Recharge enhancement in depleting aquifers: Delayed drainage by low-permeability sediments

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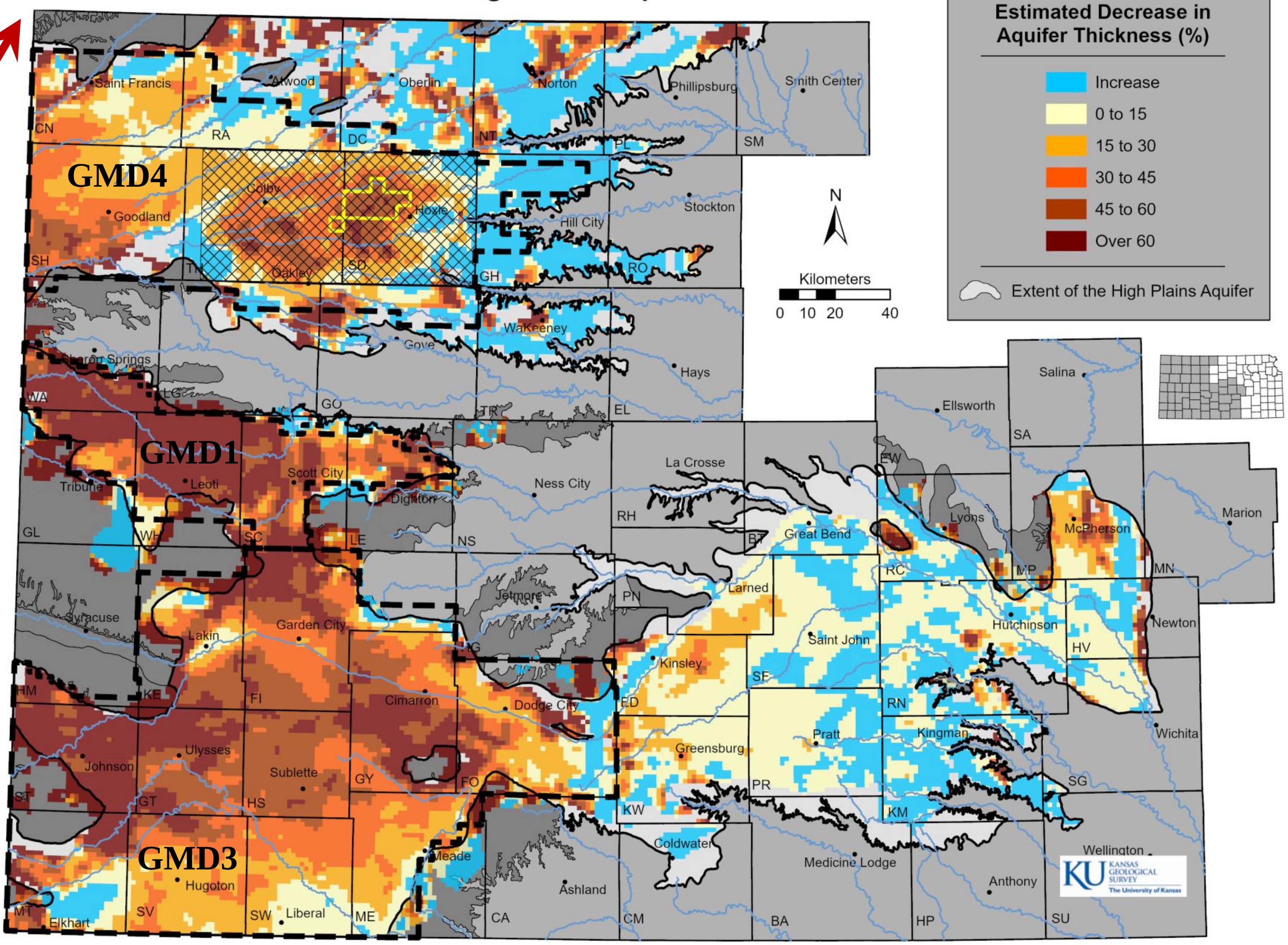
Acknowledgements

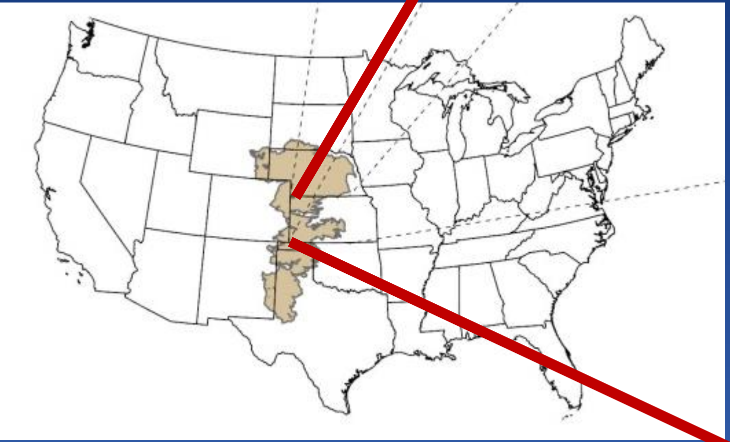
- Kansas Water Office, Kansas Water Plan, and Kansas Groundwater Management Districts.
- The United States Department of Agriculture (USDA) and the United States National Science Foundation (NSF) under USDA-NIFA/NSF INFEWS subaward RC108063UK.

Outline

- Recharge enhancement in Kansas HPA
- Delayed drainage as the major source of recharge enhancement:
  A) Lithologic logs
  B) Specific yield estimates
  C) Groundwater modeling results
- Conclusion and future work

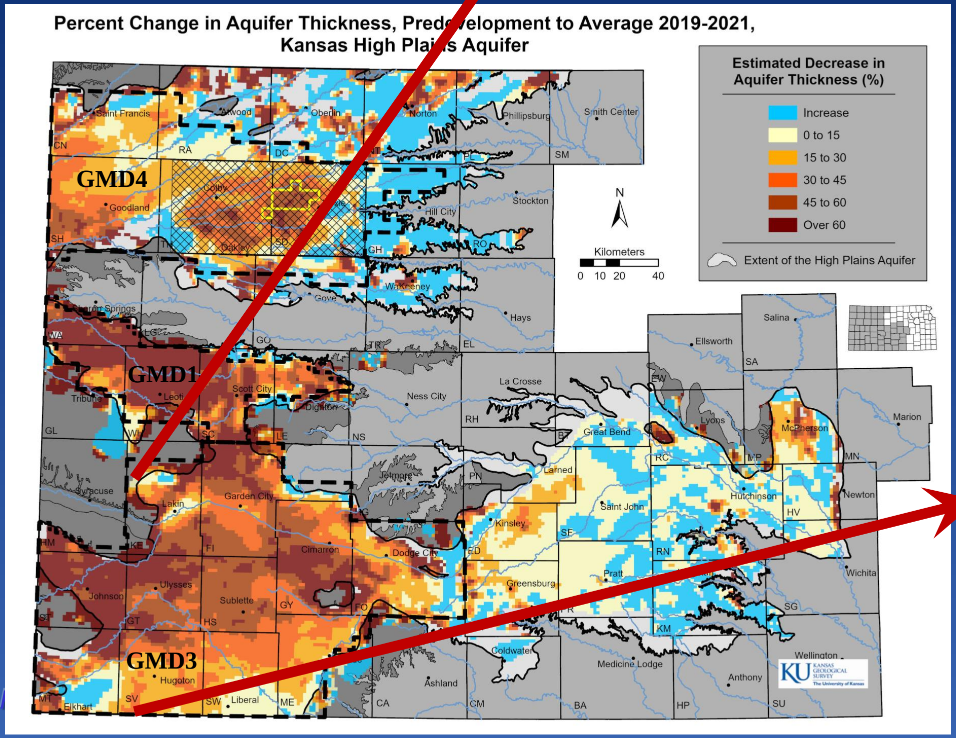
Change in Kansas HPA Thickness

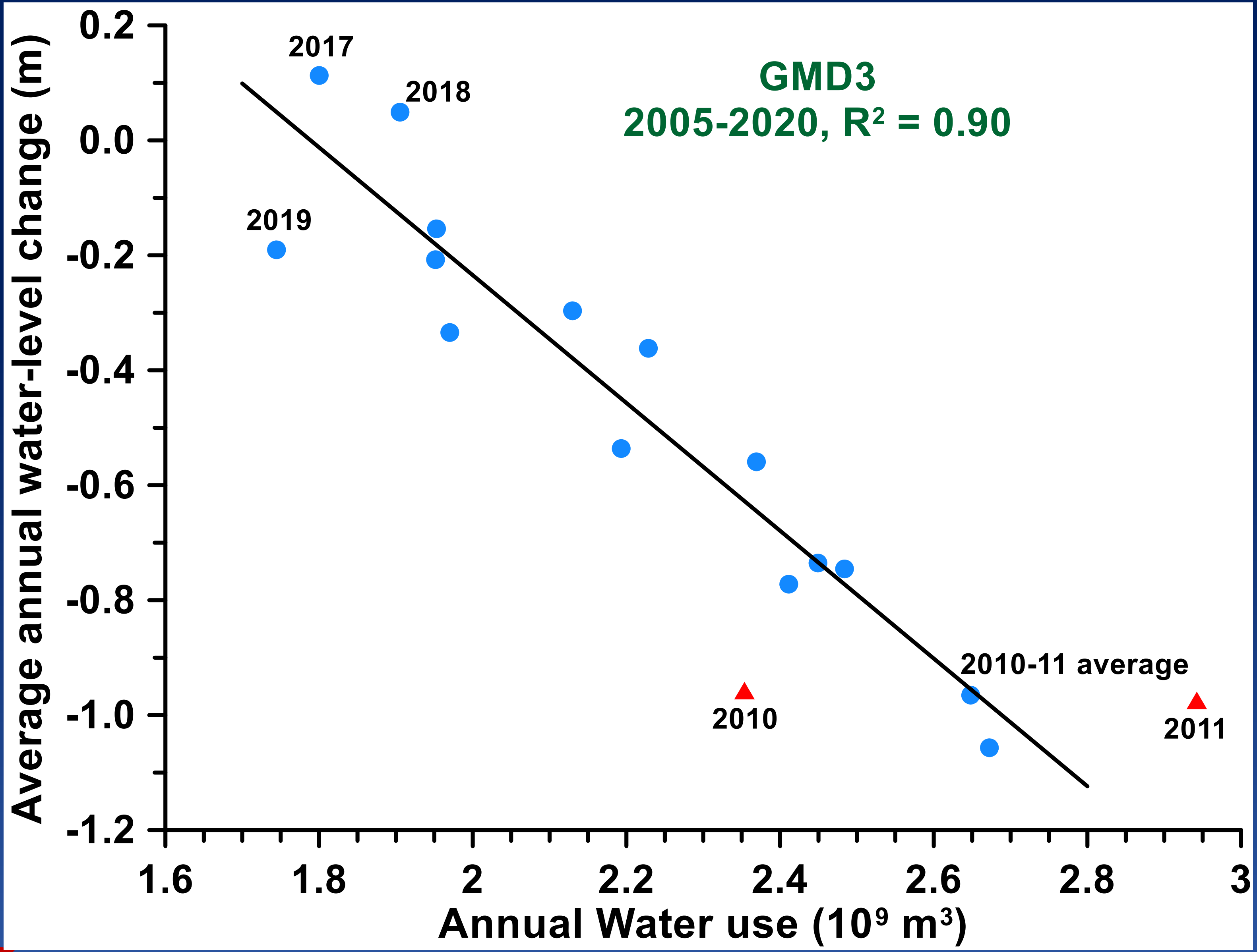




Kansas Geological Survey

GMD3 Water Balance Analysis

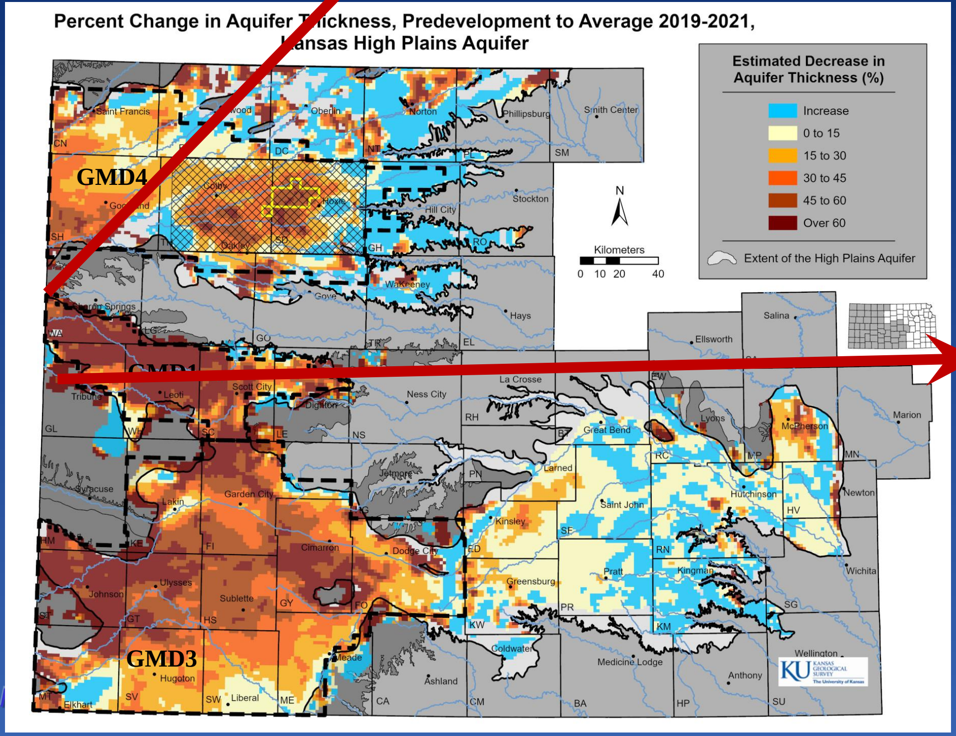


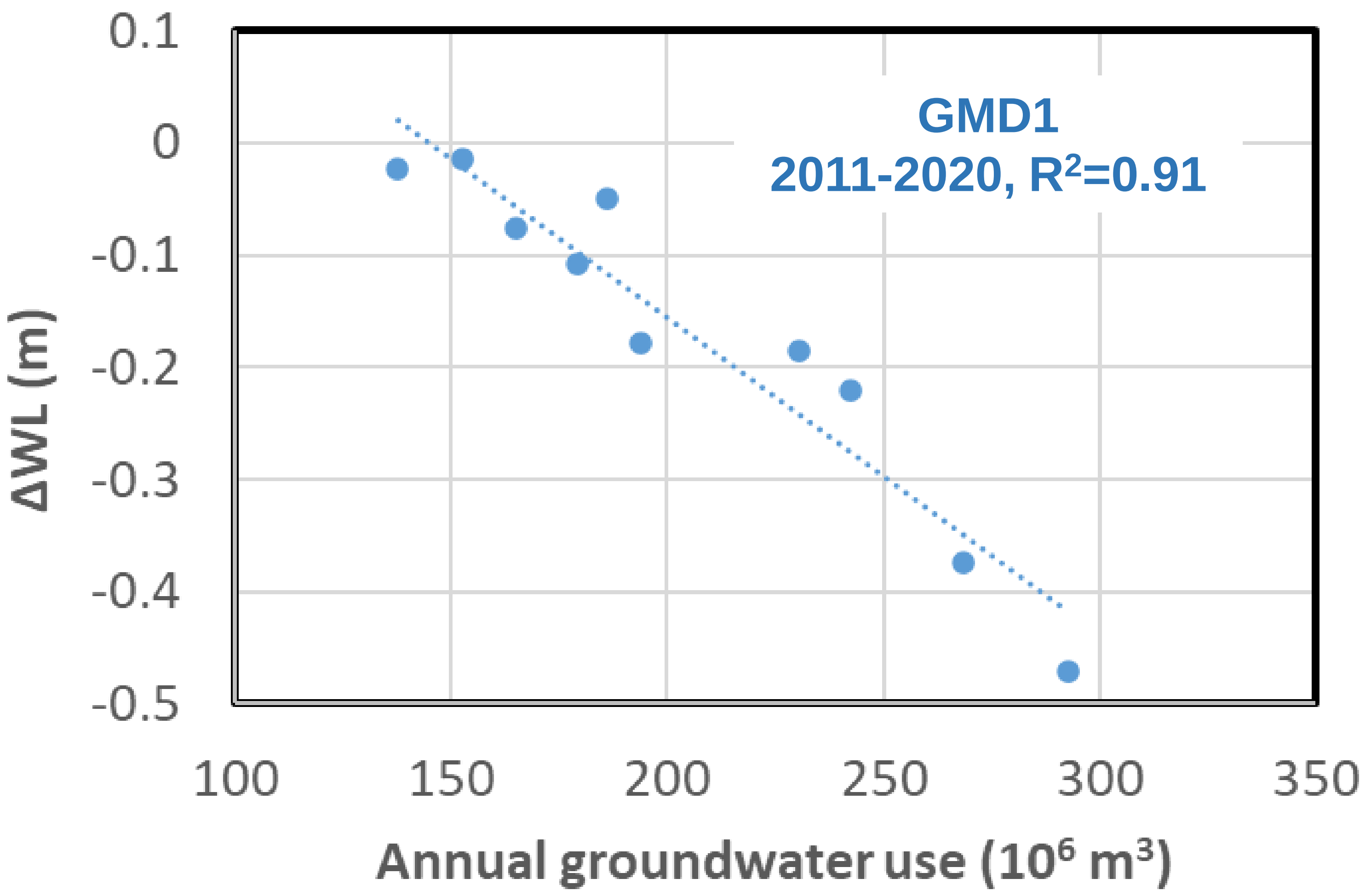


Net Inflow 8 cm/yr

Precip Recharge 2.5 cm/yr

GMD1 Water Balance Analysis

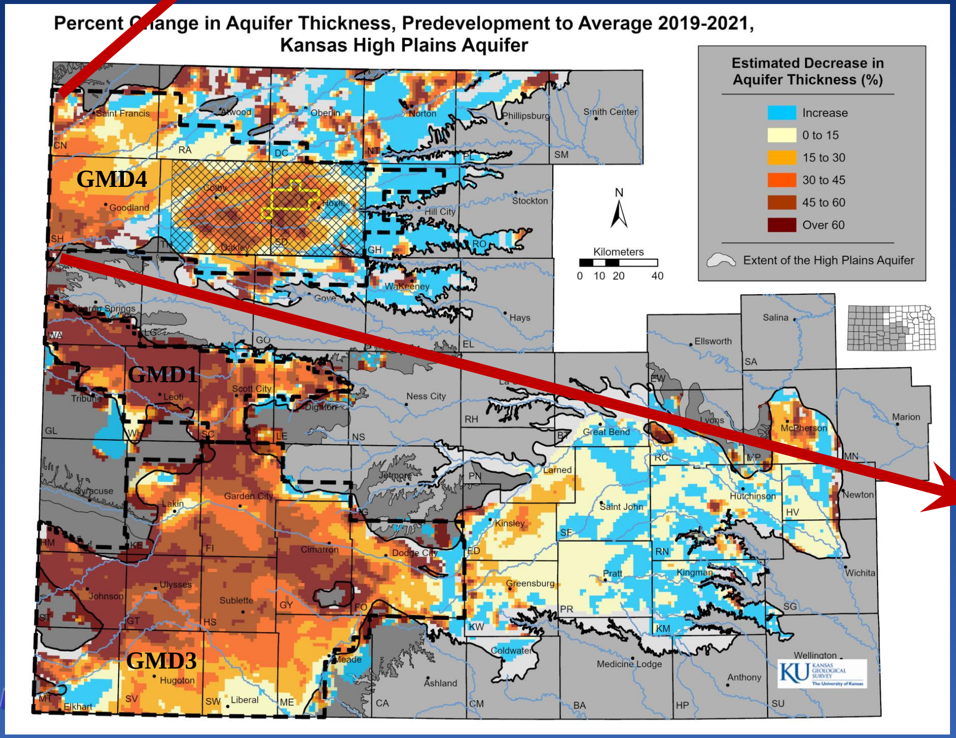


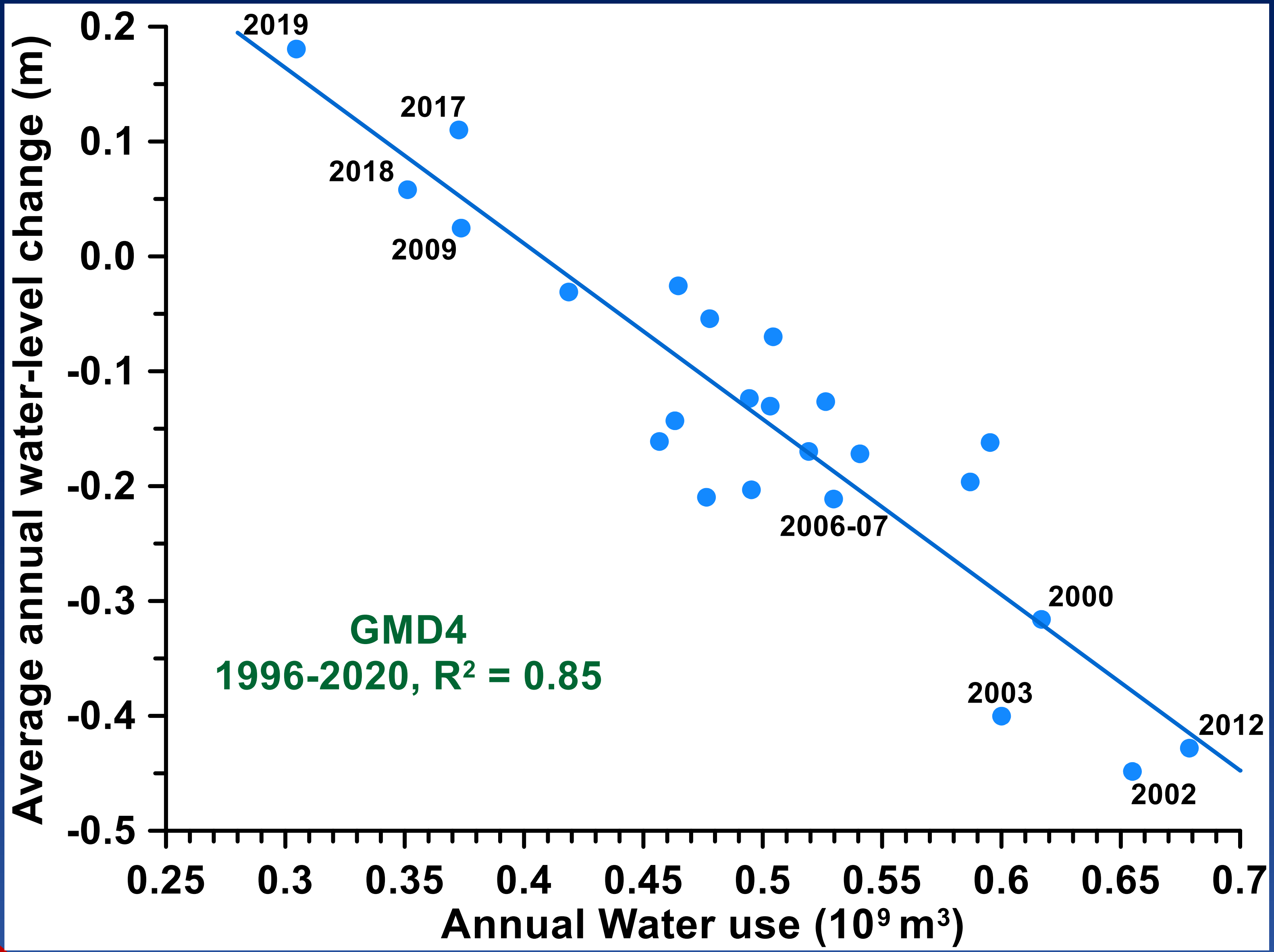


Net Inflow 3 cm/yr

Precip Recharge 1.3 cm/yr

GMD4 Water Balance Analysis

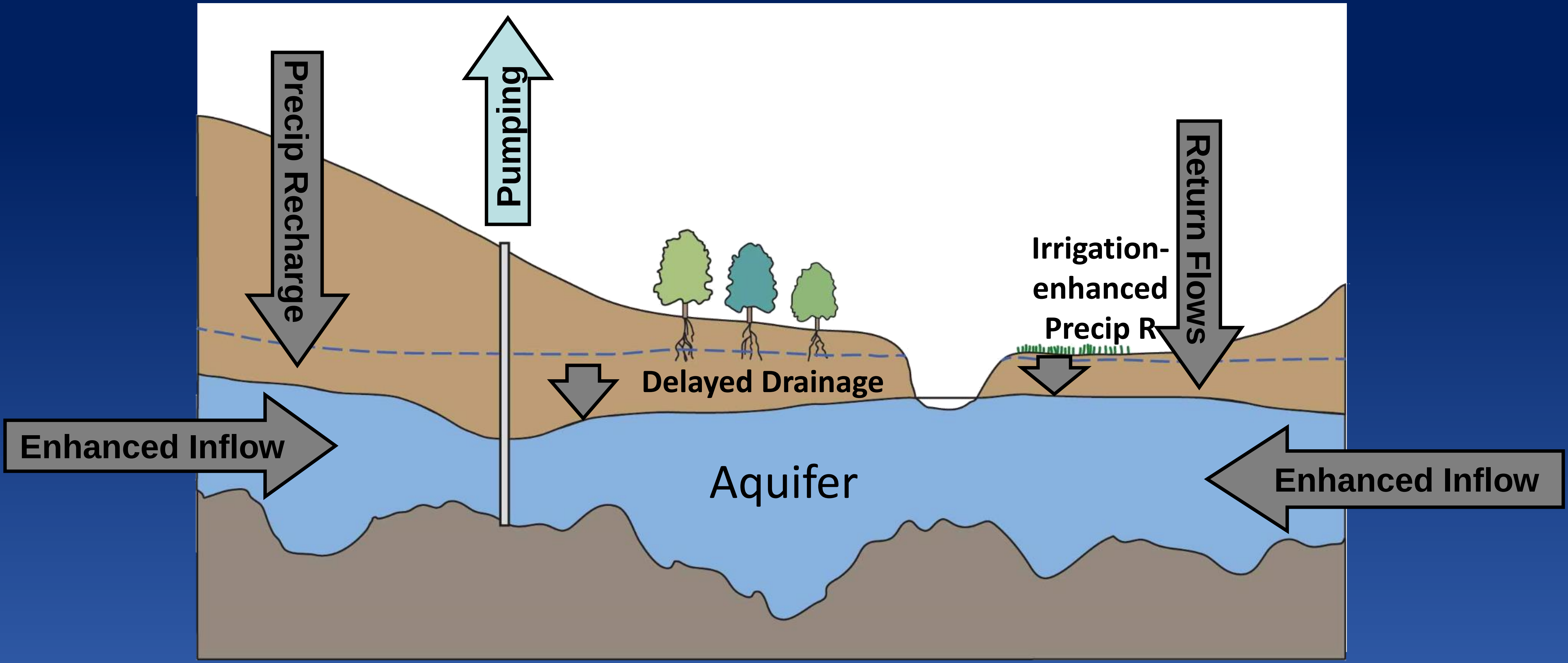




Net Inflow 3.3 cm/yr

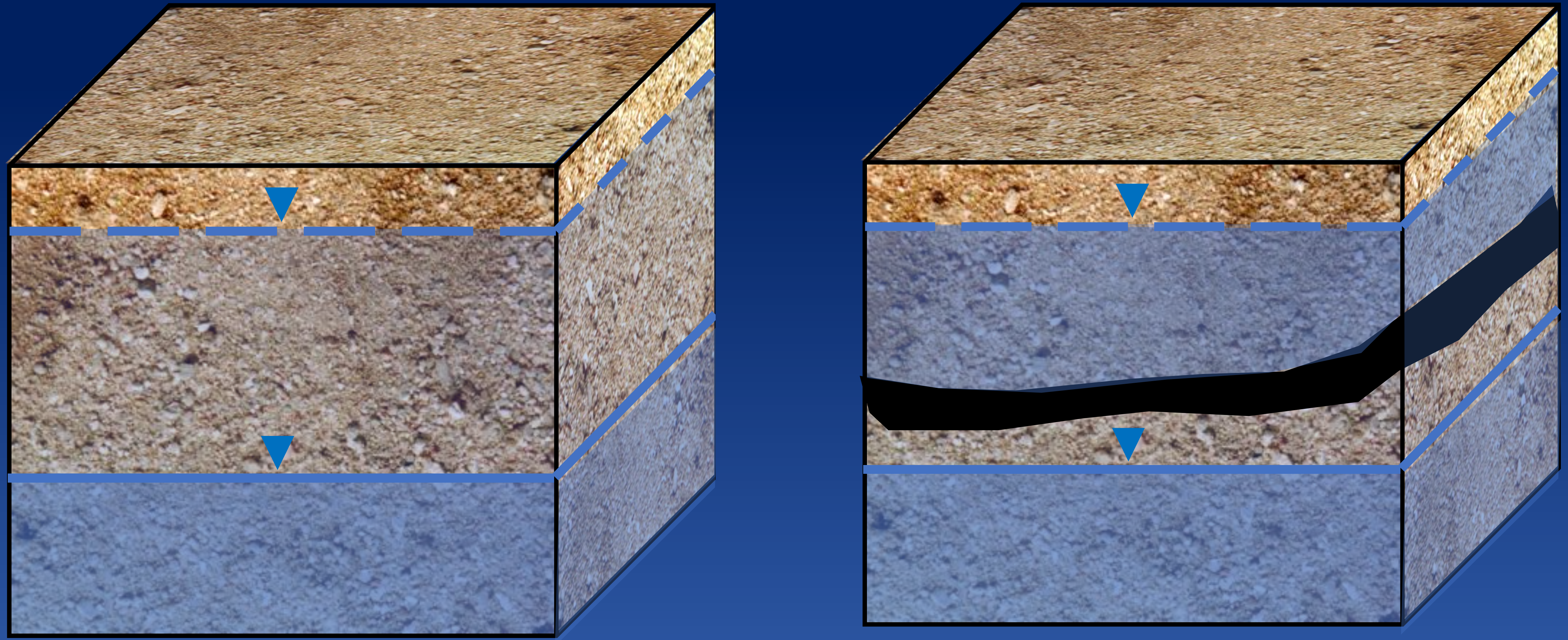
Precip Recharge 1.7 cm/yr

What is the major source of the additional inflow?



Delayed drainage by low-permeability sediments!

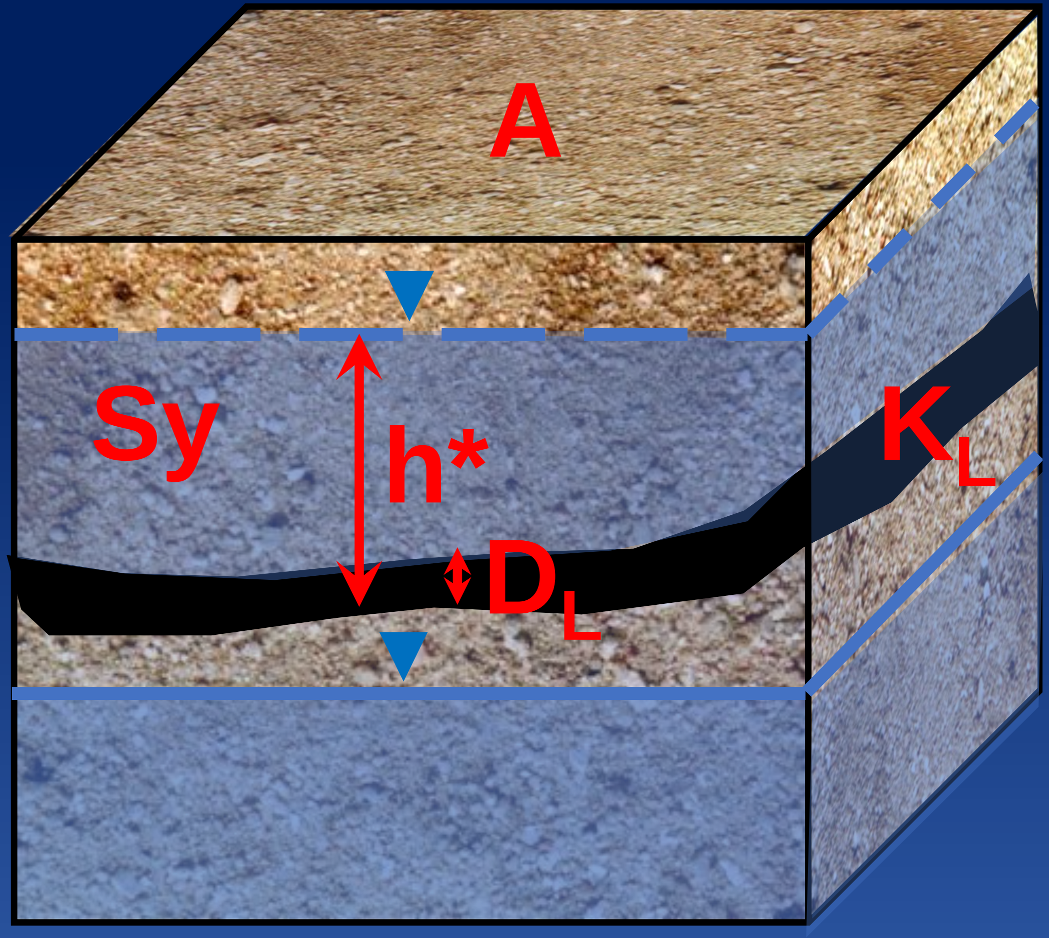
Drainage Delayed by Low-Permeability Units



Quick drainage without low-K barriers

Delayed drainage of perched water above low-K barriers

Drainage Delayed by Low-Permeability Units



Delayed drainage of perched water above low-K barriers

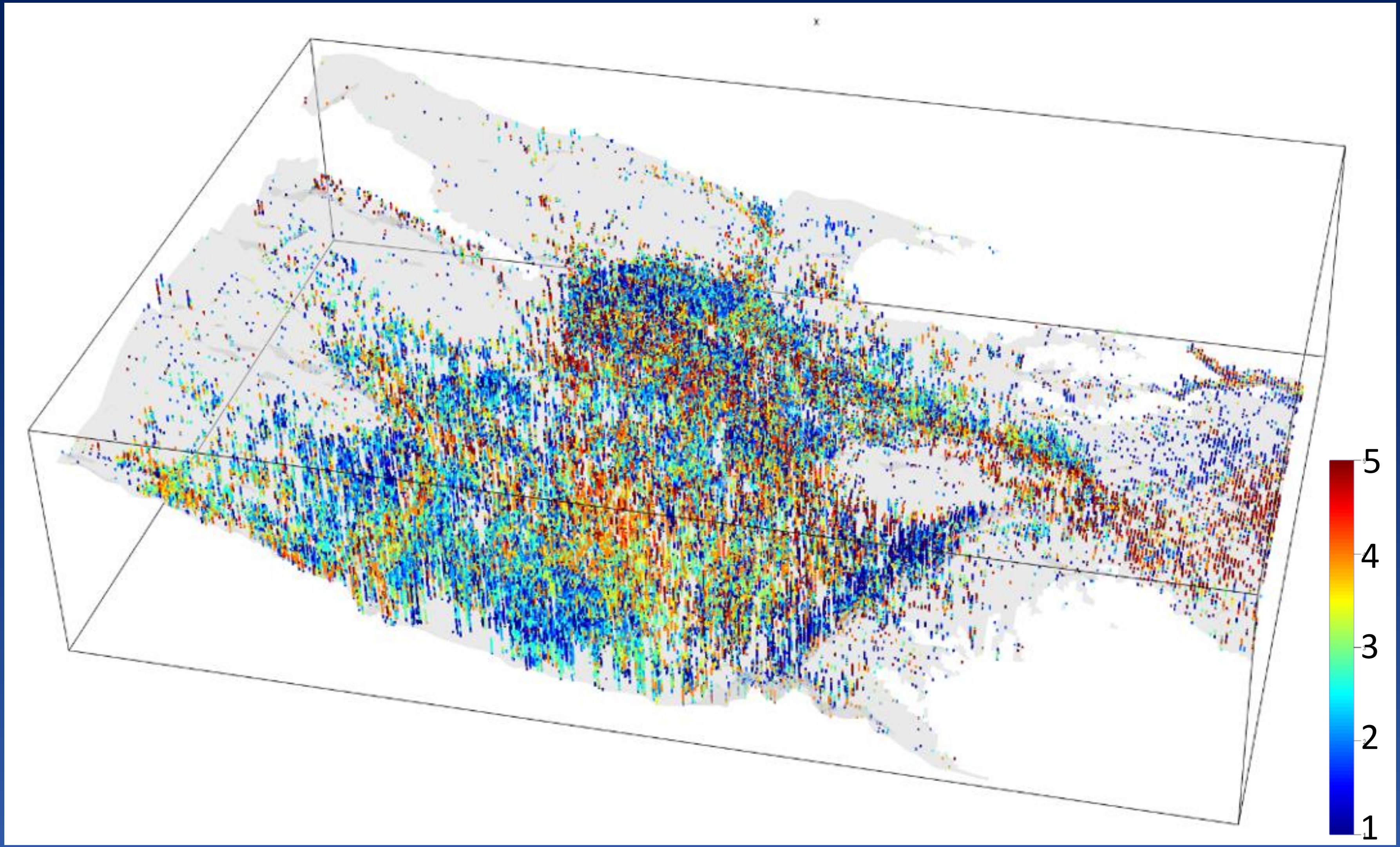
$$Q(t) = cd\,exp\left(-d(t - t^*)\right)$$

- t^* is time of initial water table decline.
- c = $Sy \times A \times h^*$
- d = K_L/D_L

Delayed drainage by low-permeability sediments

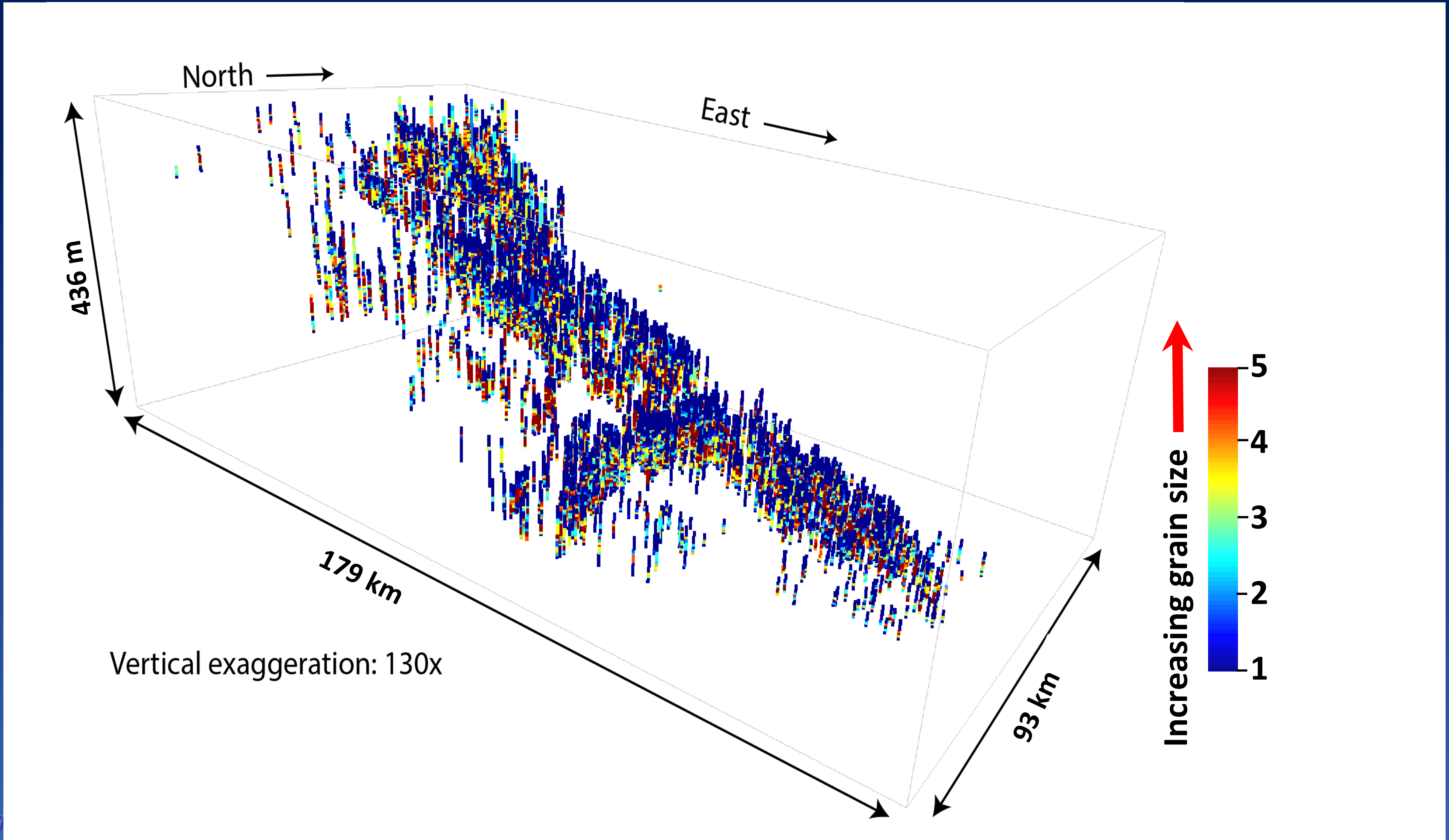
Supporting Evidence 1: Abundance of low-K lithologic units in HPA

GMD3 lithologic logs

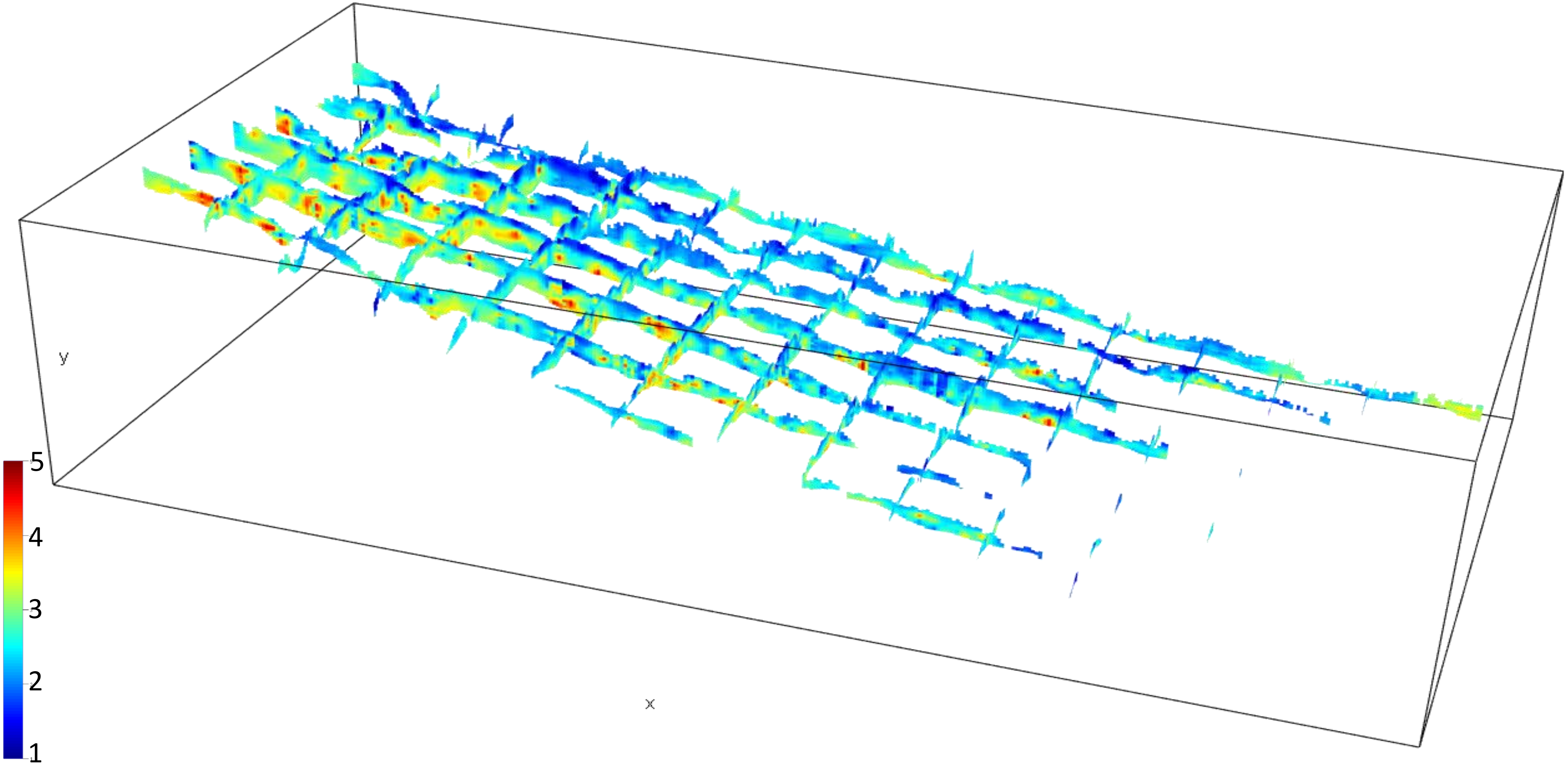


- **Each well segmented into regular 10- foot intervals.**
- **Compute the proportion of each category within each interval.**
- **5 (dark red) for highest permeability.**
- **1 (dark blue) for lowest permeability materials.**

GMD1 lithologic logs



GMD4 lithologic logs



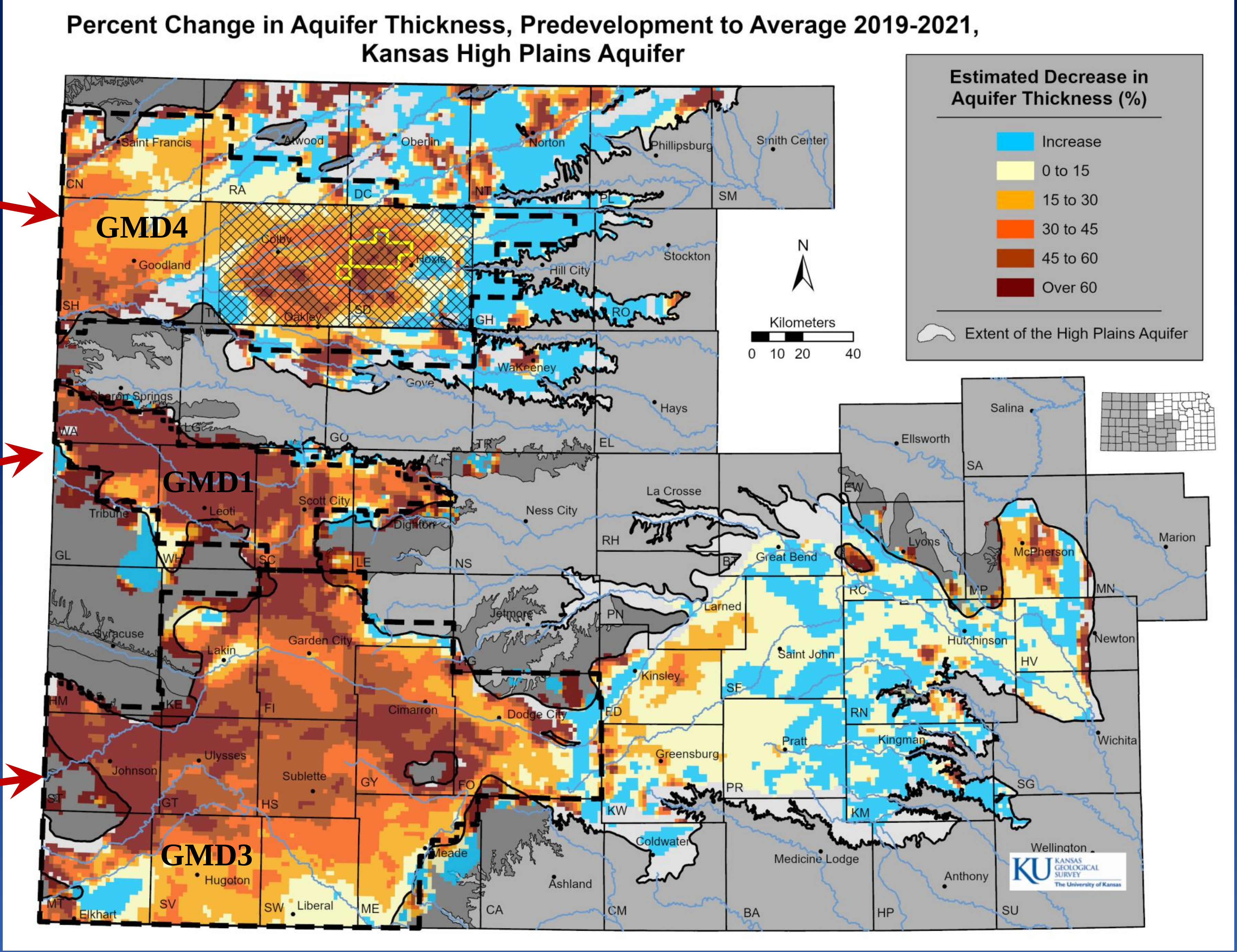
Delayed drainage by low-permeability sediments

Supporting Evidence 2: Much smaller specific yield estimates for HPA than typical values for sands and gravels.

SY=0.06 in GMD4

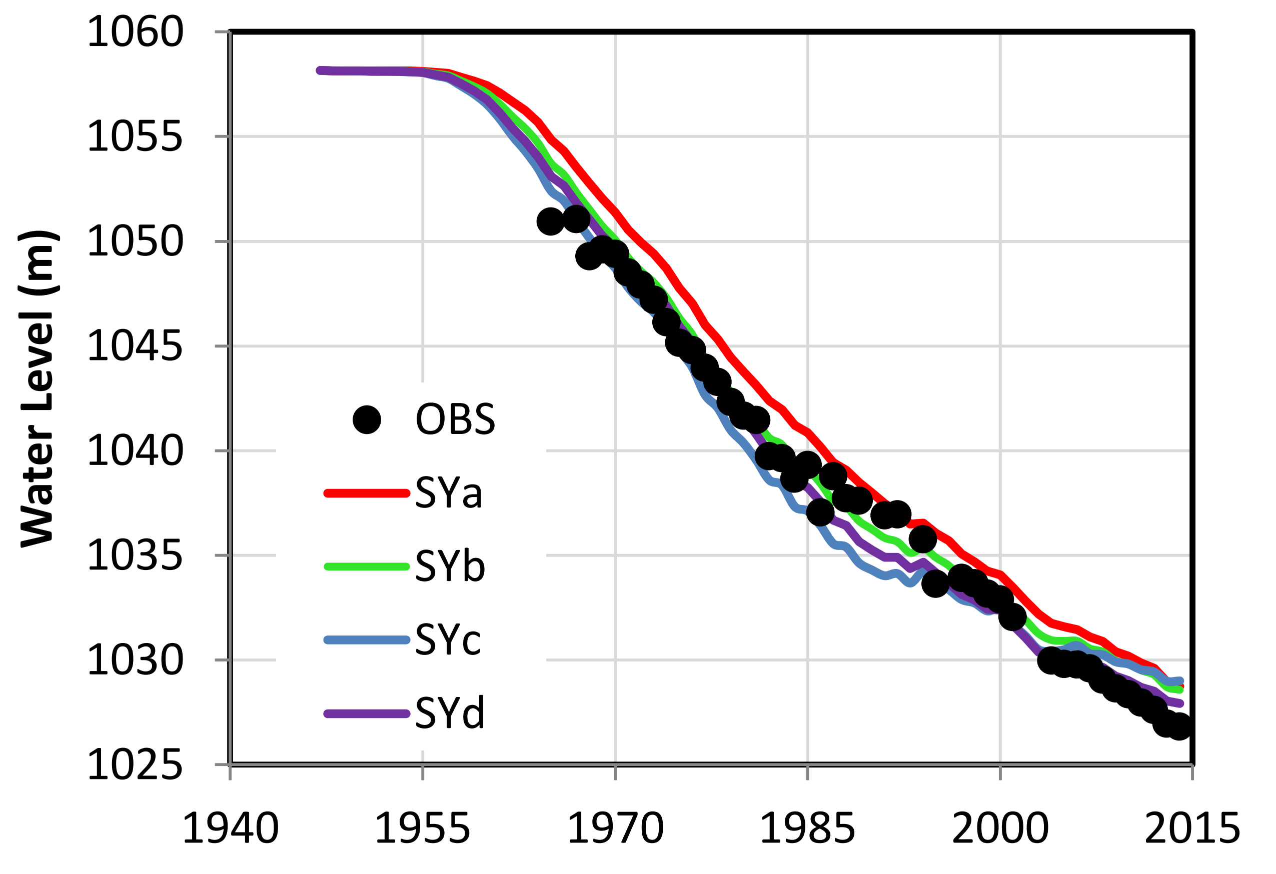
SY=0.04 in GMD1

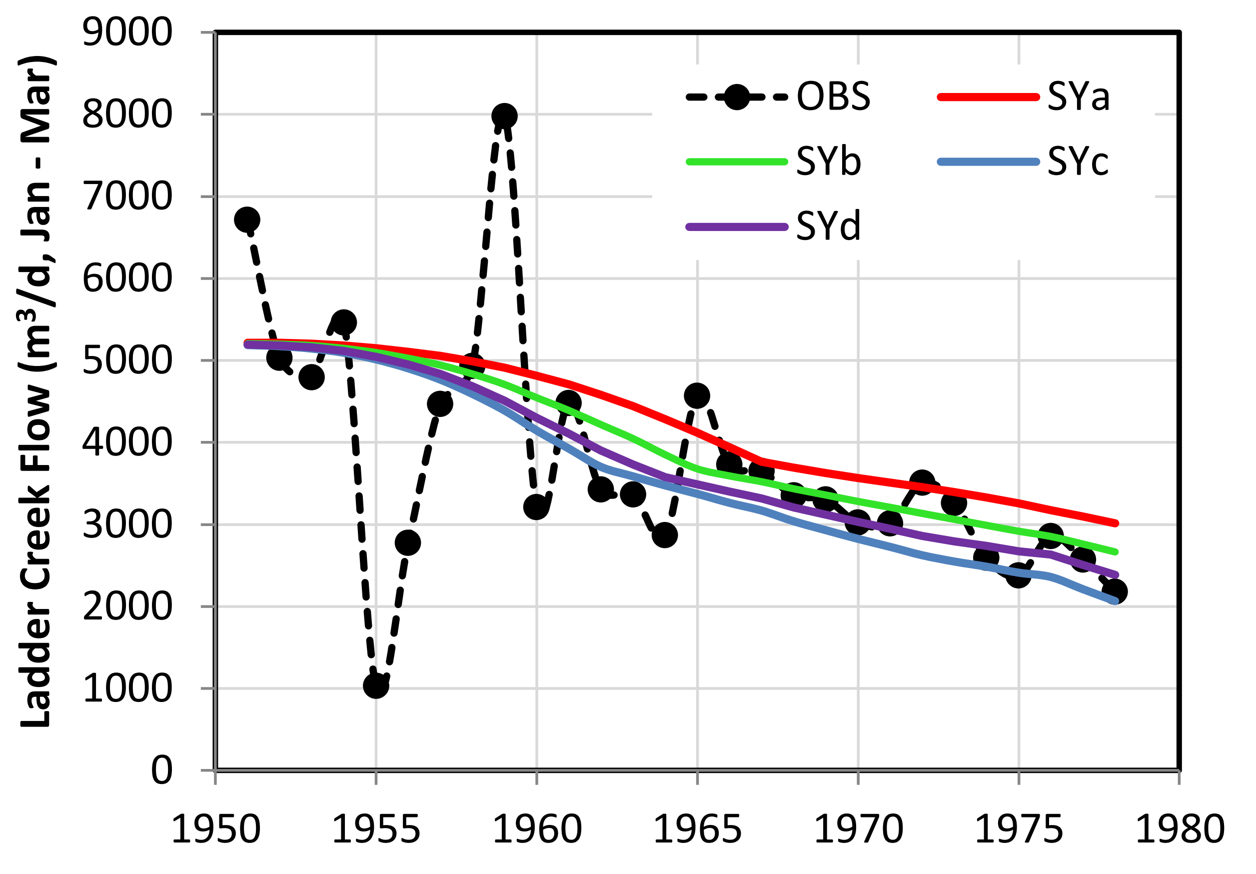
SY=0.05 in GMD3



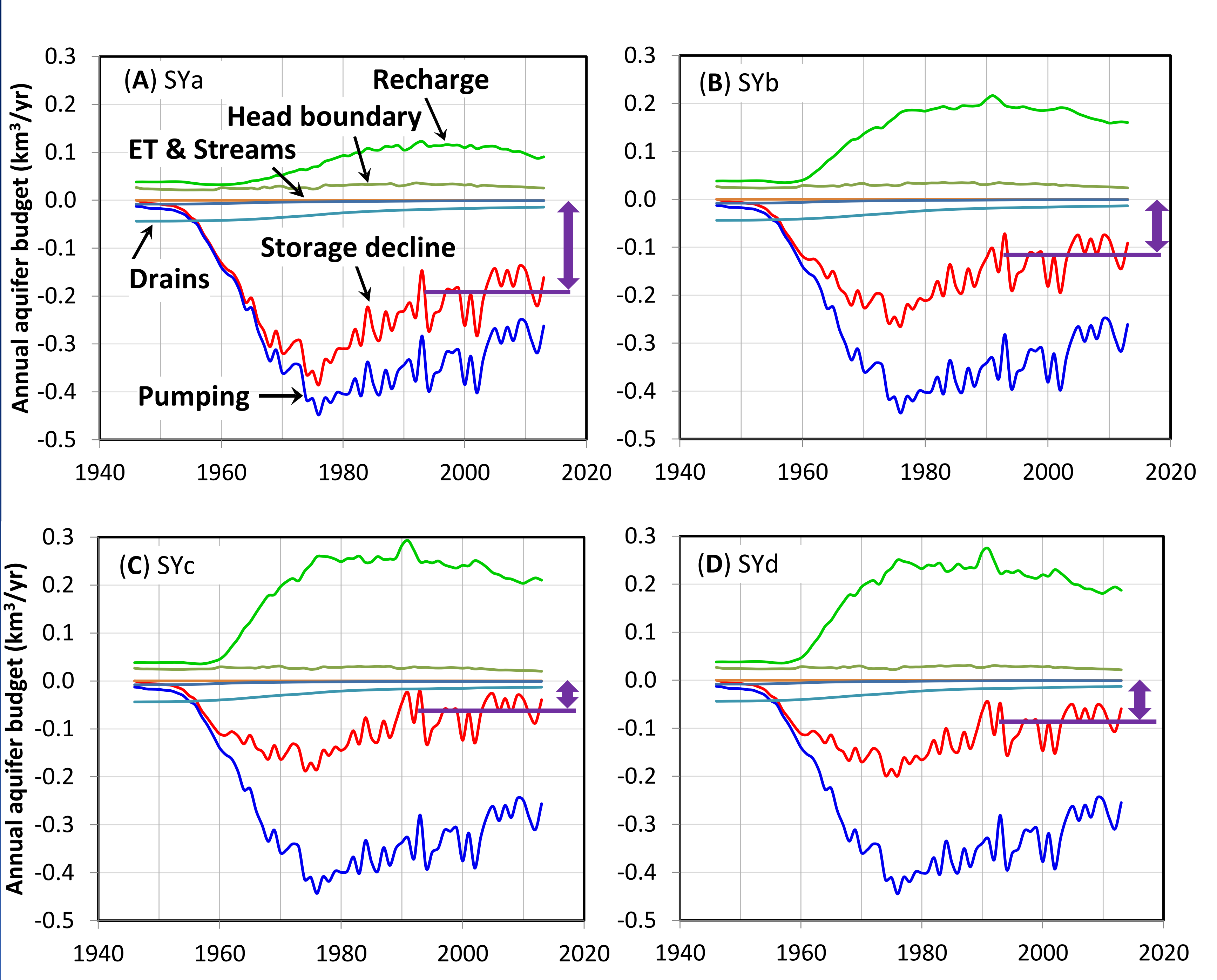
Specific yield cannot be reliably determined from model calibration – GMD1 example

- Similar match on water levels and stream flows can be obtained despite largely different specific yield values.





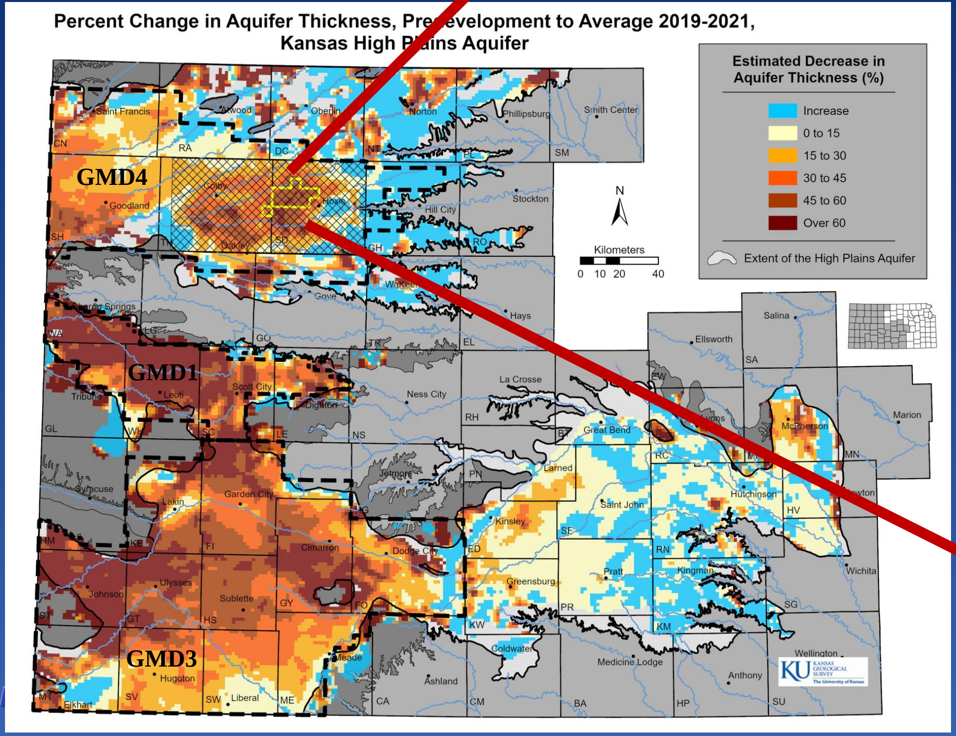
- Use of correct specific yield has critical impacts on aquifer recharge estimation and water management assessment. (Liu et al., 2022, WRR)

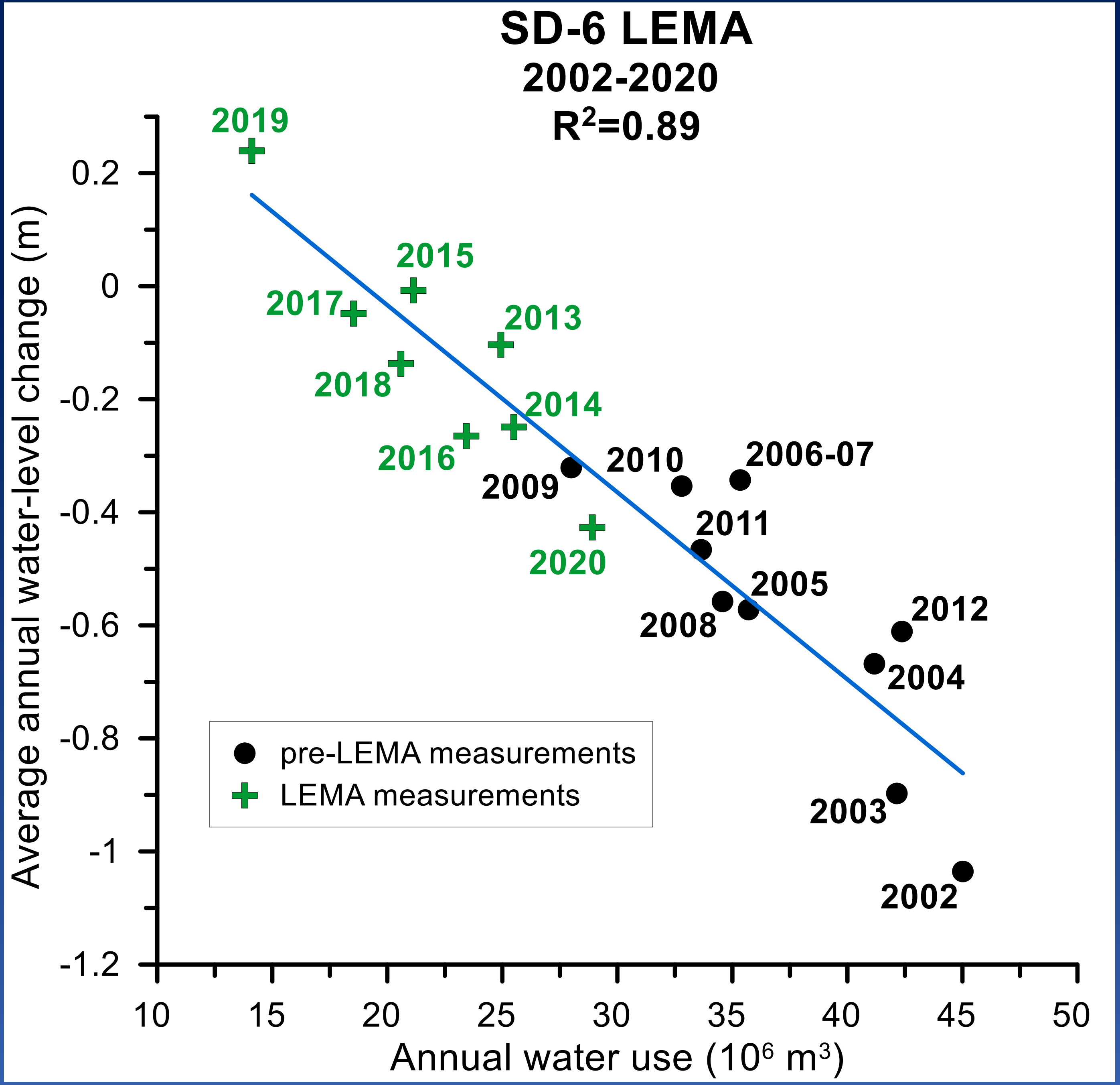


Delayed drainage by low-permeability sediments

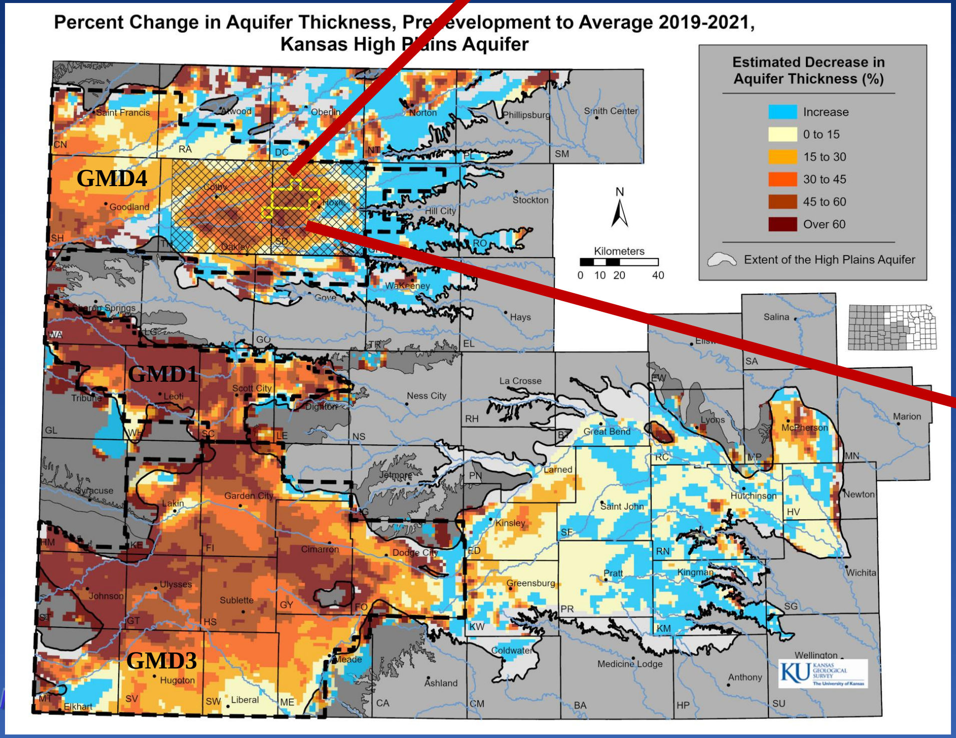
Supporting Evidence 3: Groundwater model simulation results.

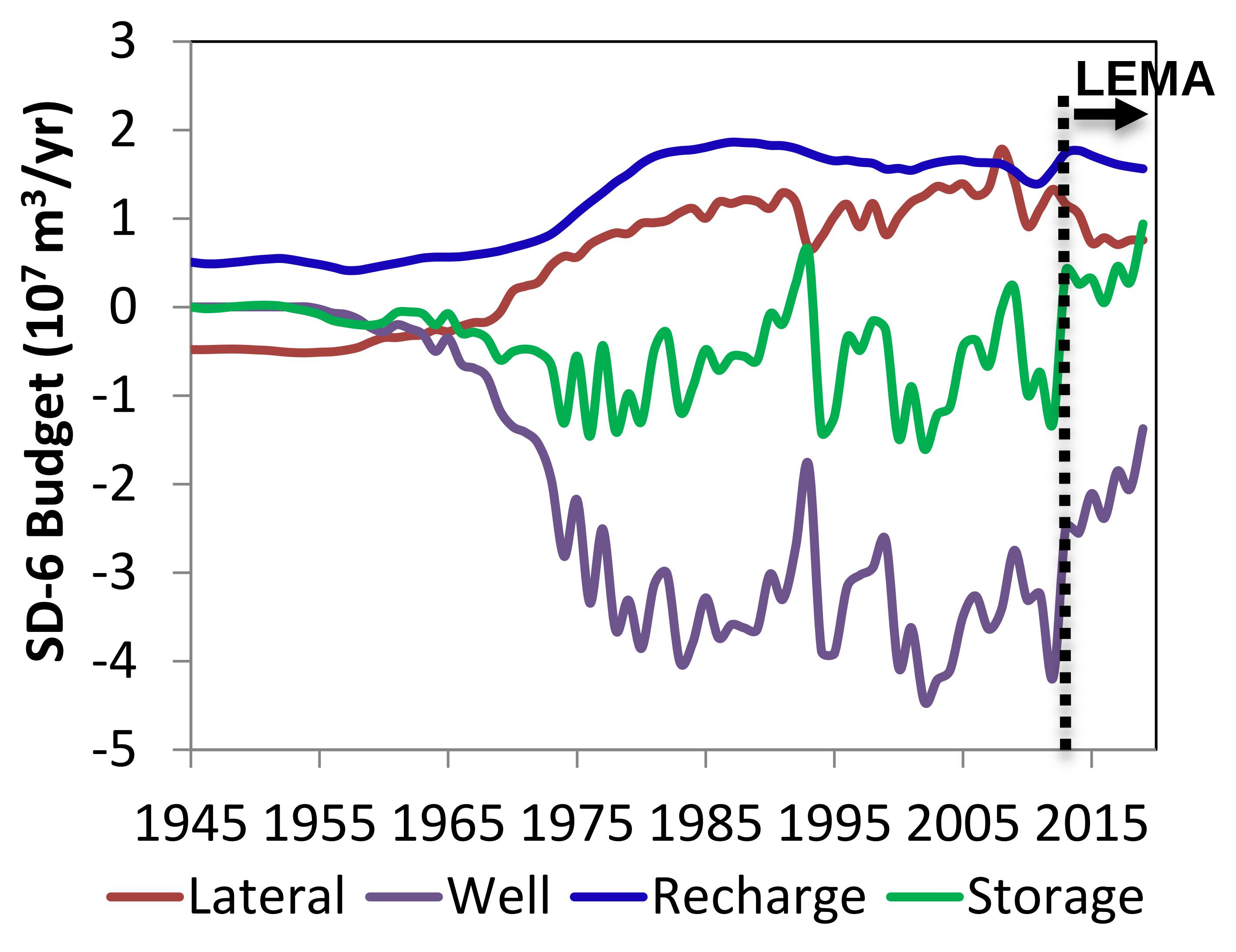
SD-6 LEMA Water Balance Analysis



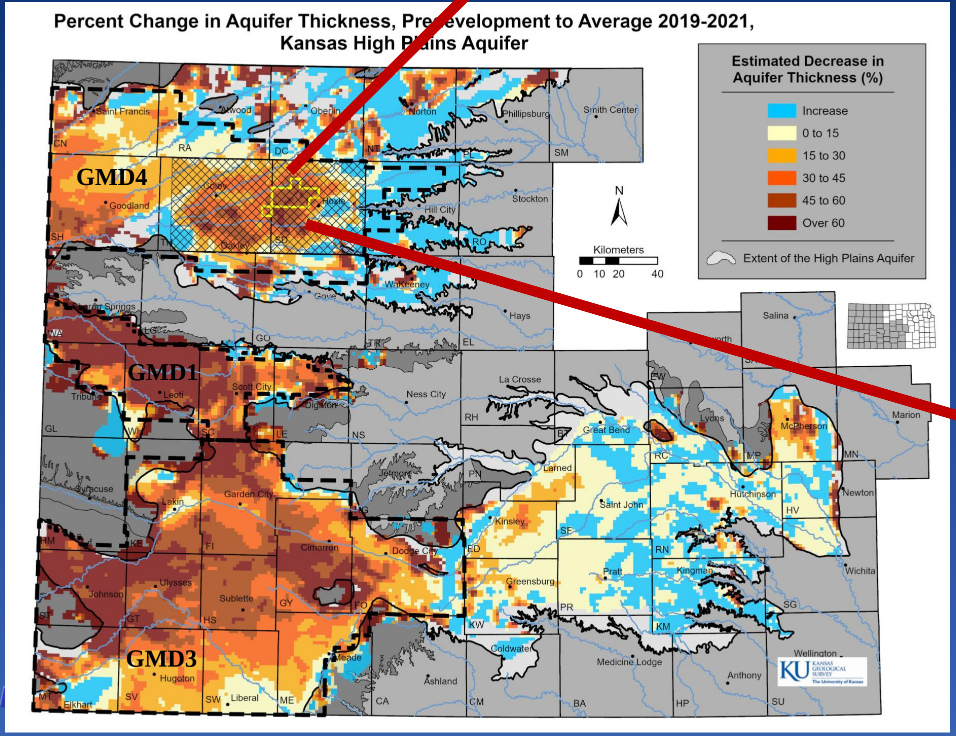


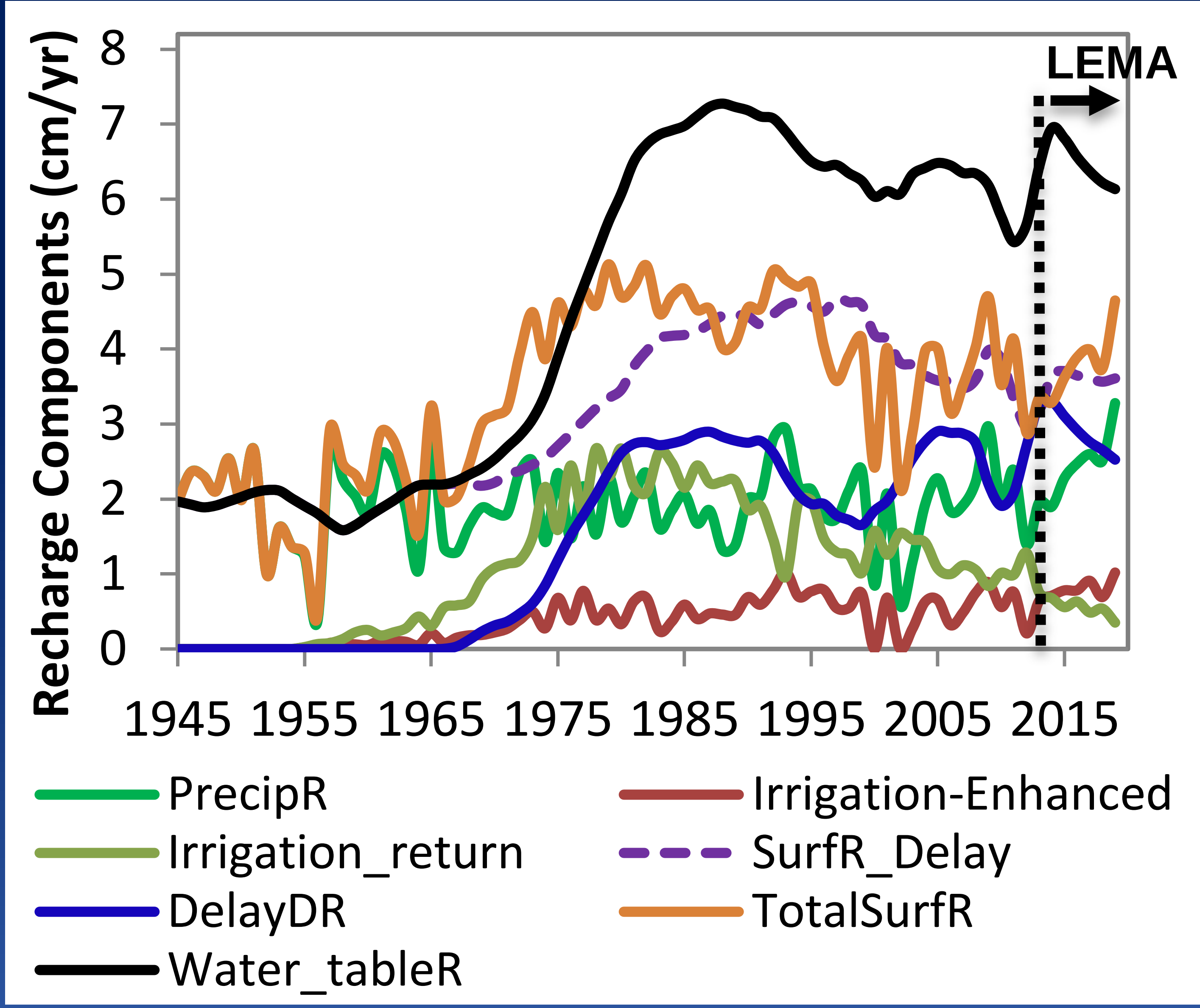
SD-6 LEMA Model Budgets





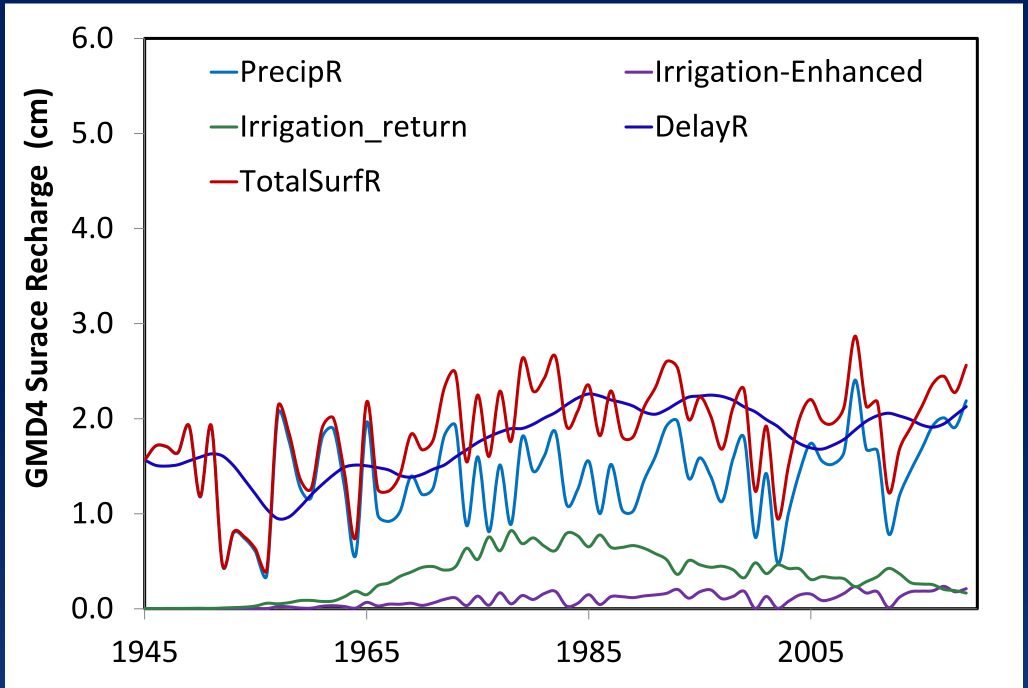
SD-6 LEMA Recharge Components

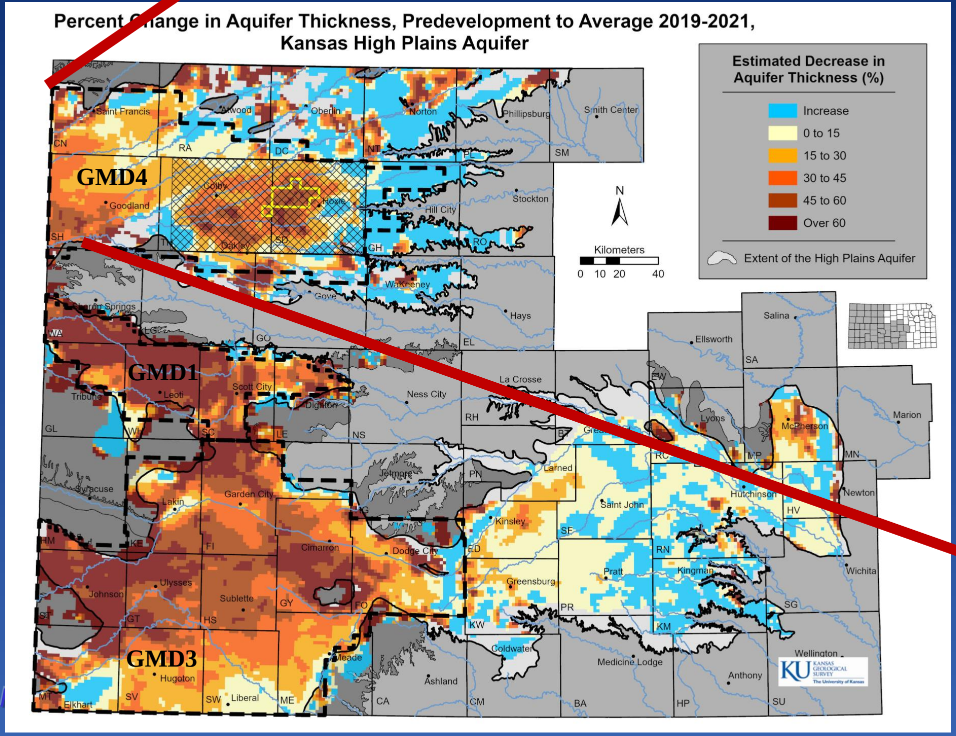


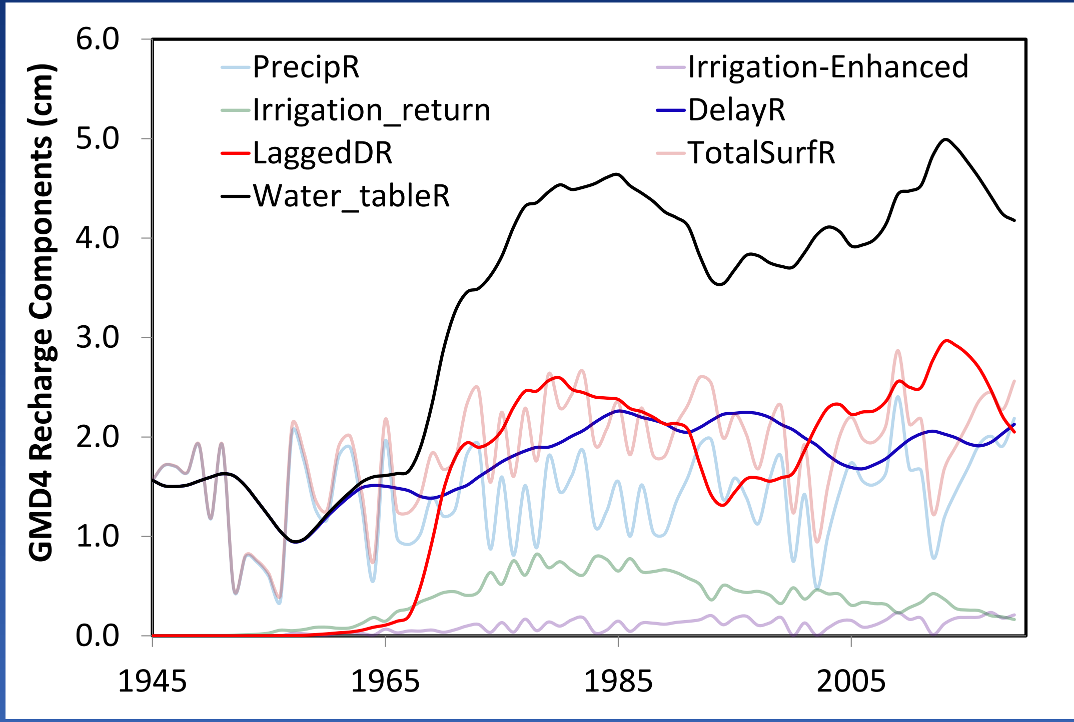


Irrigation return decreases with time.
The percentage of irrigated land is small.

GMD4 Model Recharge Components





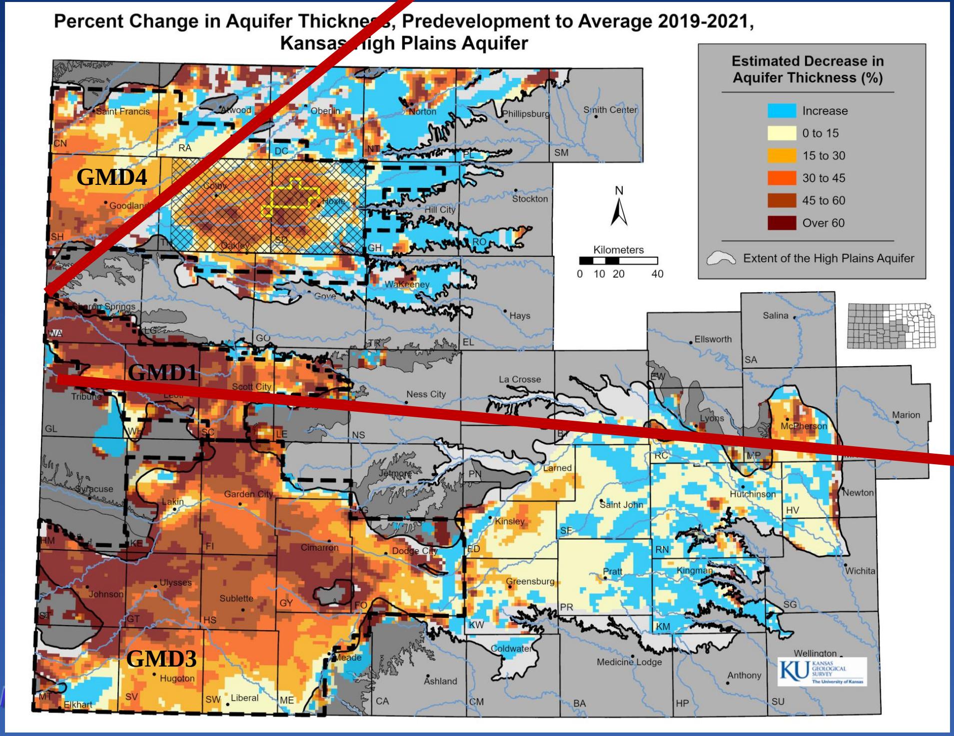


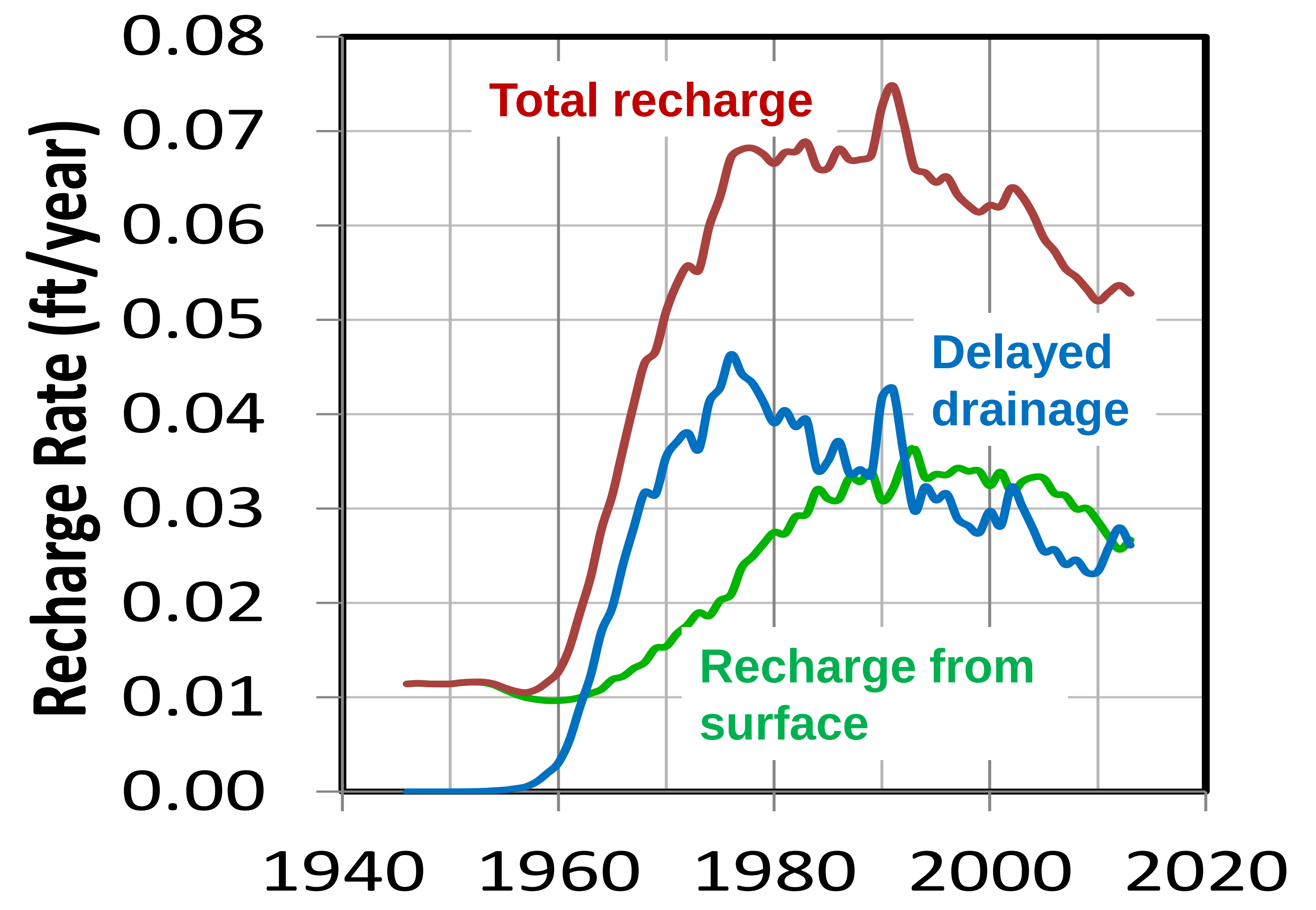
Conclusion and Future Work

- Delayed drainage of perched water above low-permeability barriers is likely the source of additional inflow observed in aquifers with significant water level declines such as the Kansas HPA.
- Further works are needed to investigate the delayed drainage and its impacts on aquifer recharge, e.g., vadose zone flow modeling, NMR logging for measuring the change of perched water with time, quantifying the impacts on future water management.

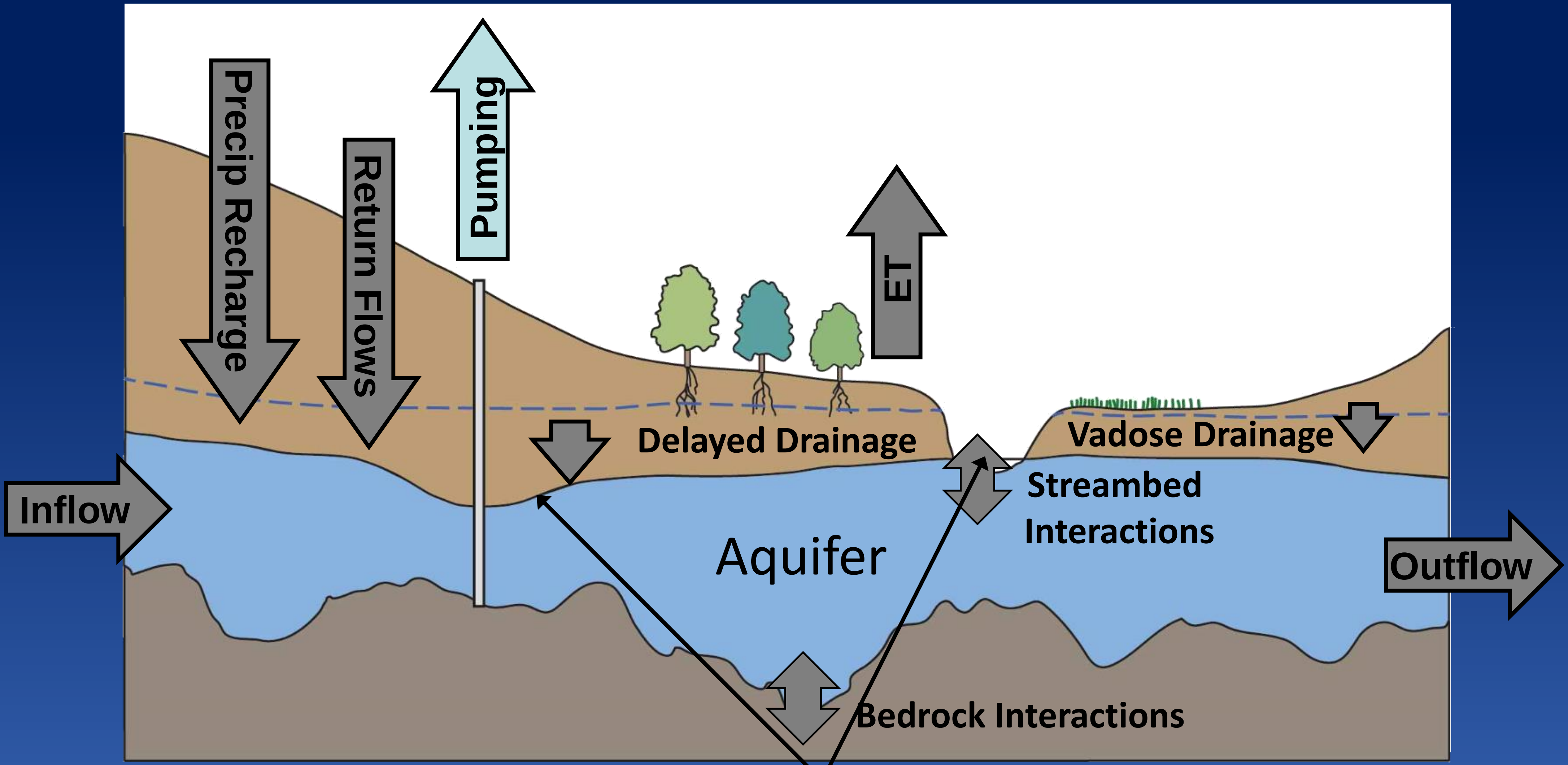
Questions?

GMD1 Model Recharge Components





Major components in a groundwater model



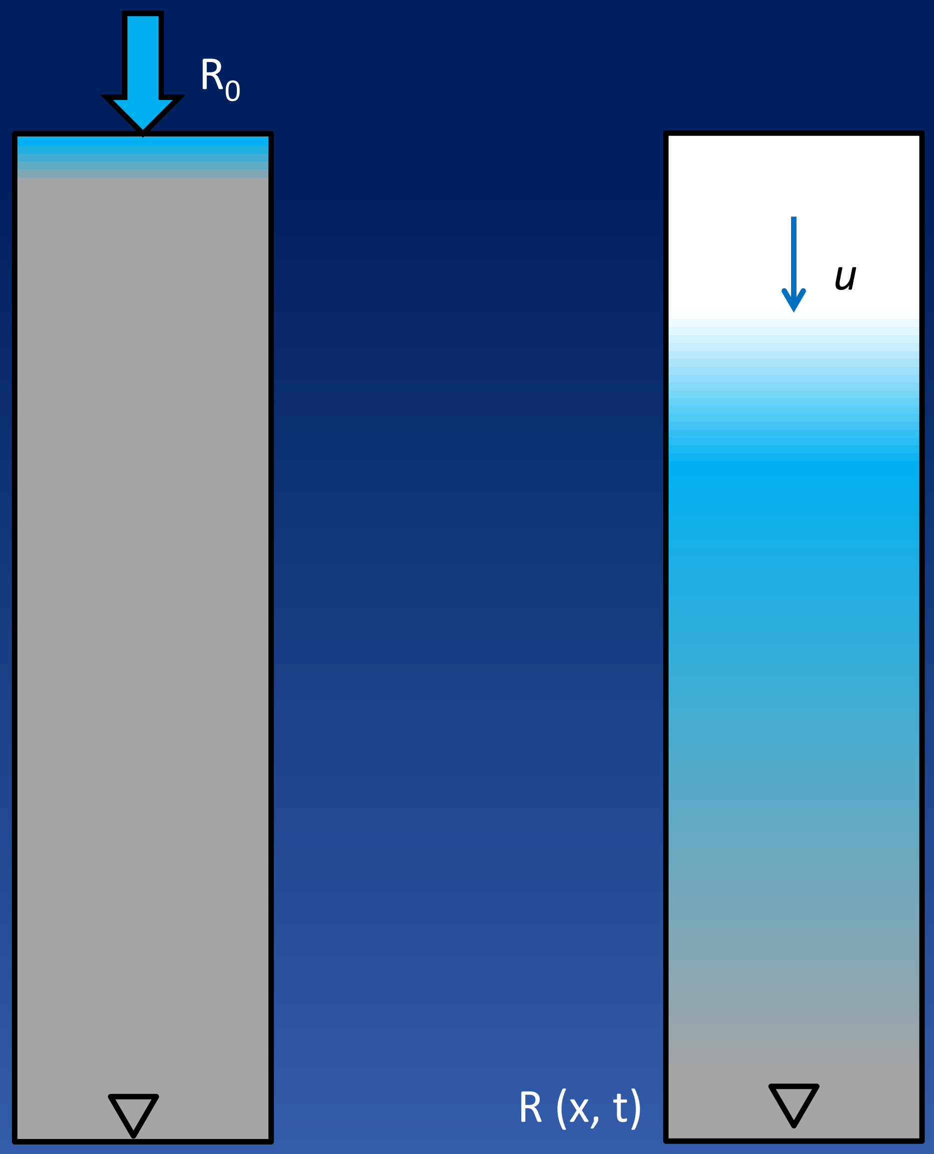
Model Computations

- Groundwater levels and Stream flows

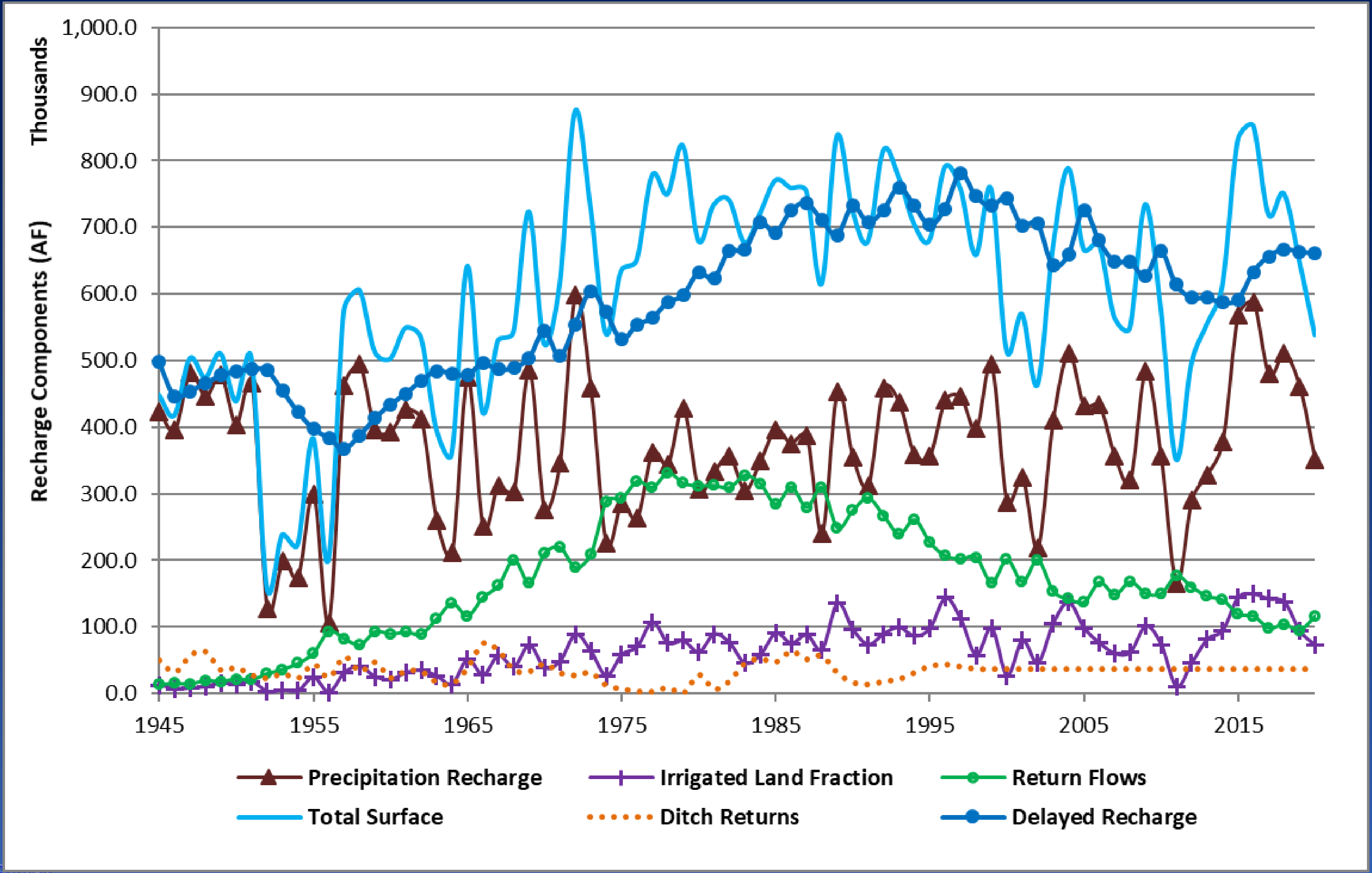
Delayed Recharge From the Surface

$$R(x,t) = \frac{R_0}{2\sqrt{\pi D t}} \exp\left(-\frac{(x-ut)^2}{4Dt} \right)$$

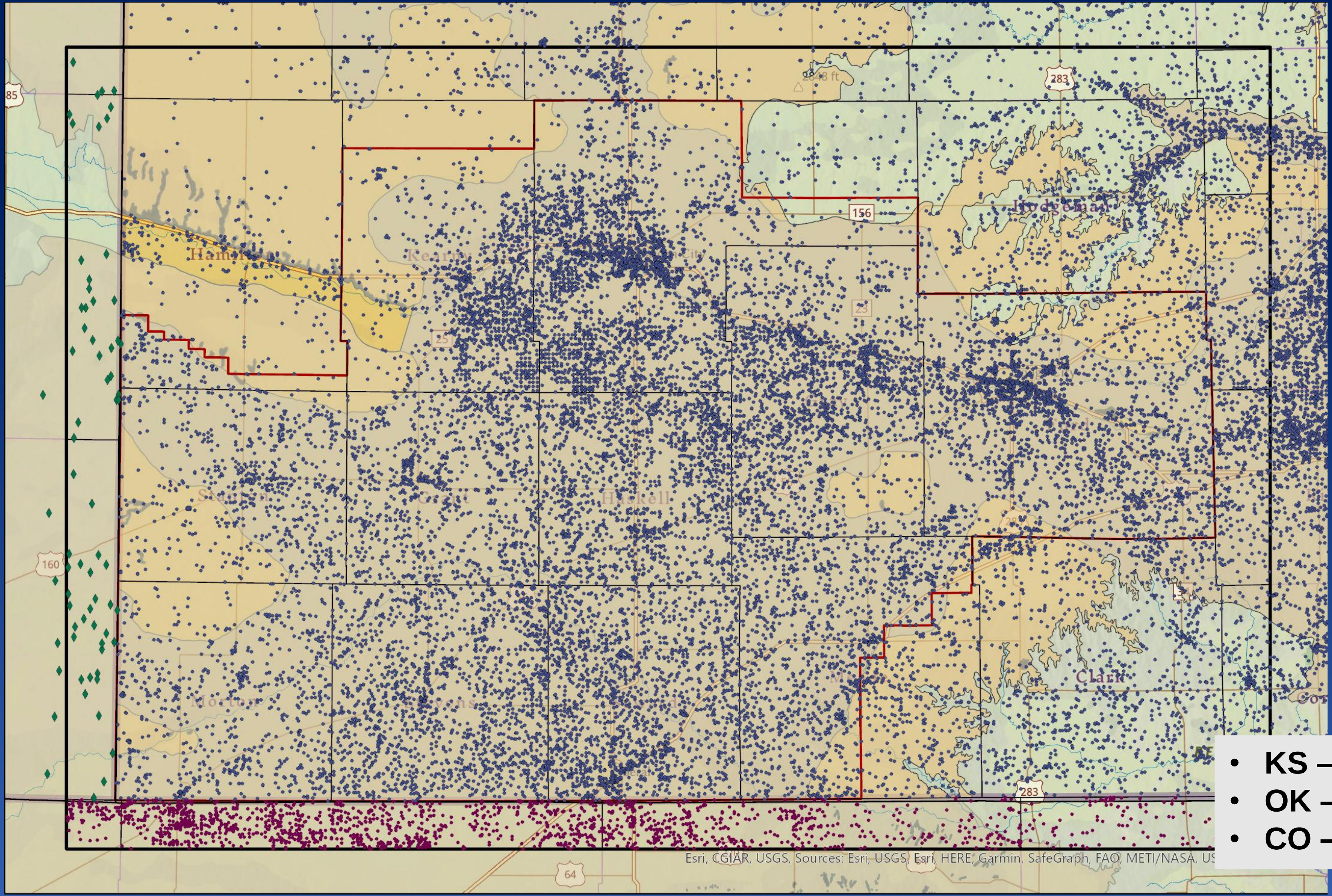
- *u* is vadose zone velocity,
- D is vadose zone diffusivity.



Surface Recharge Delayed



Lithology Data Sources – GMD3 Model

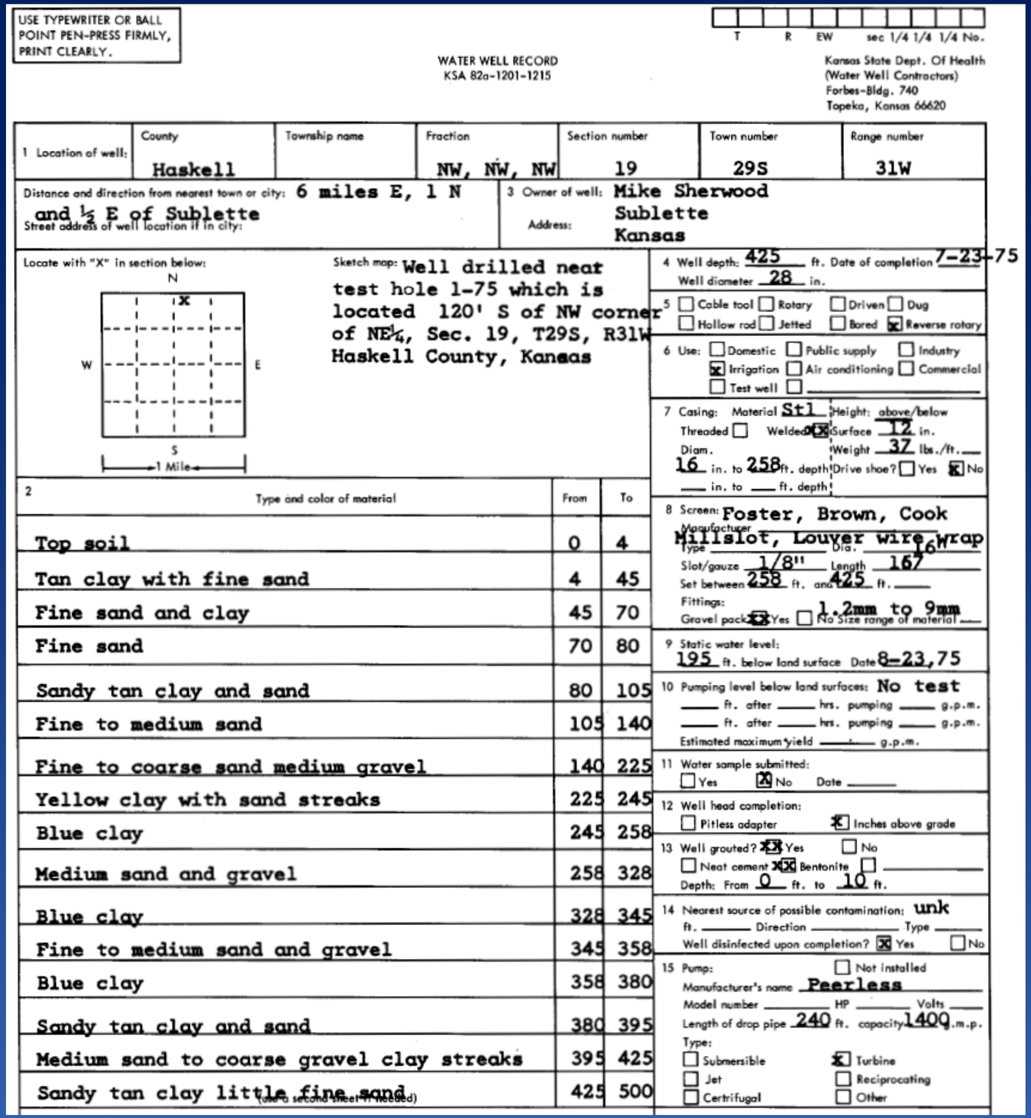


- **Driller logs vary in q**uality!

- **KS –** Water Well Completion Records
- **OK –** Water Resources Board
- **CO –** Well Permits

Not all forms/logs are created equal

Excellent



USE TYPEWRITER OR BALL POINT PEN-PRESS FIRMLY, PRINT CLEARLY.

WATER WELL RECORD
KSA 82a-1201-1215

Kansas State Dept. Of Health (Water Well Contractors) Forbes-Bldg. 740 Topeka, Kansas 66620

1 Location of well: County: Haskell; Fraction: NW, NW, NW; Section number: 19; Town number: 29S; Range number: 31W

Distance and direction from nearest town or city: 6 miles E, 1 N and ½ E of Sublette

3 Owner of well: Mike Sherwood
Address: Sublette Kansas

Sketch map: Well drilled near test hole 1-75 which is located 120' S of NW corner of NE¼, Sec. 19, T29S, R31W Haskell County, Kansas

4 Well depth: 425 ft. Date of completion 7-23-75
Well diameter 28 in.

5 Reverse rotary

6 Use: Irrigation

7 Casing: Material Stl; Welded; Diam. 16 in. to 258 ft. depth; Height: above/below Surface 12 in.; Weight 37 lbs./ft.; Drive shoe? No

8 Screen: Foster, Brown, Cook Manufacturer; Type: Millslot, Louver wire wrap; Dia. 16"; Slot/gauze 1/8"; Length 167; Set between 258 ft. and 425 ft.; Gravel pack? Yes; Size range of material: 1.2mm to 9mm

9 Static water level: 195 ft. below land surface Date 8-23-75

10 Pumping level below land surfaces: No test

11 Water sample submitted: No

12 Well head completion: Inches above grade

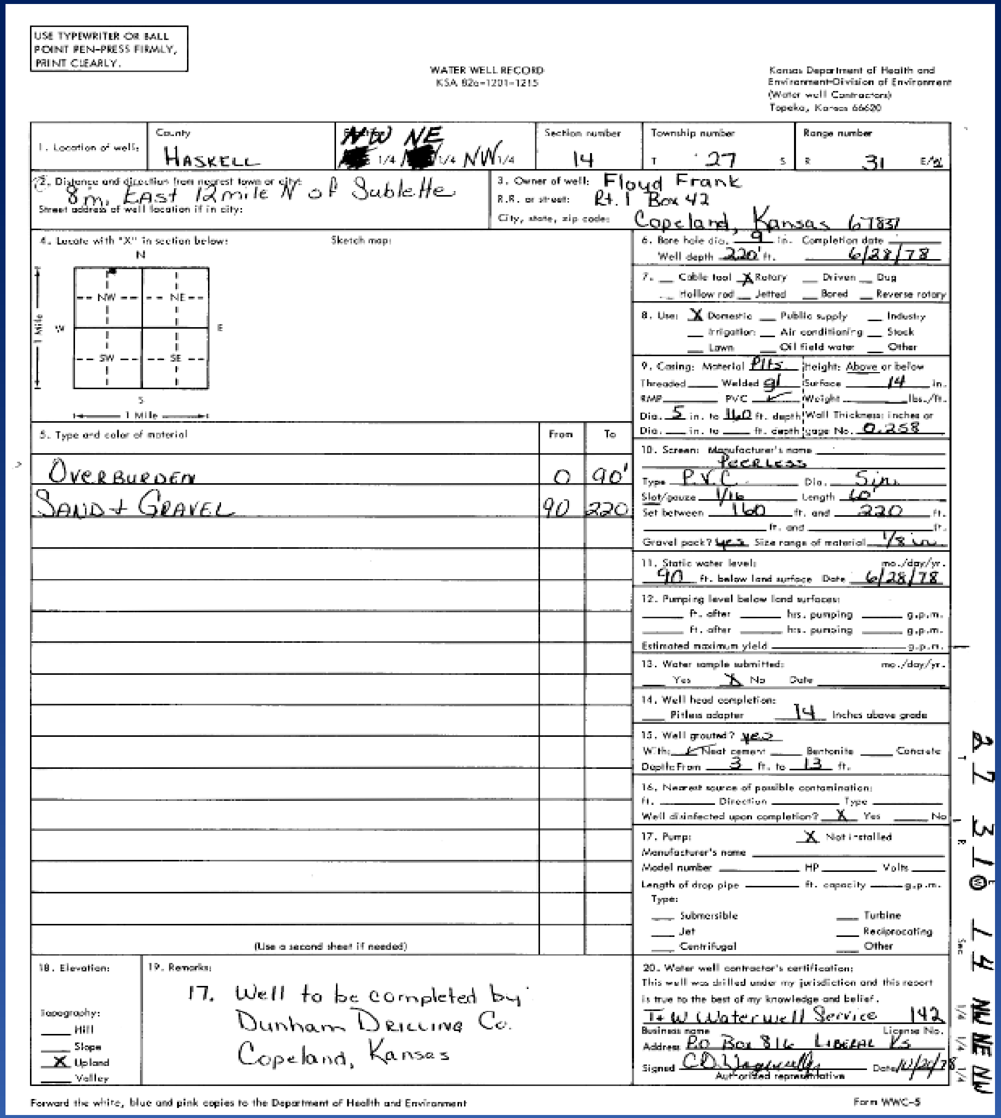
13 Well grouted? Yes; Bentonite; Depth: From 0 ft. to 10 ft.

14 Nearest source of possible contamination: unk; Well disinfected upon completion? Yes

15 Pump: Manufacturer's name Peerless; Length of drop pipe 240 ft. capacity 1400 g.p.m.; Type: Turbine

2 Type and color of material	From	To
Top soil	0	4
Tan clay with fine sand	4	45
Fine sand and clay	45	70
Fine sand	70	80
Sandy tan clay and sand	80	105
Fine to medium sand	105	140
Fine to coarse sand medium gravel	140	225
Yellow clay with sand streaks	225	245
Blue clay	245	258
Medium sand and gravel	258	328
Blue clay	328	345
Fine to medium sand and gravel	345	358
Blue clay	358	380
Sandy tan clay and sand	380	395
Medium sand to coarse gravel clay streaks	395	425
Sandy tan clay little fine sand	425	500

Poor



USE TYPEWRITER OR BALL POINT PEN-PRESS FIRMLY, PRINT CLEARLY.

WATER WELL RECORD
KSA 82a-1201-1215

Kansas Department of Health and Environment-Division of Environment (Water well Contractors) Topeka, Kansas 66620

1. Location of well: County: Haskell; NW NE NW; Section number: 14; Township number: 27 S; Range number: 31 E/W

2. Distance and direction from nearest town or city: 8 m. East 12 mile N of Sublette

3. Owner of well: Floyd Frank; R.R. or street: Rt. 1 Box 42; City, state, zip code: Copeland, Kansas 67837

6. Bore hole dia. 9 in. Completion date 6/28/78; Well depth 220' ft.

7. Rotary

8. Use: Domestic

9. Casing: Material PIPS; Welded gl; Dia. 5 in. to 160 ft. depth; Surface 14 in.; Gage No. 0.258

10. Screen: Manufacturer's name Peerless; Type P.V.C.; Dia. 5in.; Slot/gauze 1/16; Length 60'; Set between 160 ft. and 220 ft.; Gravel pack? yes; Size range of material 1/8 in.

11. Static water level: 90 ft. below land surface Date 6/28/78

13. Water sample submitted: No

14. Well head completion: Pitless adapter 14 Inches above grade

15. Well grouted? yes; Neat cement; Depth: From 3 ft. to 13 ft.

16. Well disinfected upon completion? Yes

17. Pump: Not installed

5. Type and color of material	From	To
Overburden	0	90'
Sand + Gravel	90	220

18. Elevation: Topography: Upland

19. Remarks: 17. Well to be completed by Dunham Drilling Co. Copeland, Kansas

20. Water well contractor's certification: This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief. Business name: T+W Waterwell Service; License No. 142; Address: PO Box 816 Liberal Ks; Date 11/28/78

Forward the white, blue and pink copies to the Department of Health and Environment. Form WWC-5

Hydraulic Conductivity (K) and Specific Yield (Sy) Calculation from Lithology

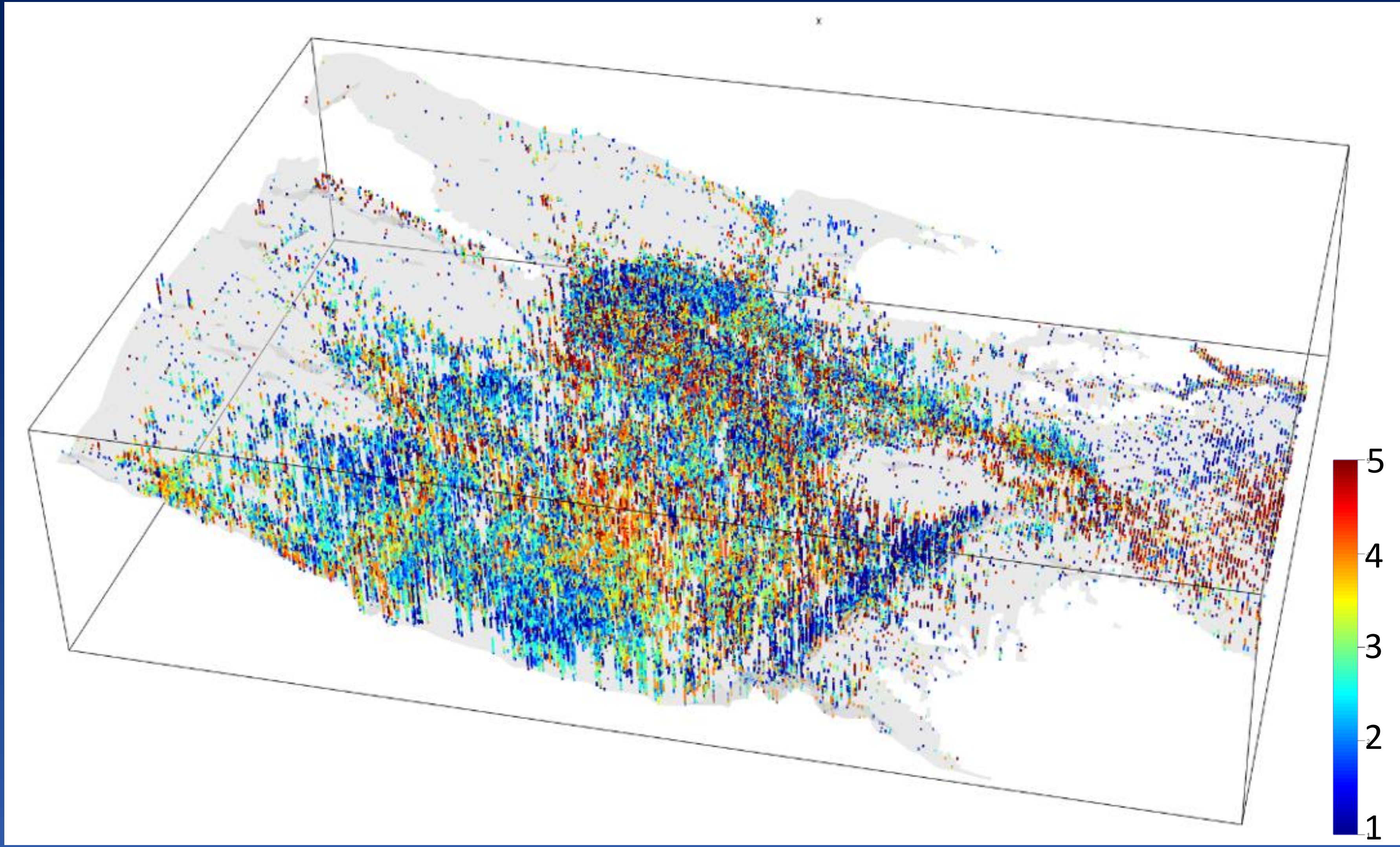
A) Categorize lithologic description into 5 categories:

1: clays, 2: clays and silts, 3: silts and sands, 4: sands, 5: sands and gravels

B) Assign representative K and Sy values to each category. The lithologic K values are adjusted during model calibration; the Sy values are estimated using the KGS water balance approach.

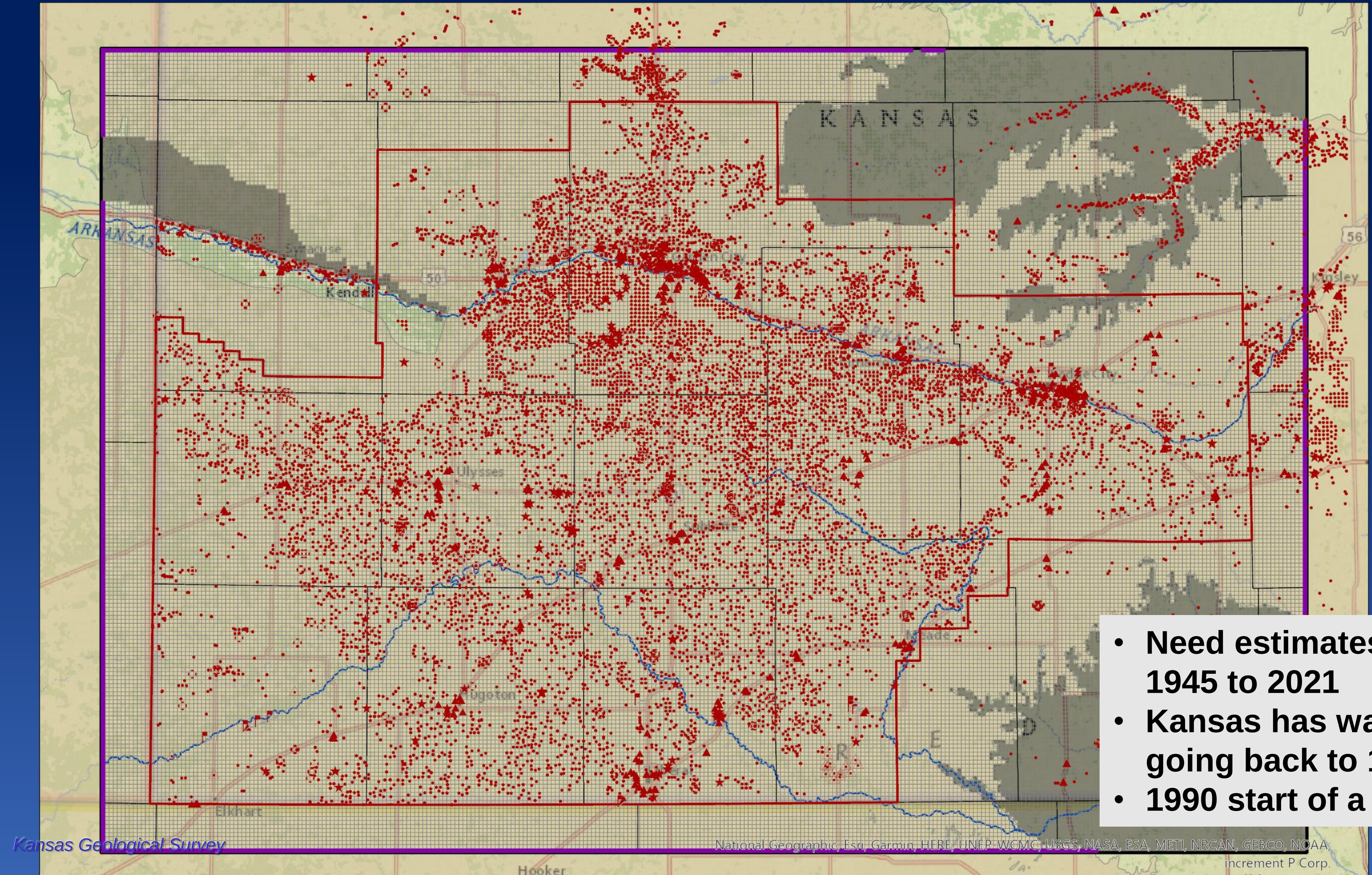
C) Using Kriging to populate the K and Sy values from the lithologic log locations onto the entire model grid.

Proportion-weighted Average Lithology Categories by Well



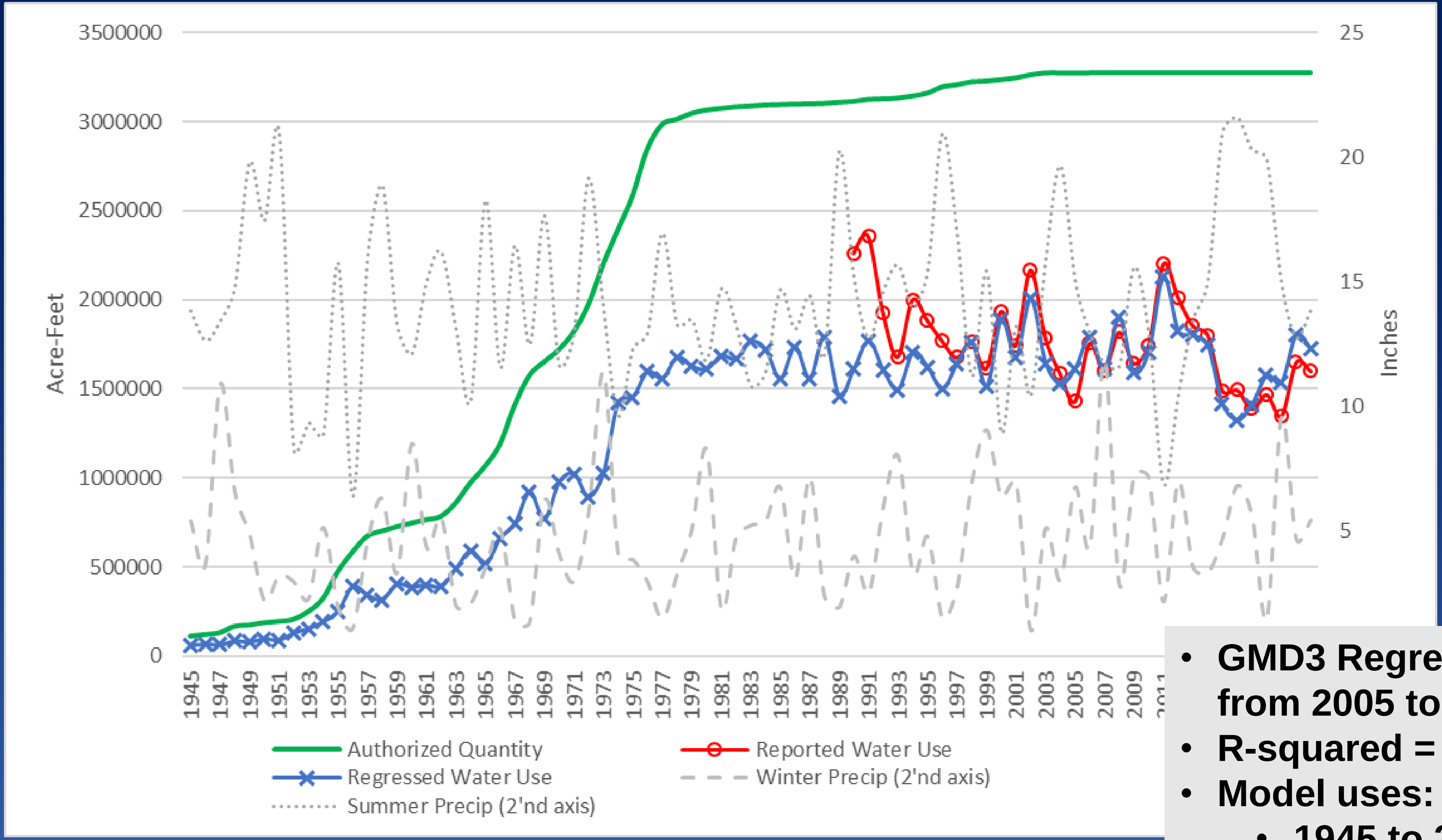
- Each well segmented into regular 10- foot intervals.
- Compute the proportion of each category within each interval.
- 5 (dark red) for highest permeability.
- 1 (dark blue) for lowest permeability materials.

GMD3 Groundwater Right Wells



- Need estimates of pumping from 1945 to 2021
- Kansas has water use records going back to 1958.
- 1990 start of a QA/QC program.

Pumping Estimation: Records & Regression



- **GMD3 Regression based on conditions from 2005 to 2021**
- **R-squared = 0.75, P < 0.00007**
- **Model uses:**
  - **1945 to 2005: regressed water use**
  - **2005 to 2021: reported water use**
  - **Future year: regressed water use**