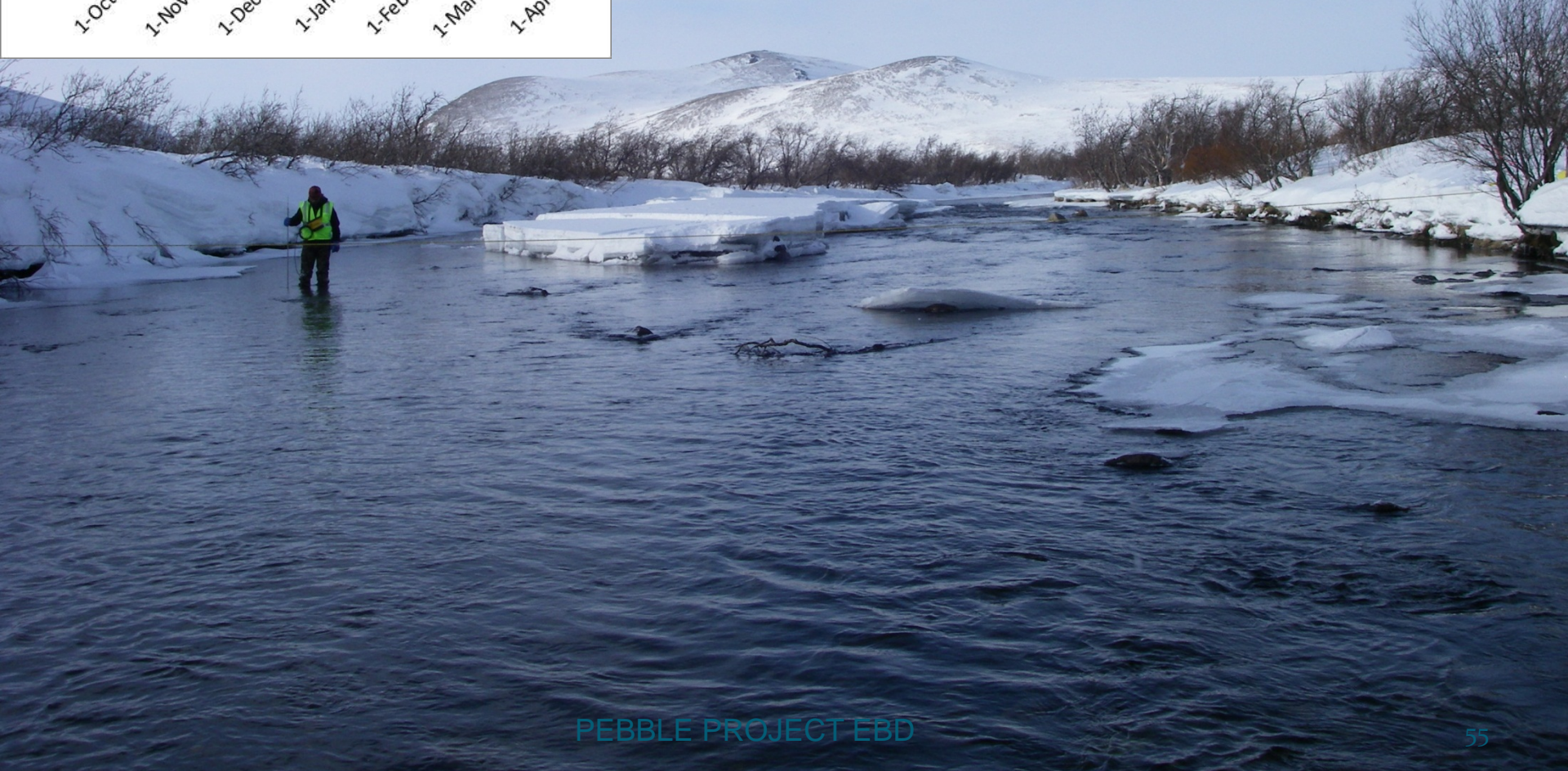
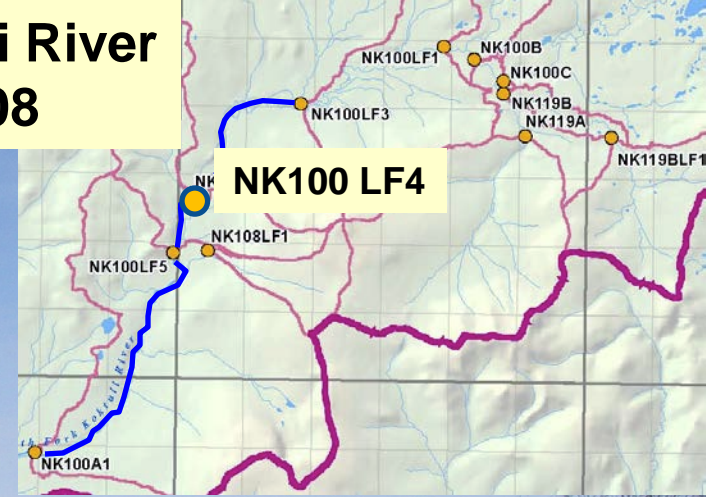
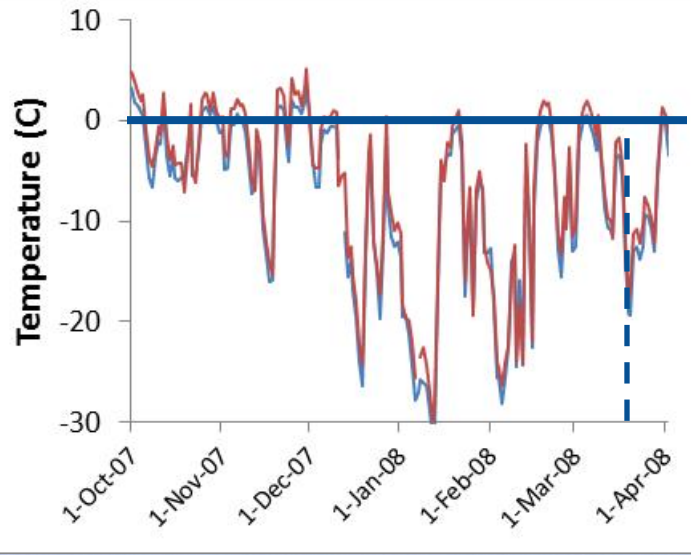


PEBBLE PROJECT EBD

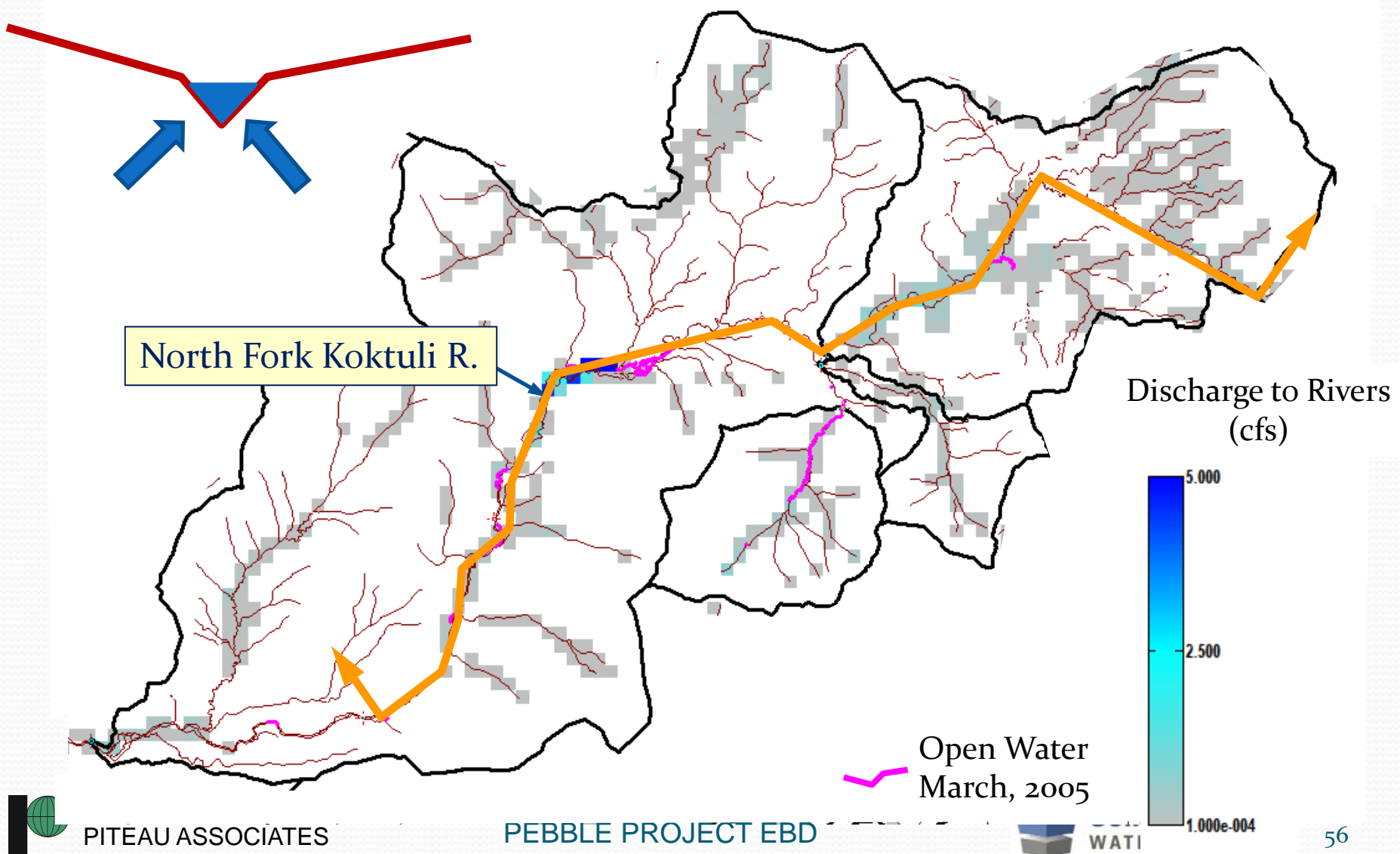
North Fork Koktuli River



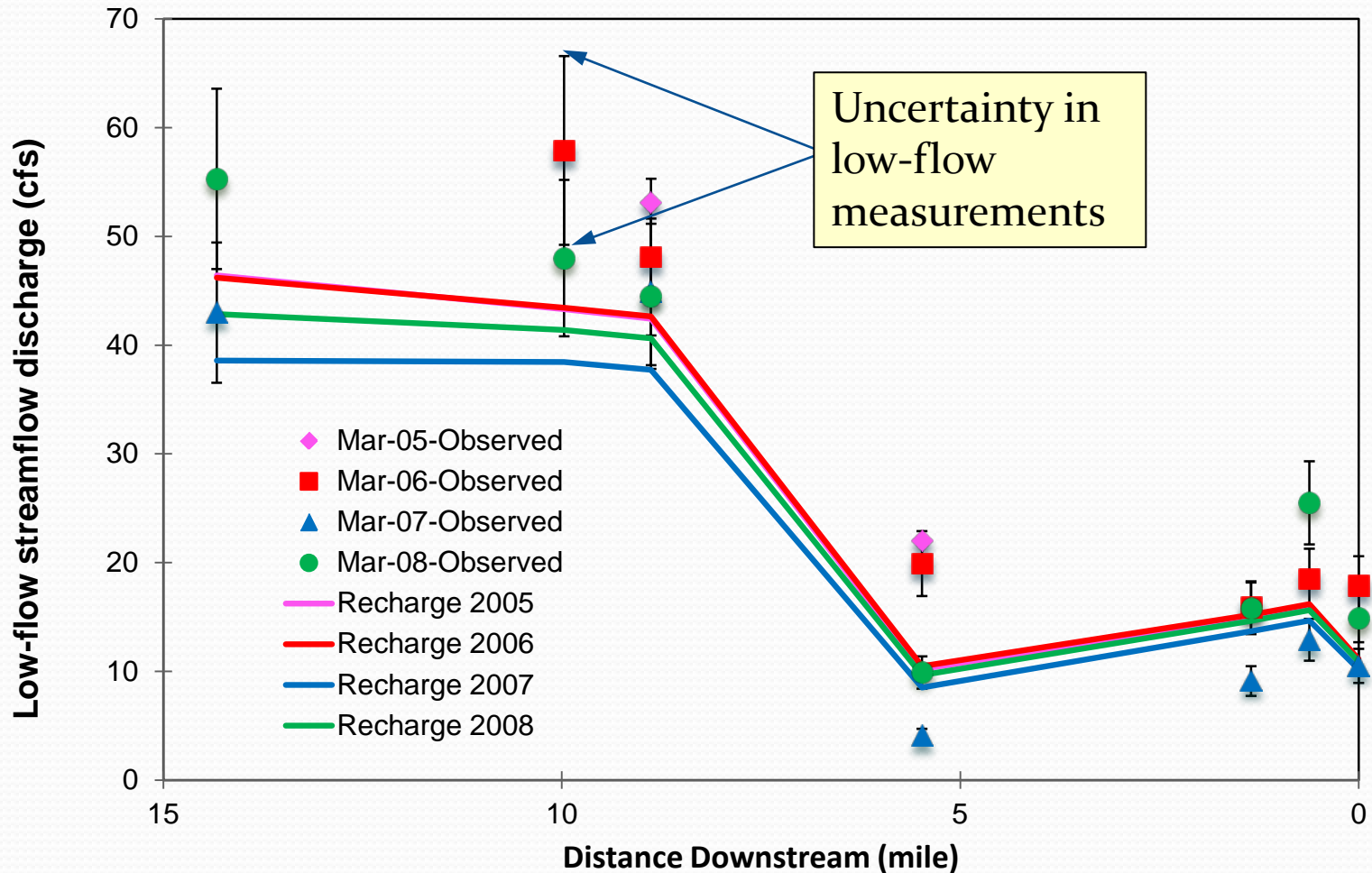
North Fork Kootenai River March 25, 2008



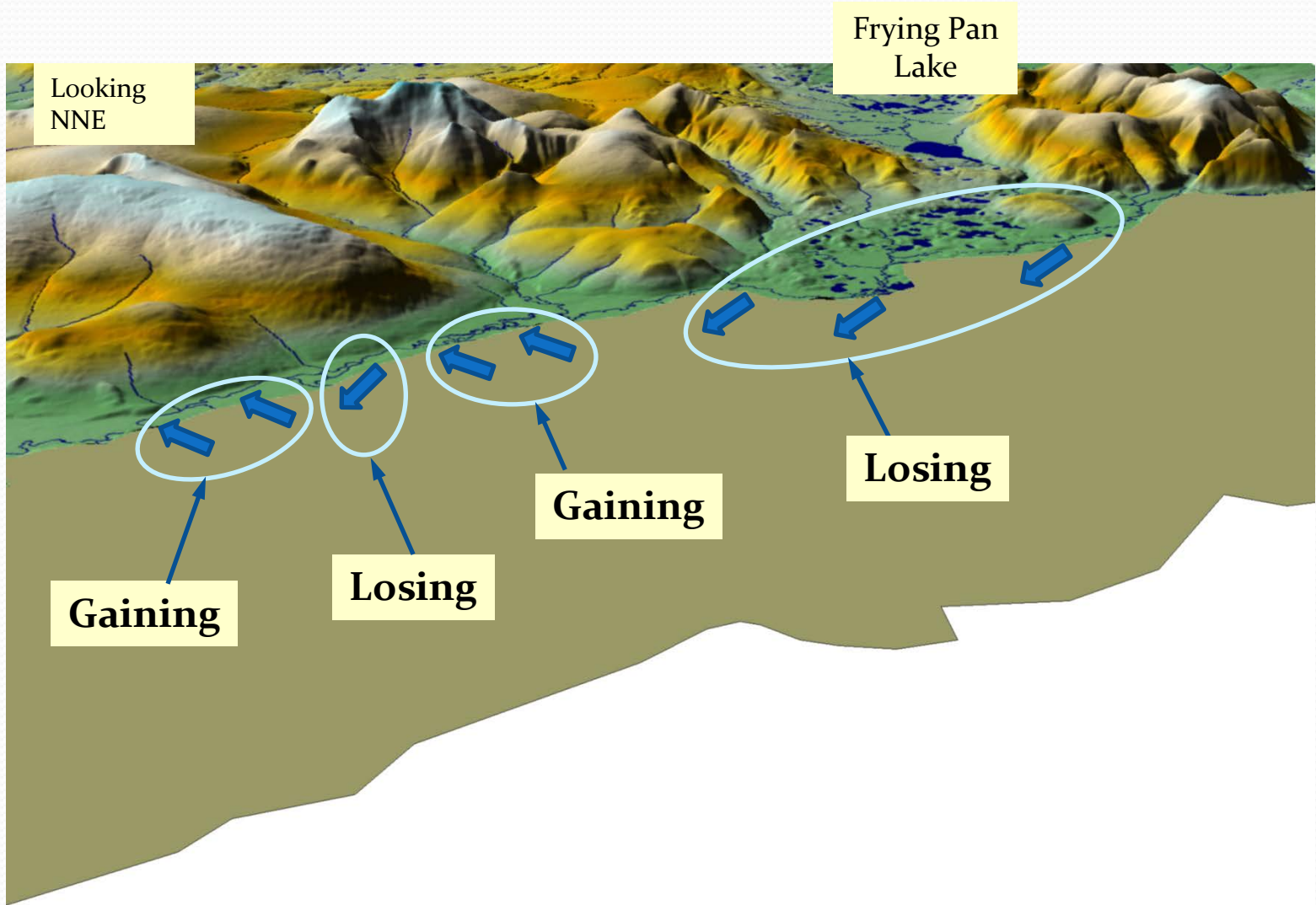
Groundwater Discharge to Rivers North Fork Koktuli River, March, 2005



Results of calibration to low-flow groundwater discharge North Fork Koktuli River



South Fork Koktuli River

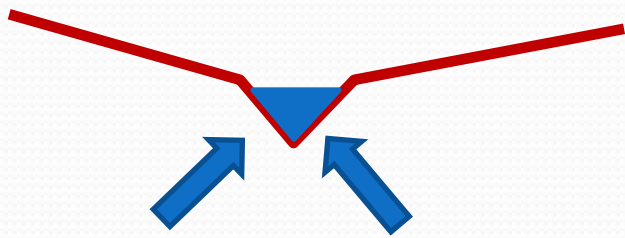
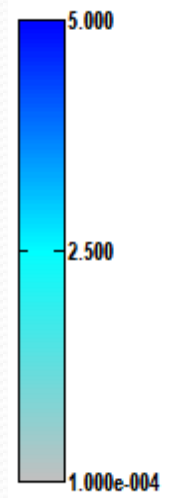


Groundwater Discharge to Rivers

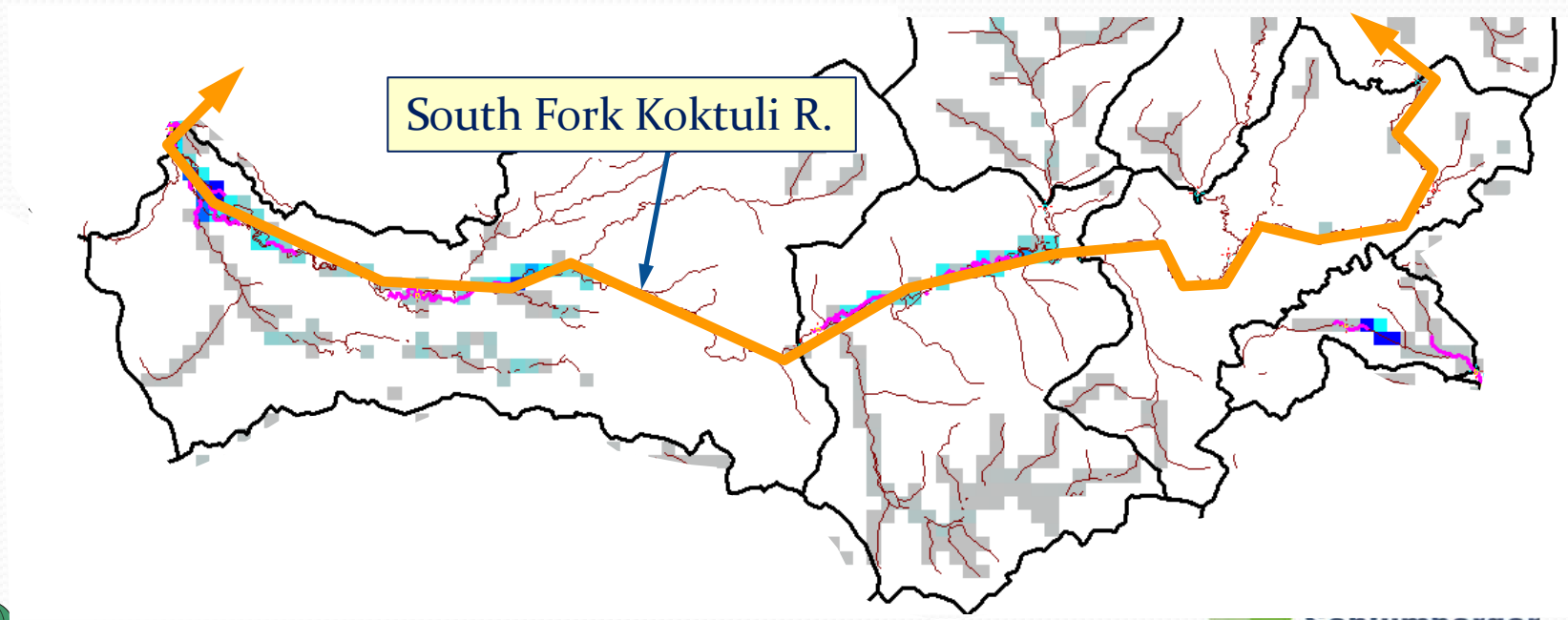
South Fork Koktuli River

March, 2005

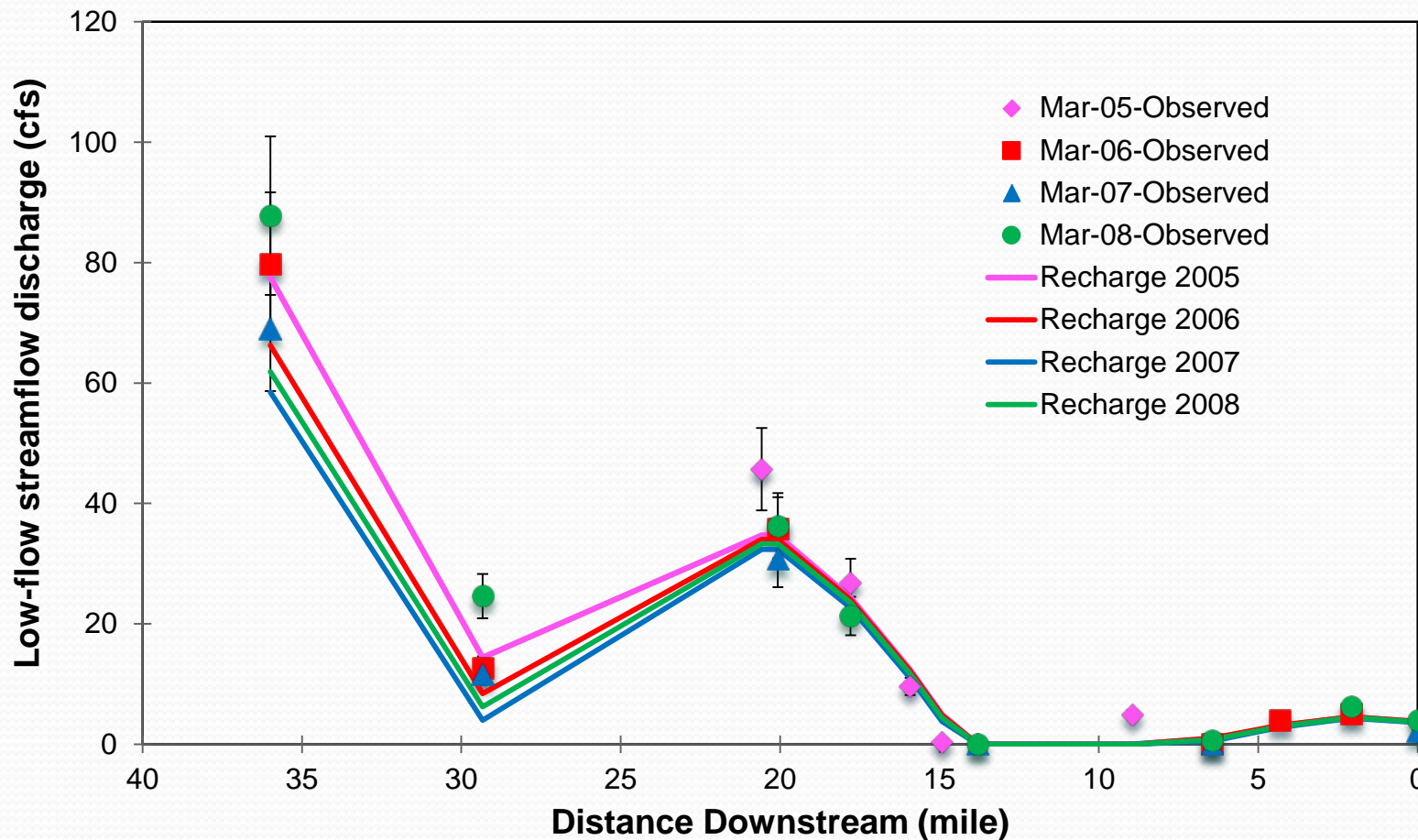
Discharge to Rivers
(cfs)



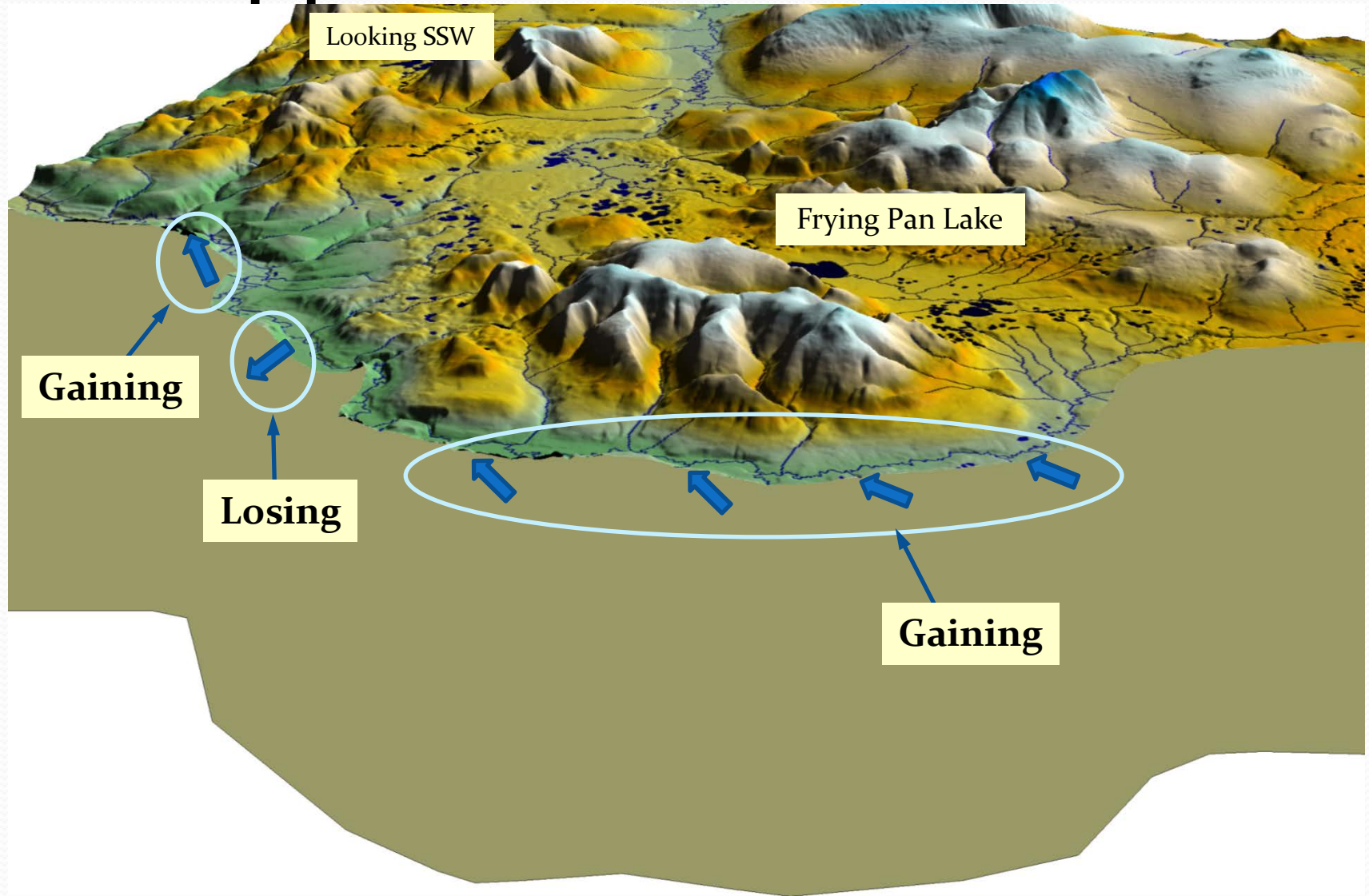
Open Water
March, 2005



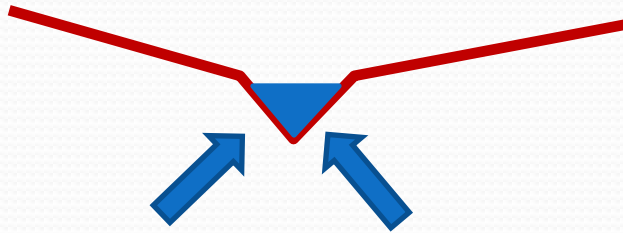
Results of calibration to low-flow groundwater discharge South Fork Kocktuli River



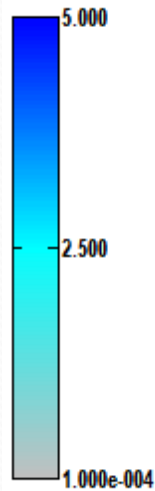
Upper Talarik Cr.



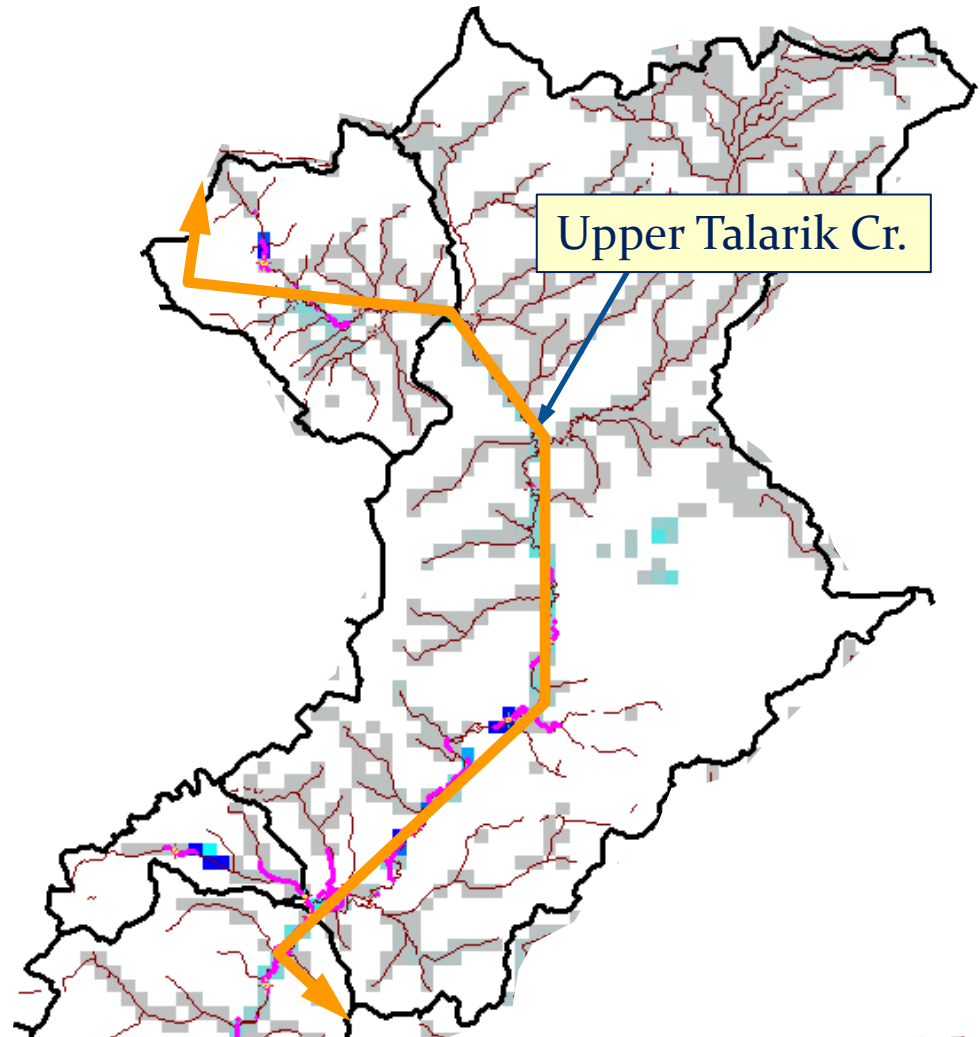
Groundwater Discharge to Rivers Upper Talarik Creek, March, 2005



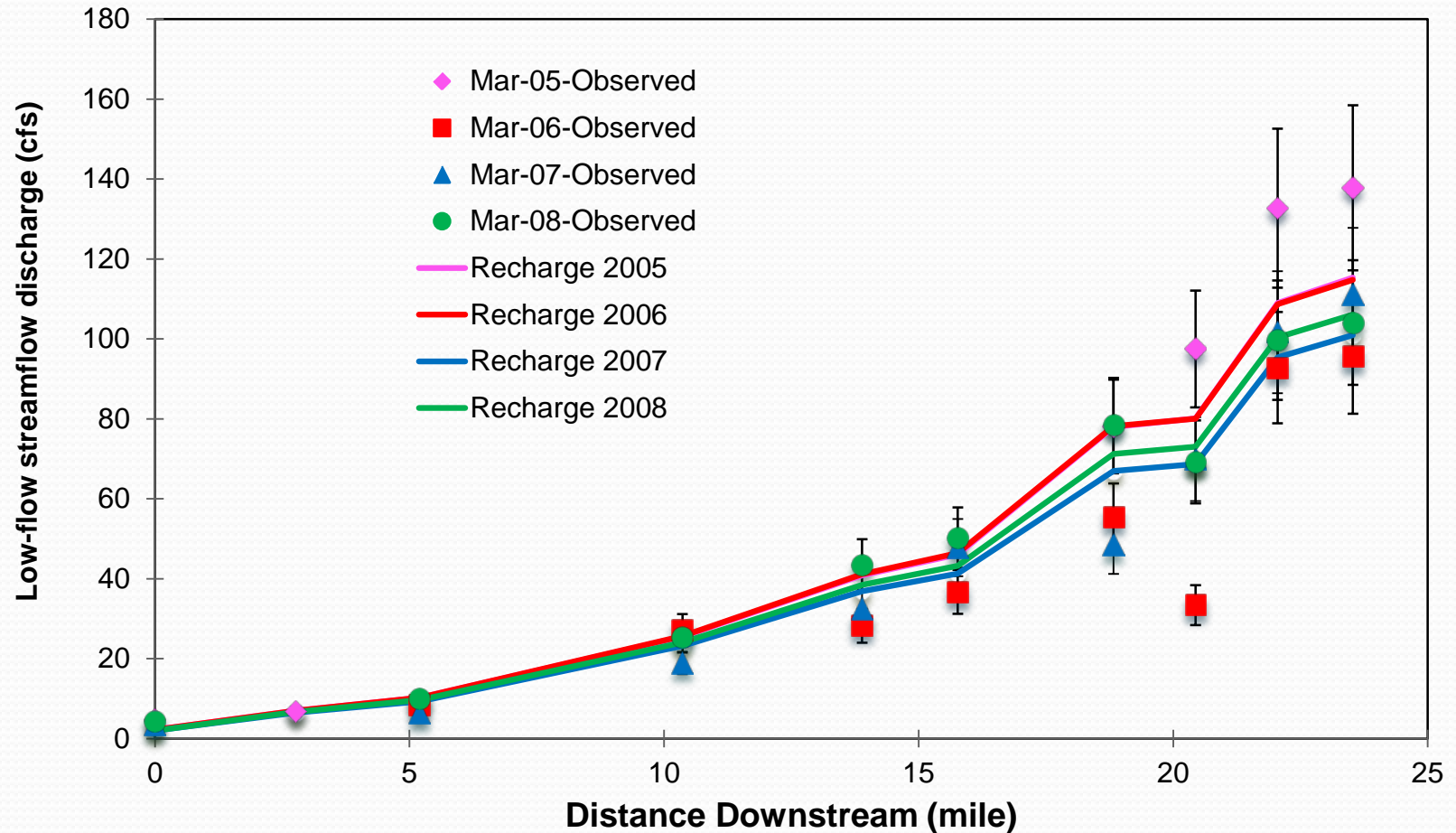
Discharge to Rivers
(cfs)



Open Water
March, 2005



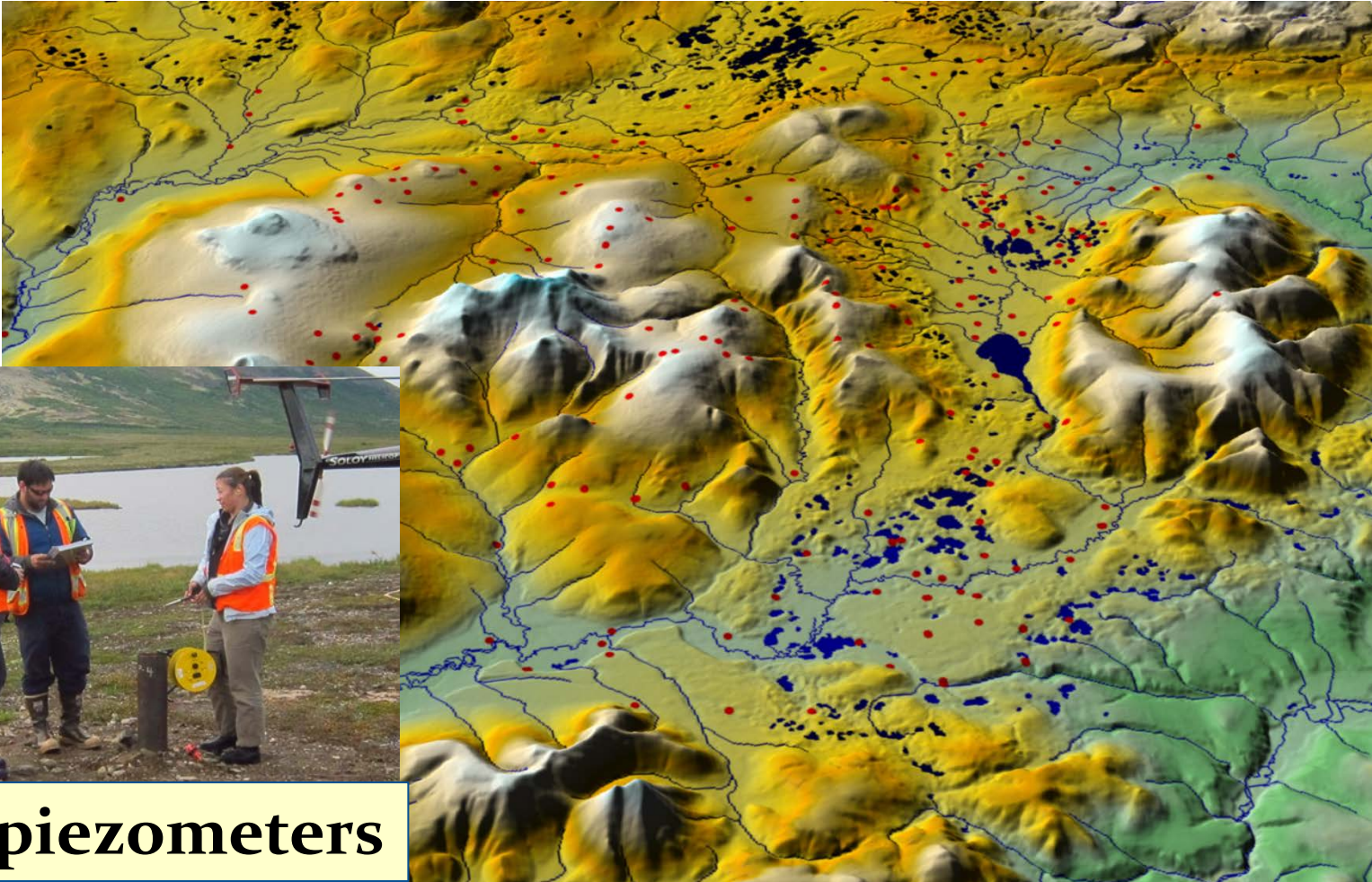
Results of calibration to low-flow groundwater discharge Upper Talarik Creek



Calibration Targets cont'd

- Groundwater Flows:
 - inter-watershed groundwater flows
 - net groundwater discharge
- **Groundwater Elevations**
- Calibrating to both heads *and* flows increases model uniqueness

Groundwater Elevation Targets

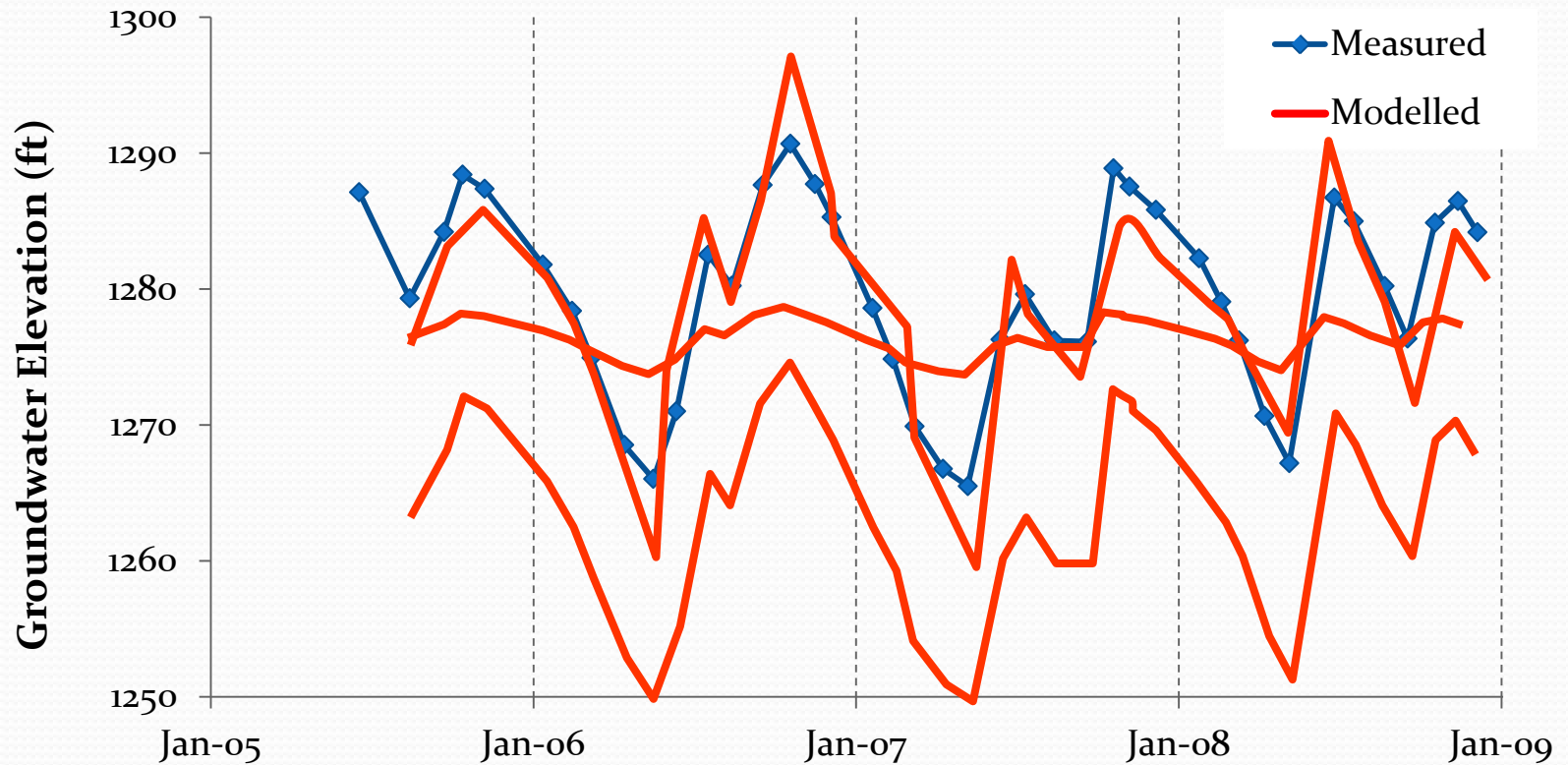


293 piezometers

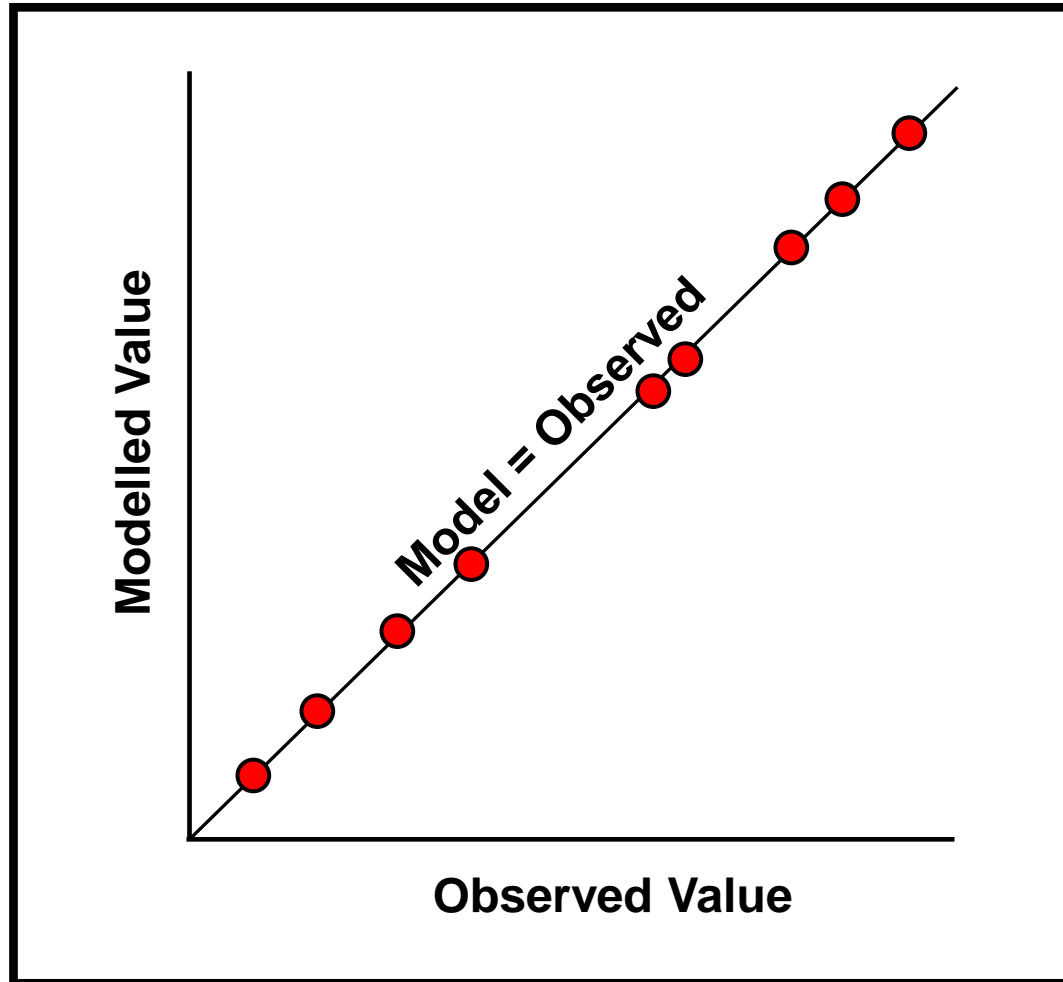
Groundwater Elevation vs. Time

Matching range and/or average

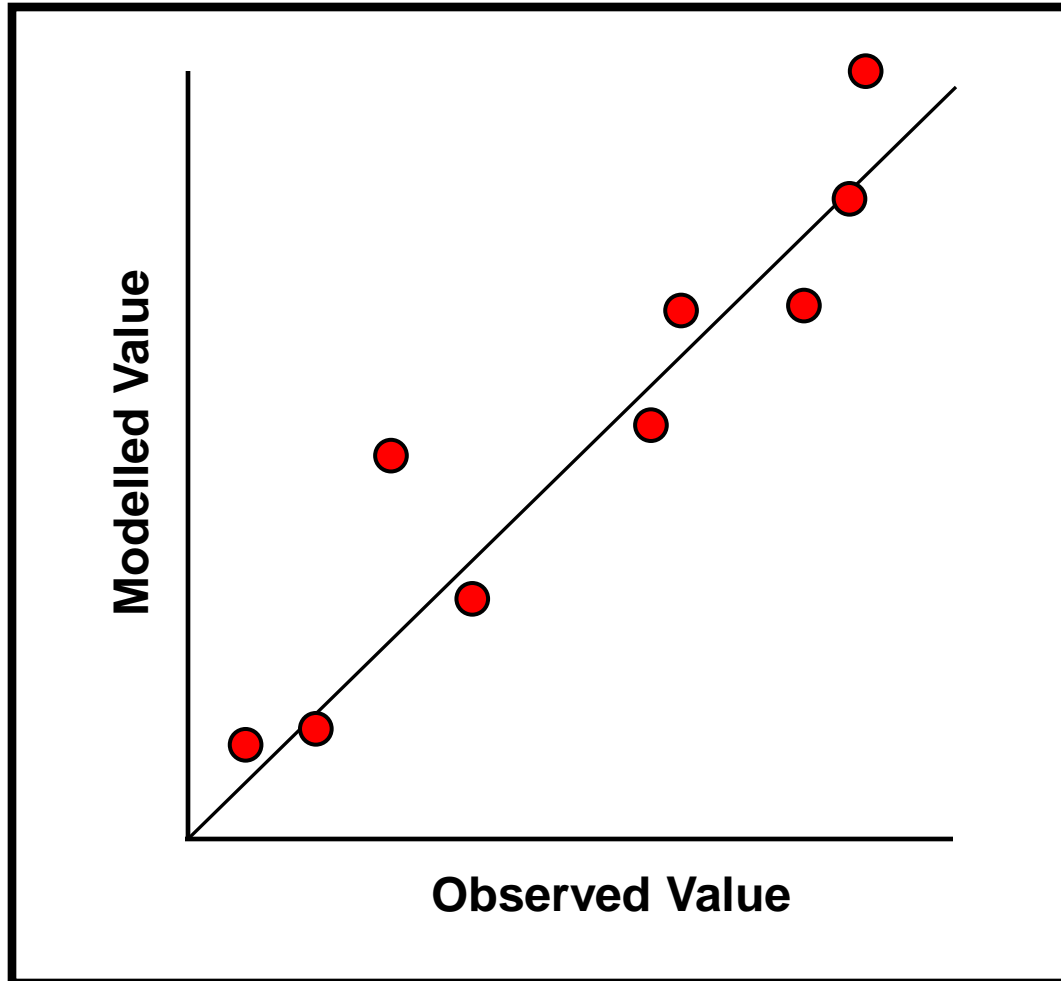
ave ave average elevation ✓ range ✓



Perfect Calibration

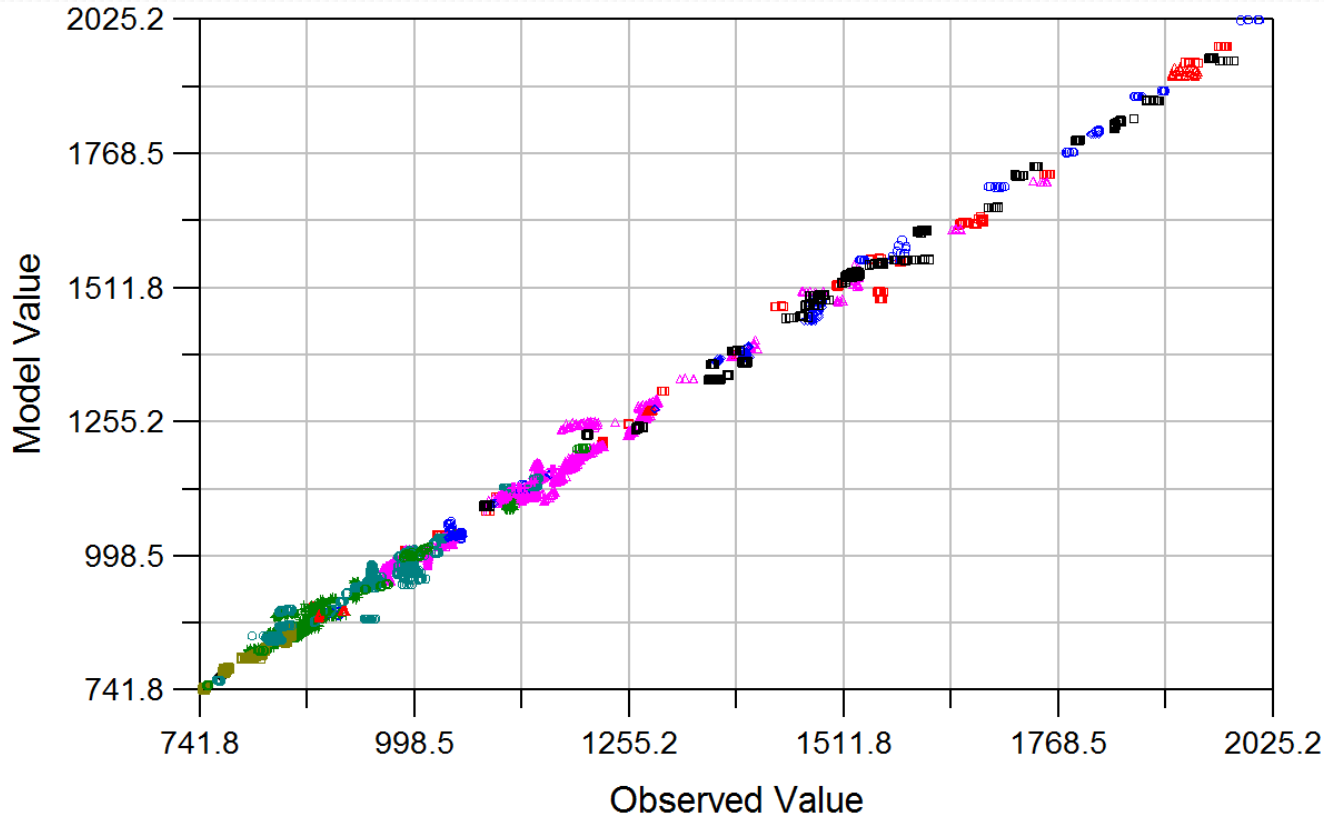


Real-life Calibration



Model vs. Observed Groundwater Elevation Transient Recharge (2005-2008) Whole Study Area

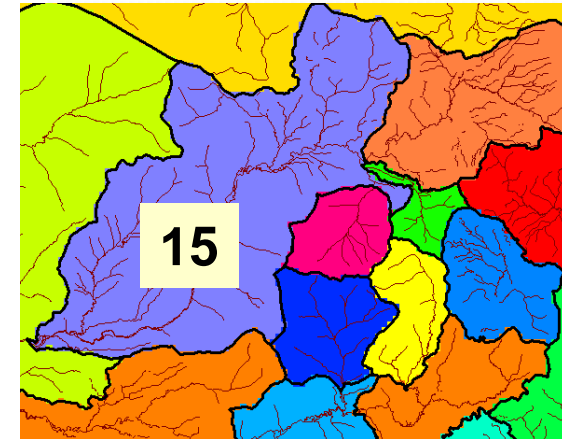
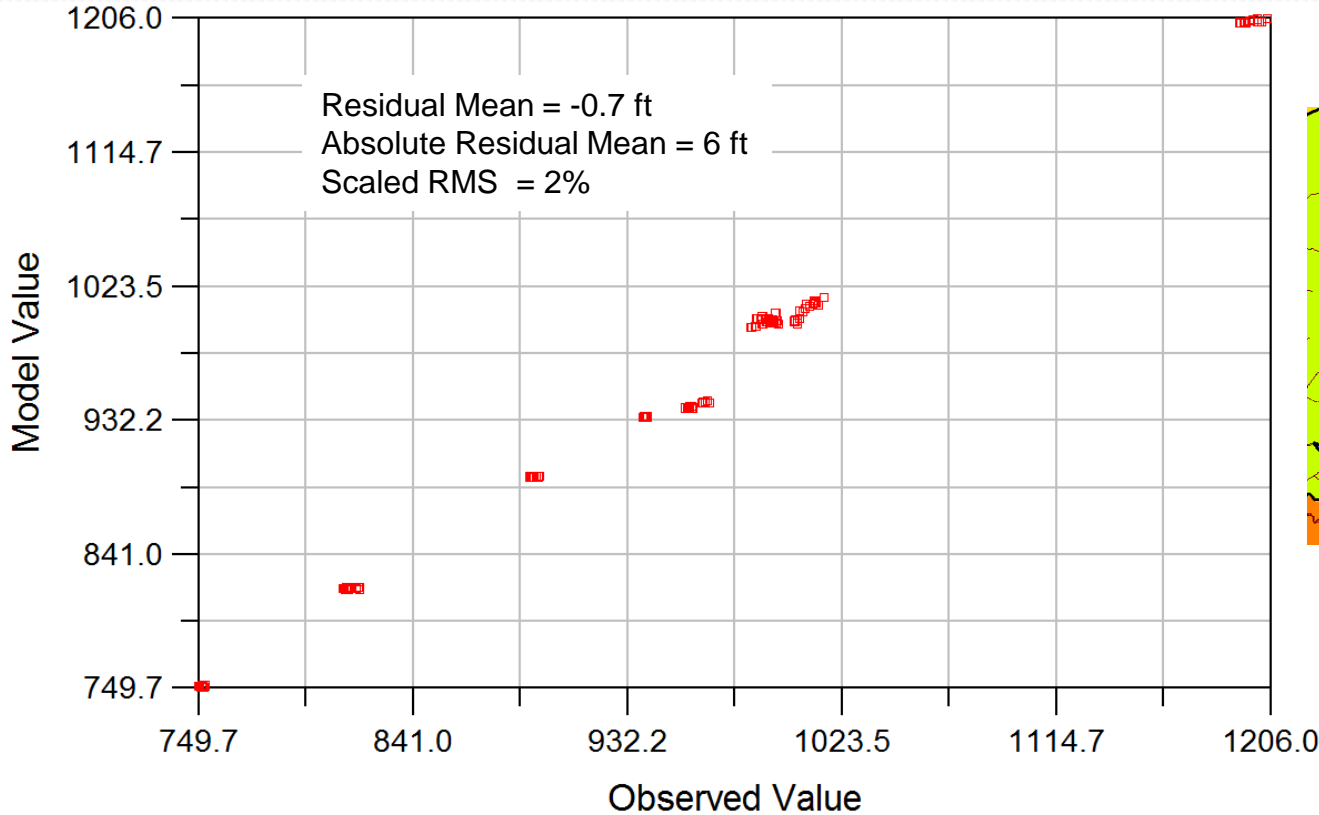
Modeled vs. Observed Value



Residual Mean = -0.8 ft
 Absolute Residual Mean = 11 ft
 Scaled RMS = 1%

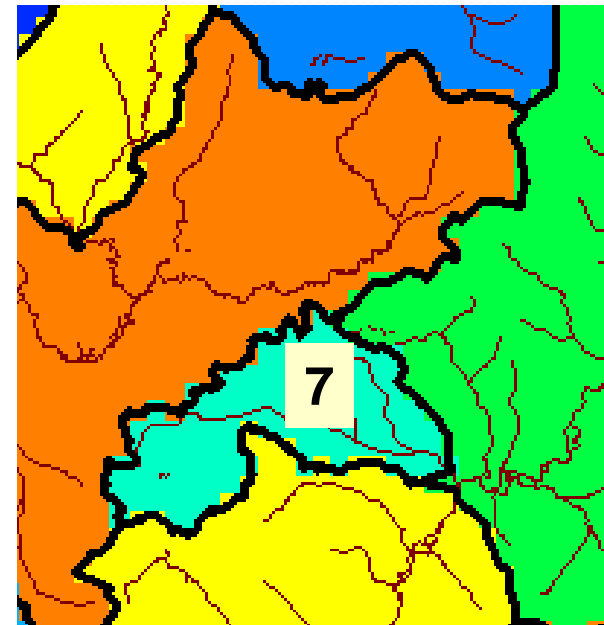
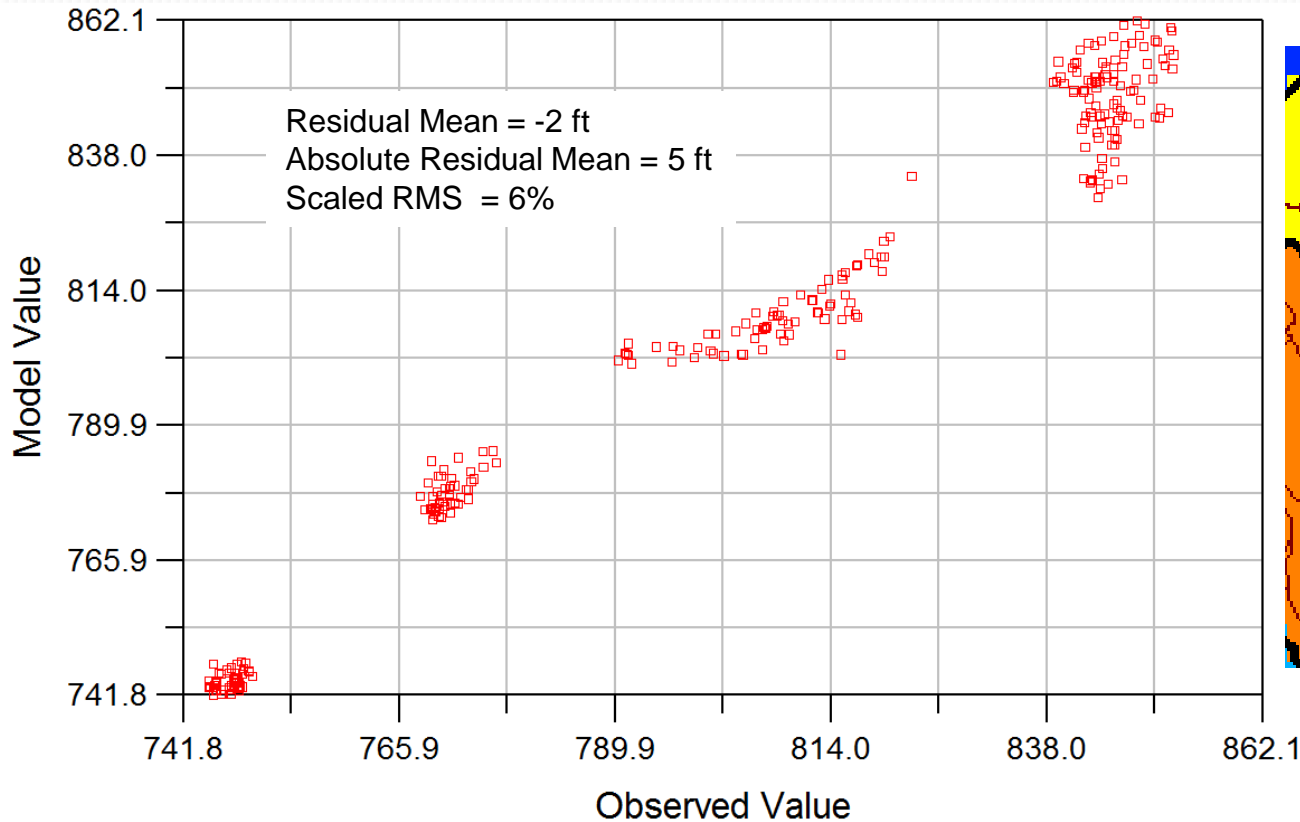
Model vs. Observed Groundwater Elevation Transient Recharge (2005-2008) North Fork Koktuli River (Area 15)

Modeled vs. Observed Value



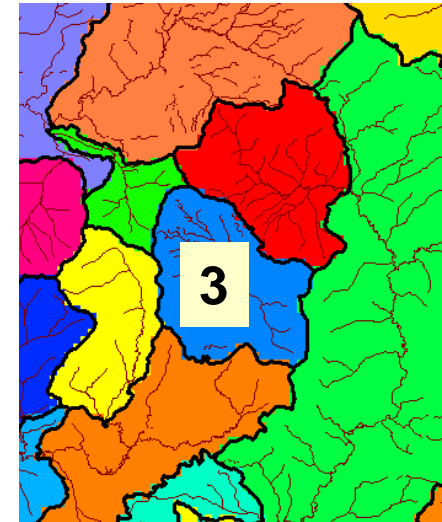
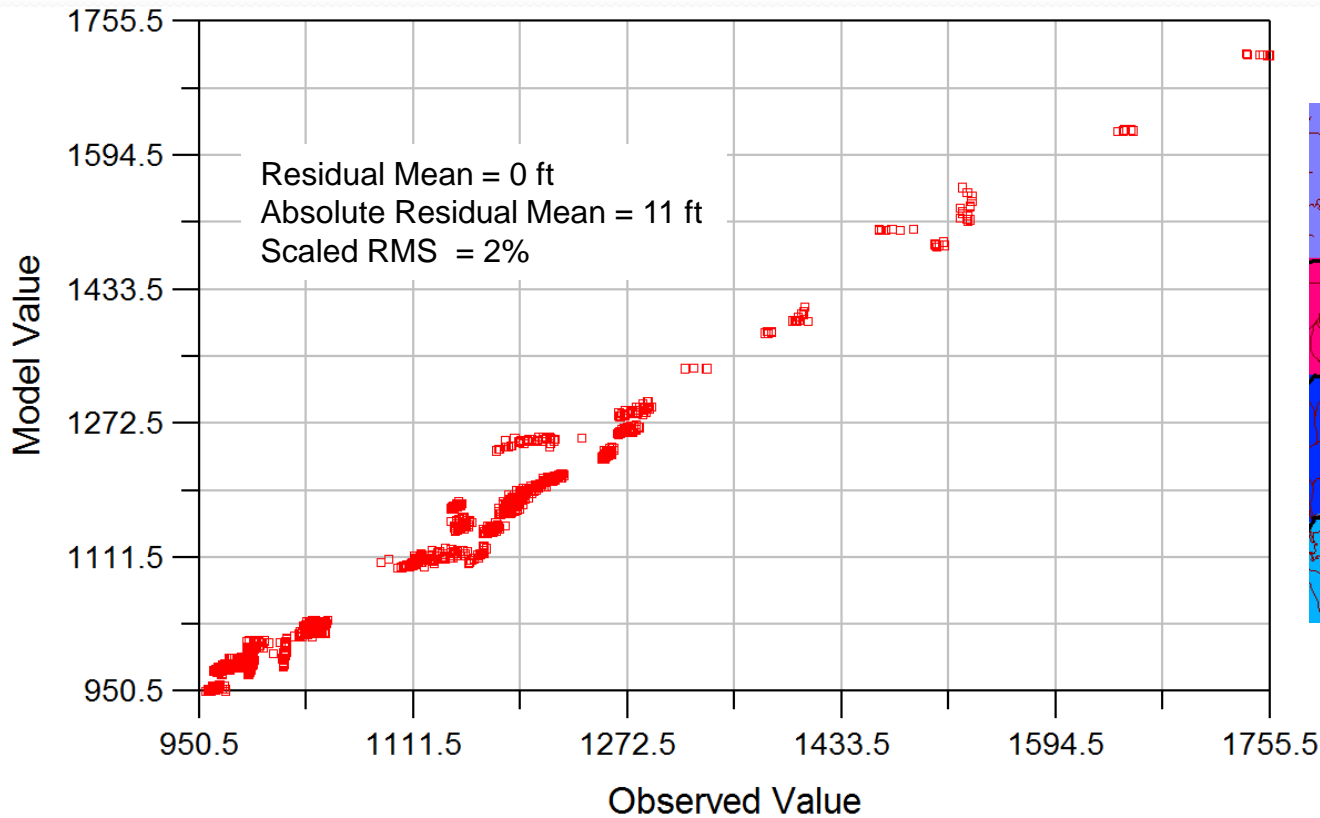
Model vs. Observed Groundwater Elevation Transient Recharge (2005-2008) Upper Talarik Creek (Area 7)

Modeled vs. Observed Value



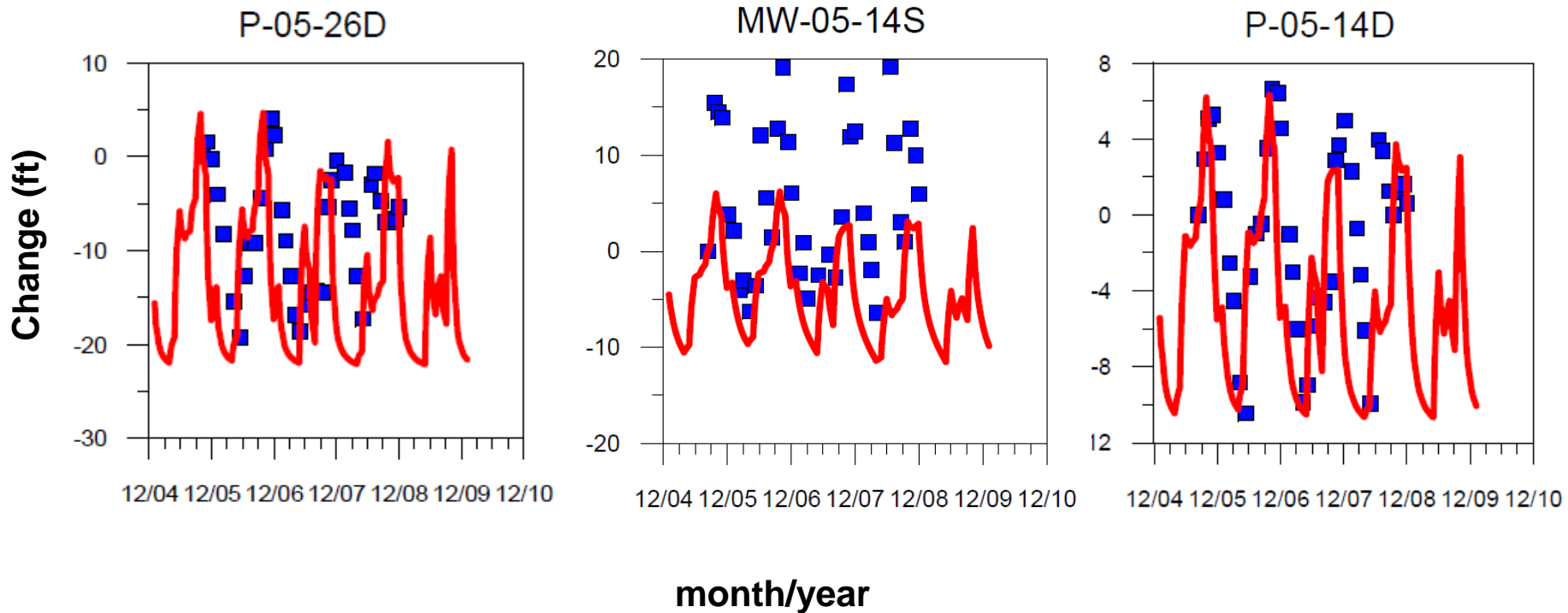
Model vs. Observed Groundwater Elevation Transient Recharge (2005-2008) South Fork Kaktuli River (Area 3)

Modeled vs. Observed Value



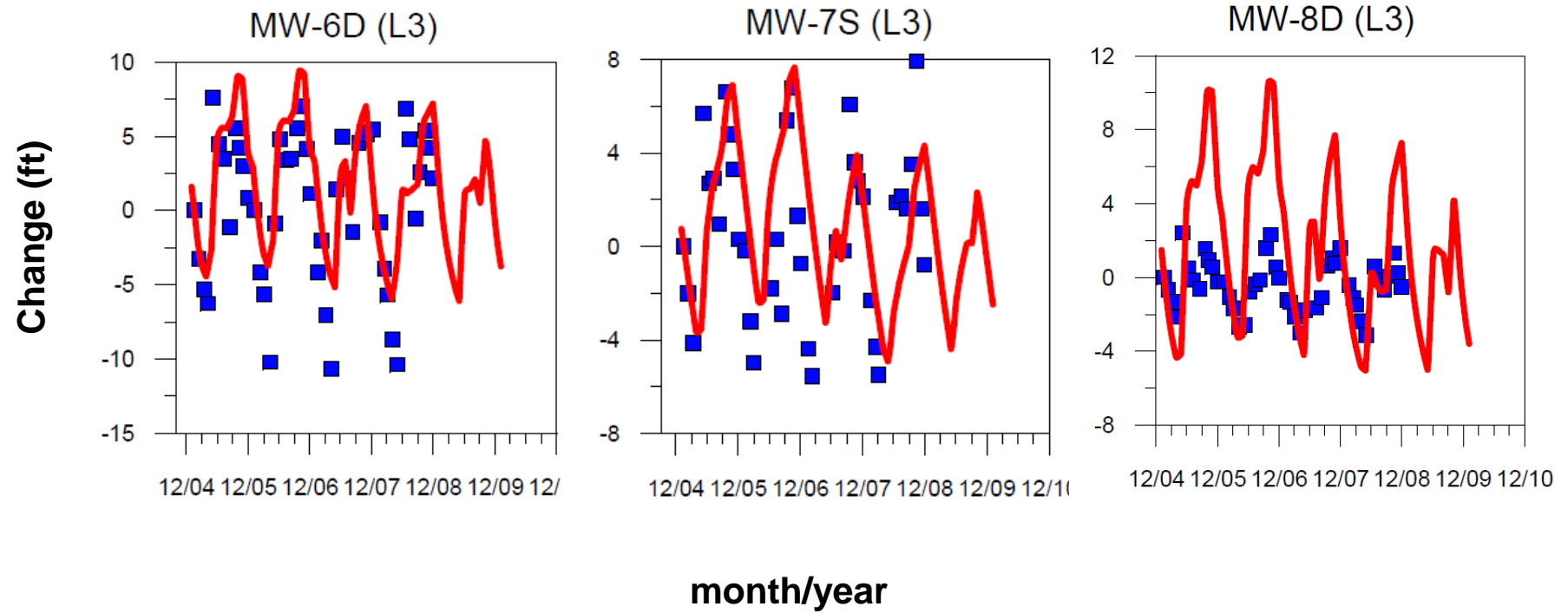
Calibration to Transient Groundwater Elevation Changes

South Fork Kocktuli (Area 5)



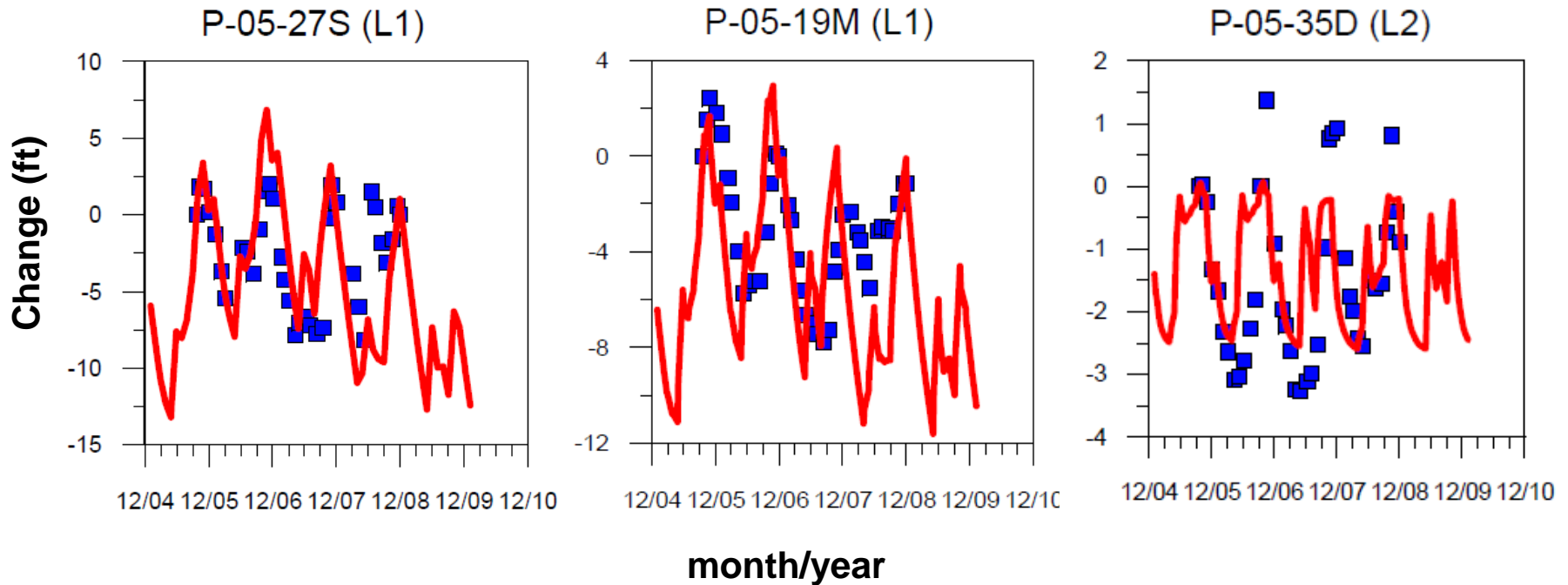
Calibration to Transient Groundwater Elevation Changes

North Fork Koktuli (Areas 12 and 13)



Calibration to Transient Groundwater Elevation Changes

Upper Talarik (Areas 7 and 9)



Agenda

1. Modeling Objectives
2. Conceptual Model
3. Integrated Modeling Approach
4. Calibration Process
5. Summary

Summary

1/2

Approach to Groundwater Modeling

- integrated approach
 - water balance: lumped flows
 - groundwater model:
geology + groundwater elevations + flows
- transient recharge (2005-2008)
- distributed recharge
- geology in groundwater model based on drill holes
- groundwater-surface-water interaction
 - water balance calibration emphasized low flows of continuous stations
 - additional stations measured during low-flow periods
- monthly groundwater elevations at multiple depths

Summary

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Calibration Results

- inter-watershed groundwater flows matched reasonably for most watersheds
- groundwater discharge matched reasonably for most watersheds
- low flows matched reasonably in most cases
- the character of losing and gaining reaches along the rivers matched well
- average groundwater elevations matched well for most watersheds
- range of groundwater elevations (monthly response)
 - excellent in some cases
 - some areas under- or over-responded

Questions ...

