GROUNDWATER IN THE DAIRY ENVIRONMENT

Water Education Foundation – Groundwater Tour

September 24-25, 2015

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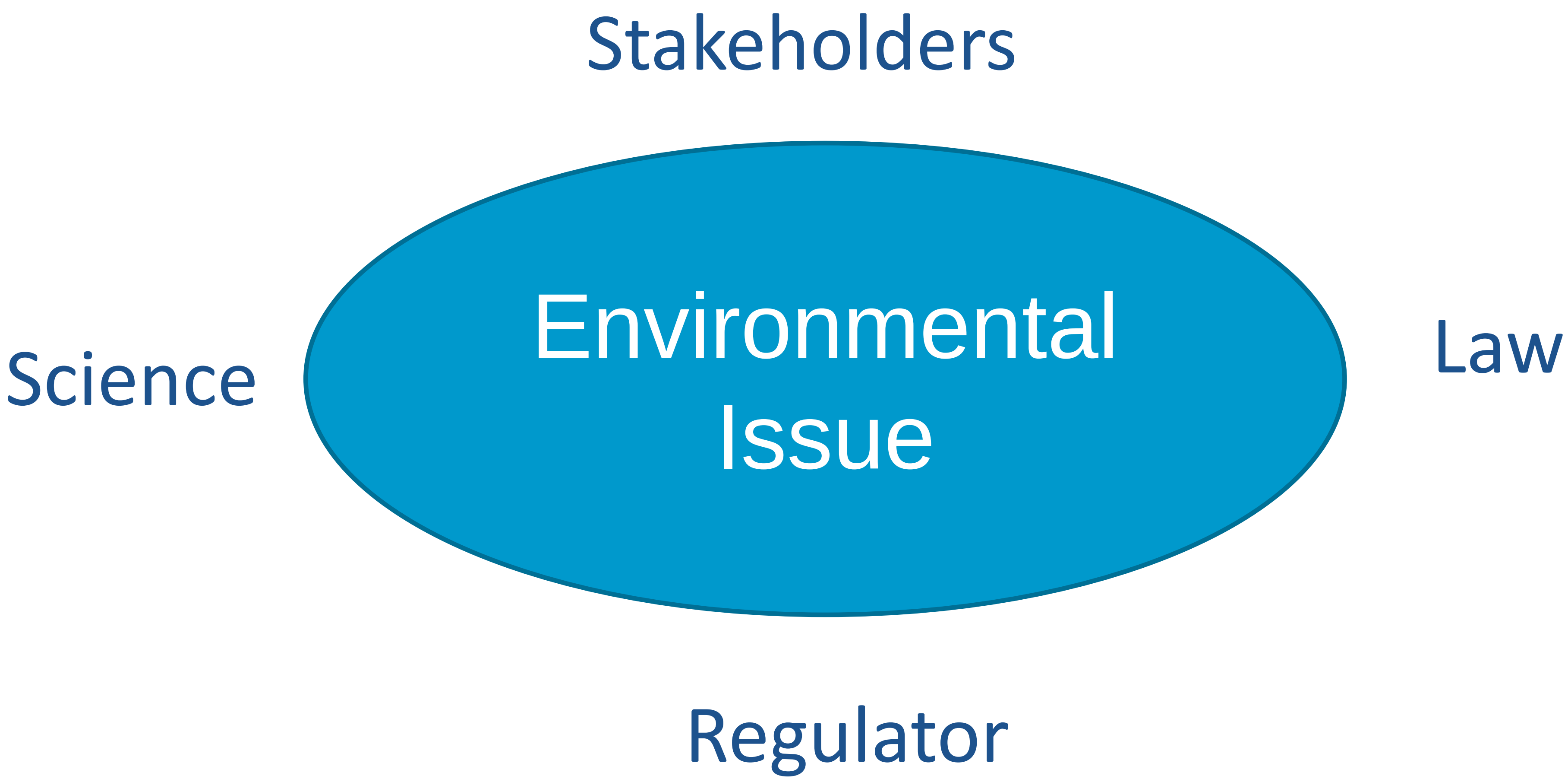
http://groundwater.ucdavis.edu

Understanding Challenges to Sustainable Dairy Management

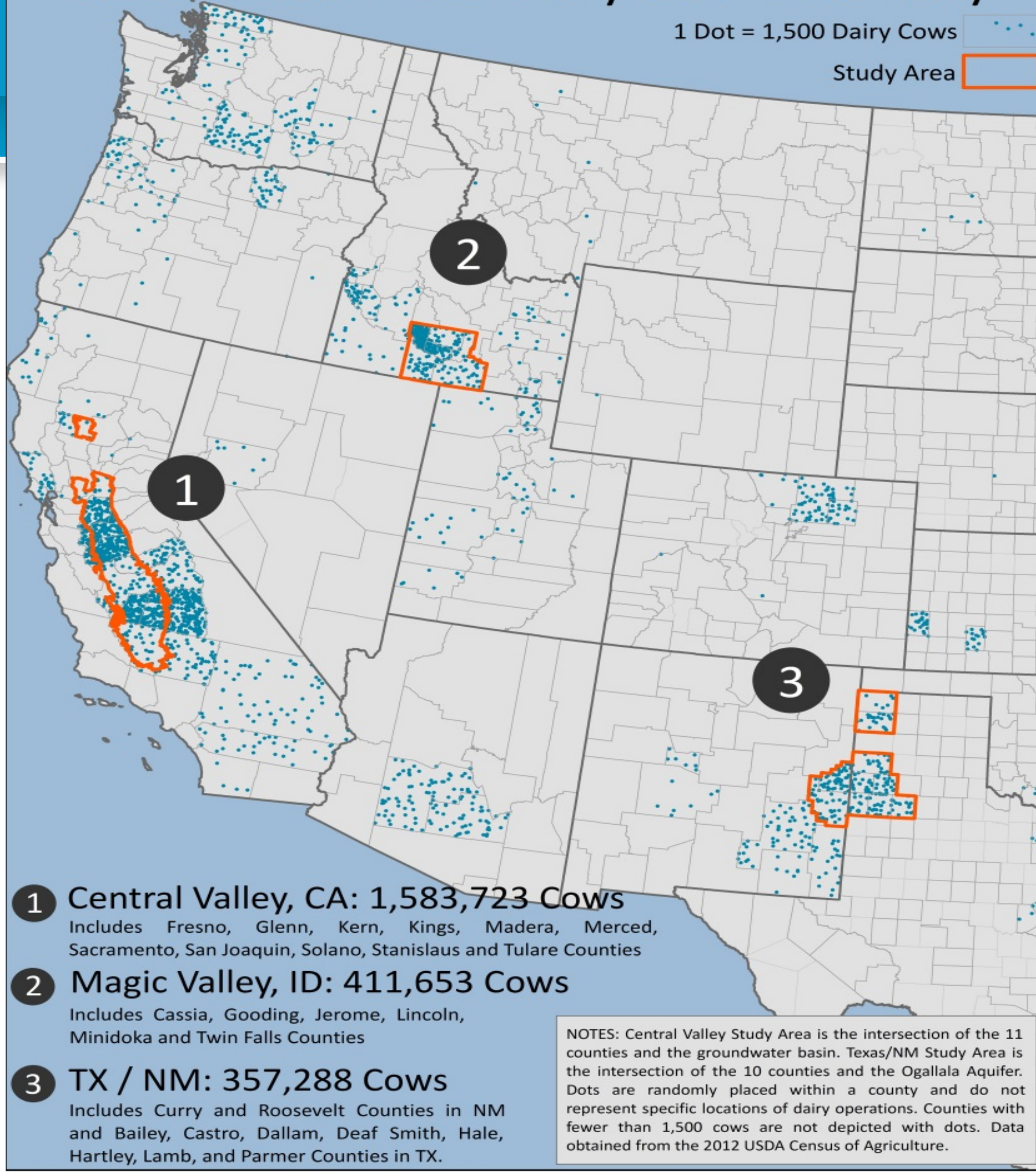
Breaking down the issue:



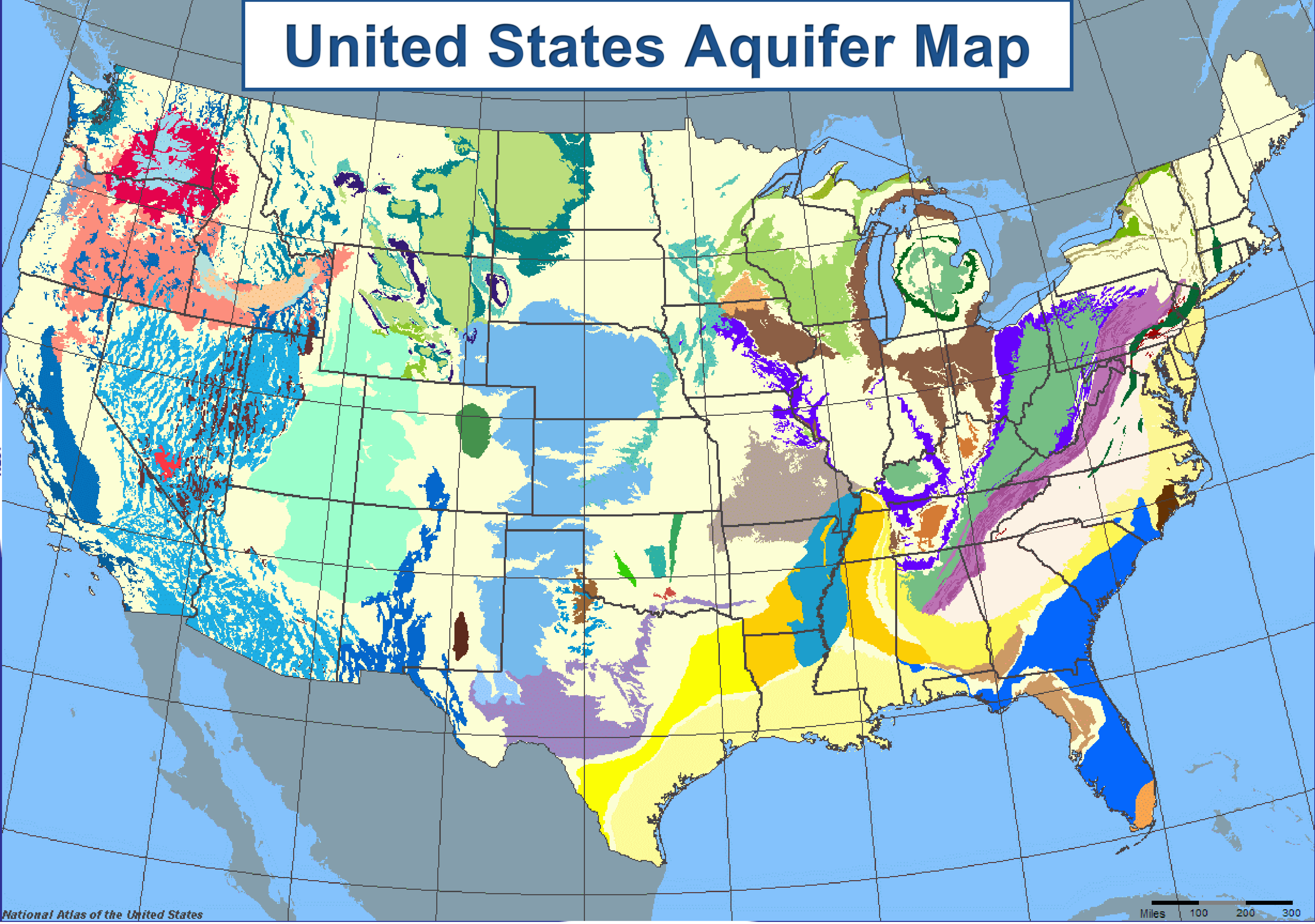
Background

- **Groundwater v watersheds**
- Dairy and groundwater impacts
- Regulations
- Monitoring

2012 Western US Dairy Cow Inventory



United States Aquifer Map



http://nationalatlas.gov/mapmaker

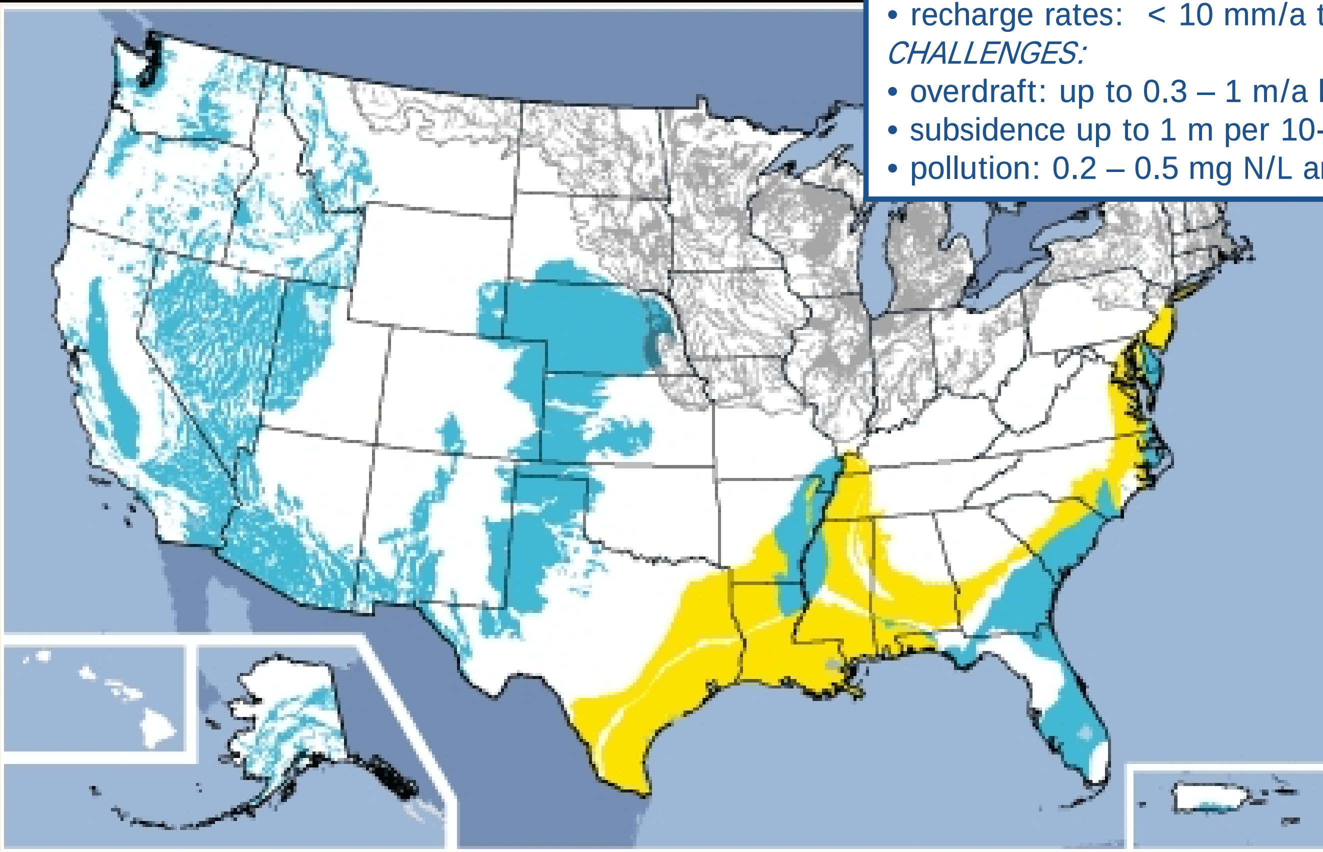
U.S. Sand & Gravel Aquifers

GENERAL PROPERTIES (exceptions ar*e the rule!)*

- K values = 1 m/d – 100 m/d
- gradients 0.1 – 1%
- effective porosity of 5-15%
- velocity: ~10^1 m/a to ~10^3 m/a
- recharge rates: < 10 mm/a to 500 mm/a

CHALLENGES:

- overdraft: up to 0.3 – 1 m/a head loss (30 – 200 mm/a gw loss)
- subsidence up to 1 m per 10-50 m drawdown
- pollution: 0.2 – 0.5 mg N/L annual increase in nitrate-N

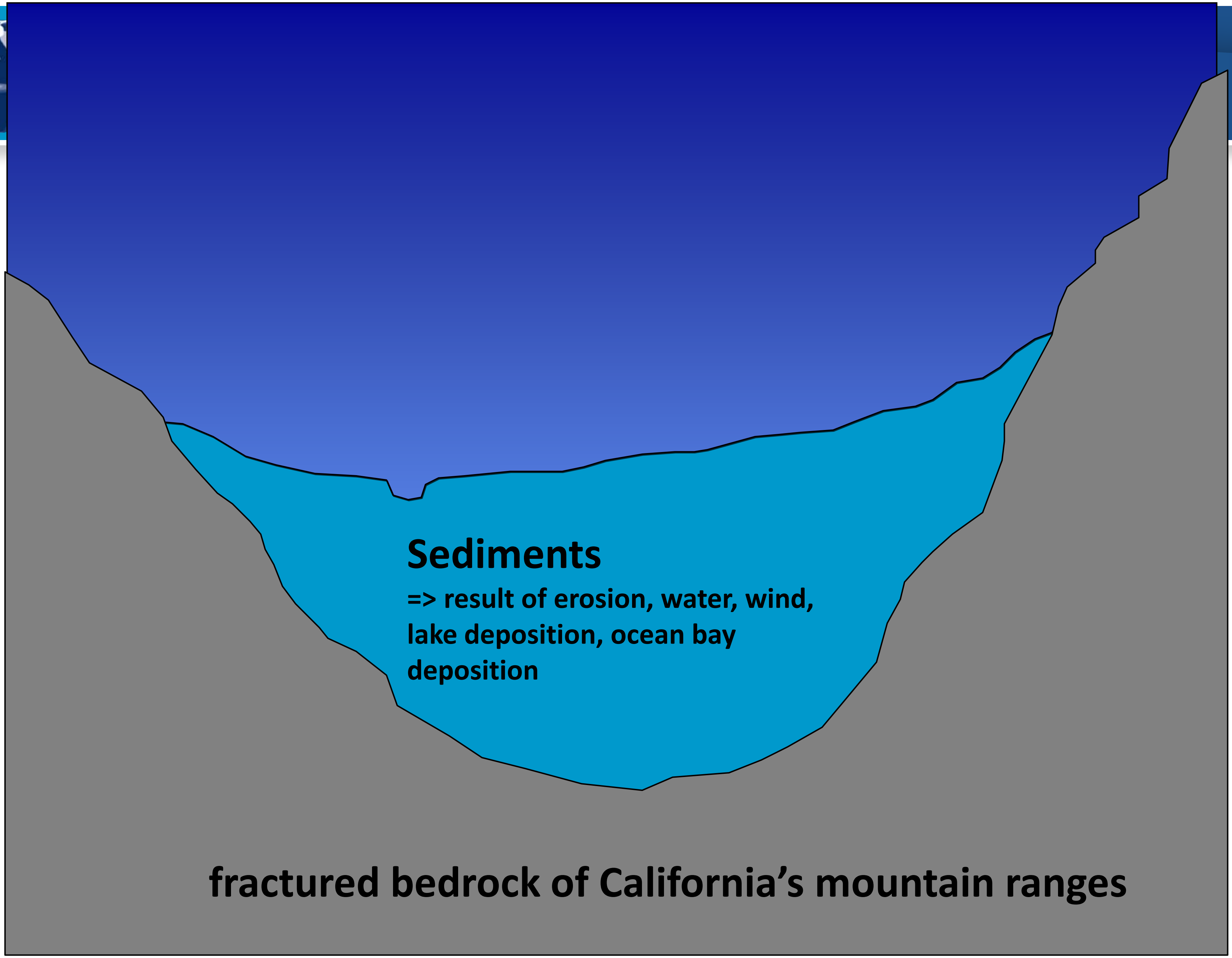


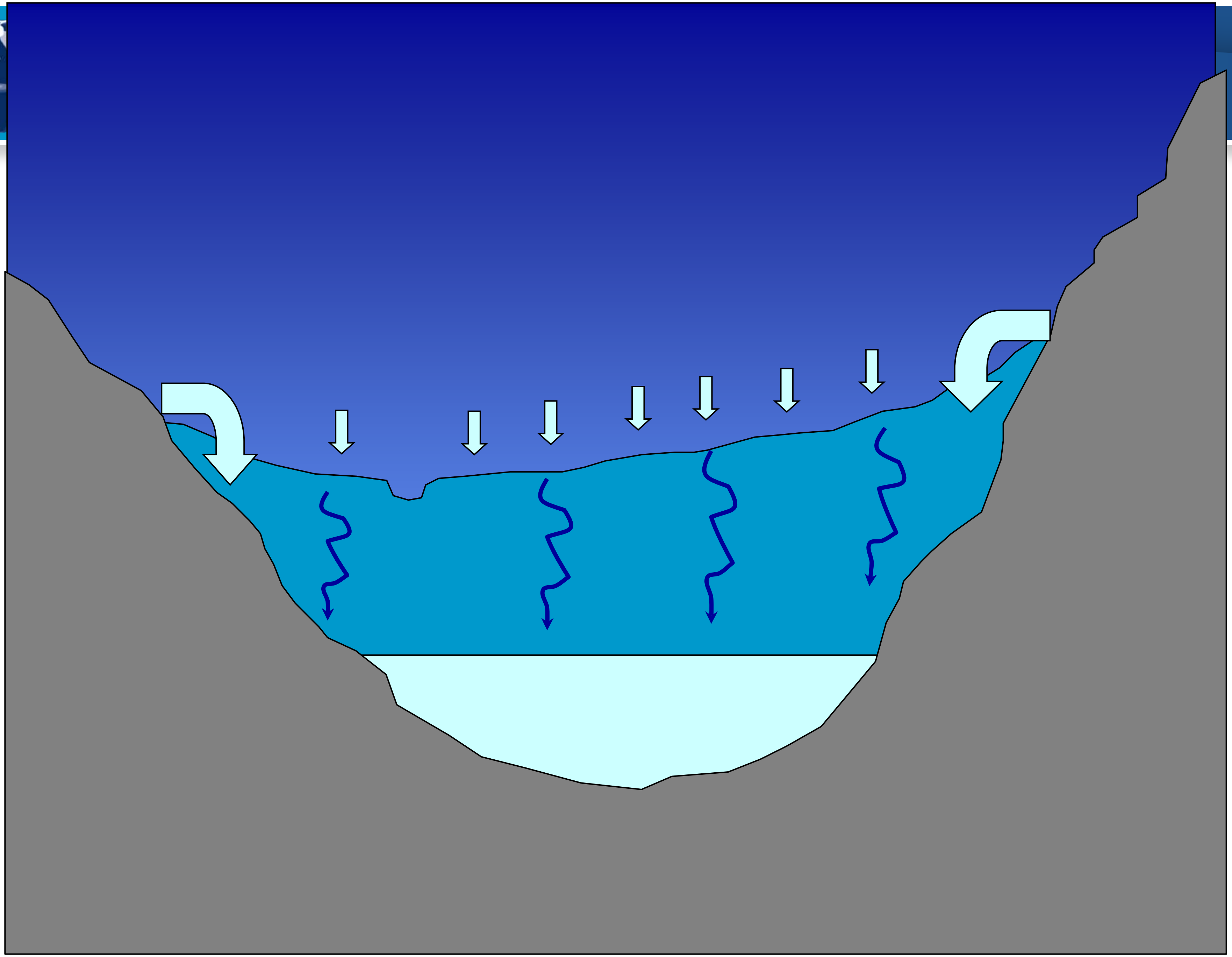
Unconsolidated sand and gravel aquifers at or near the land surface.

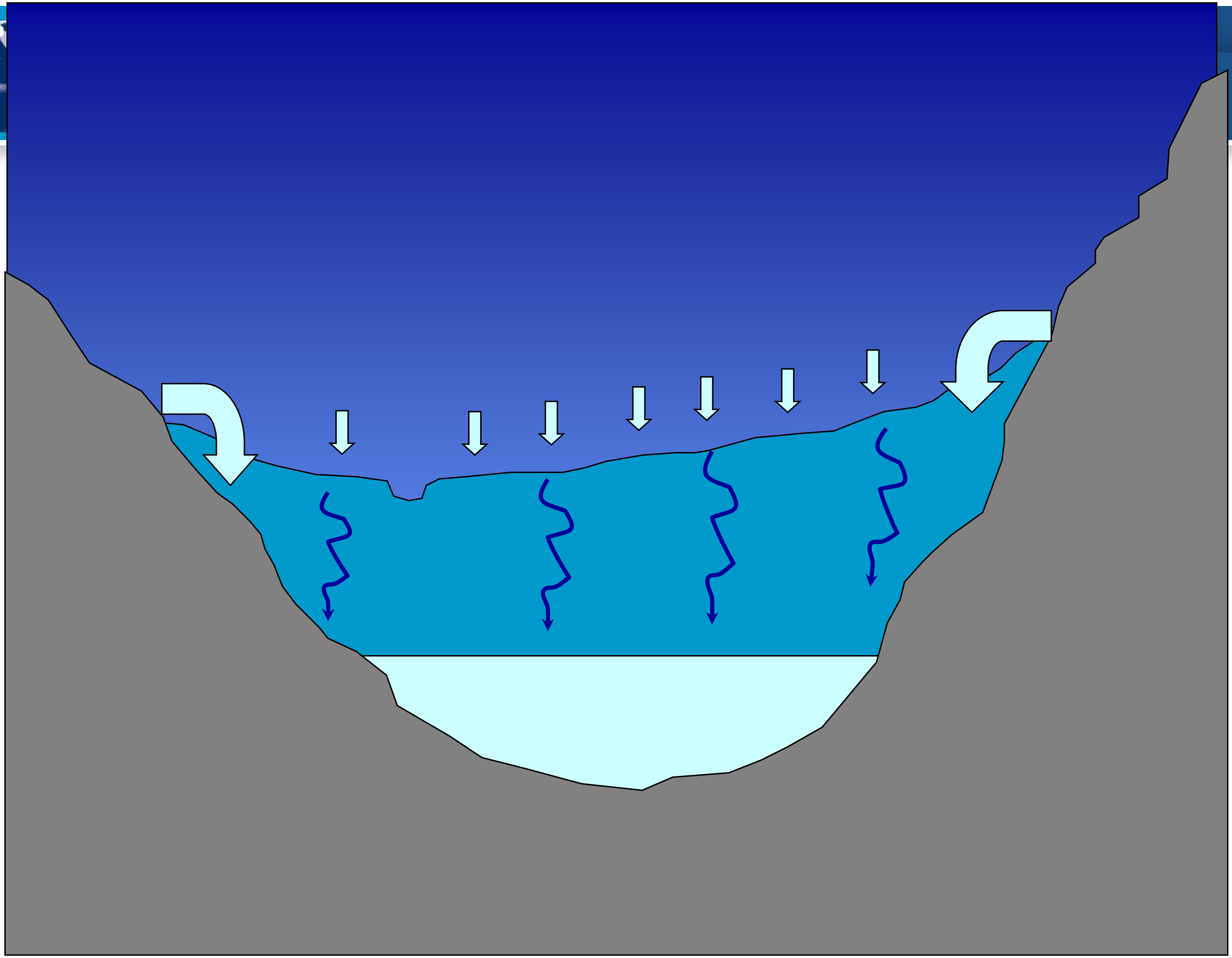
Semiconsolidated sand and gravel aquifers.

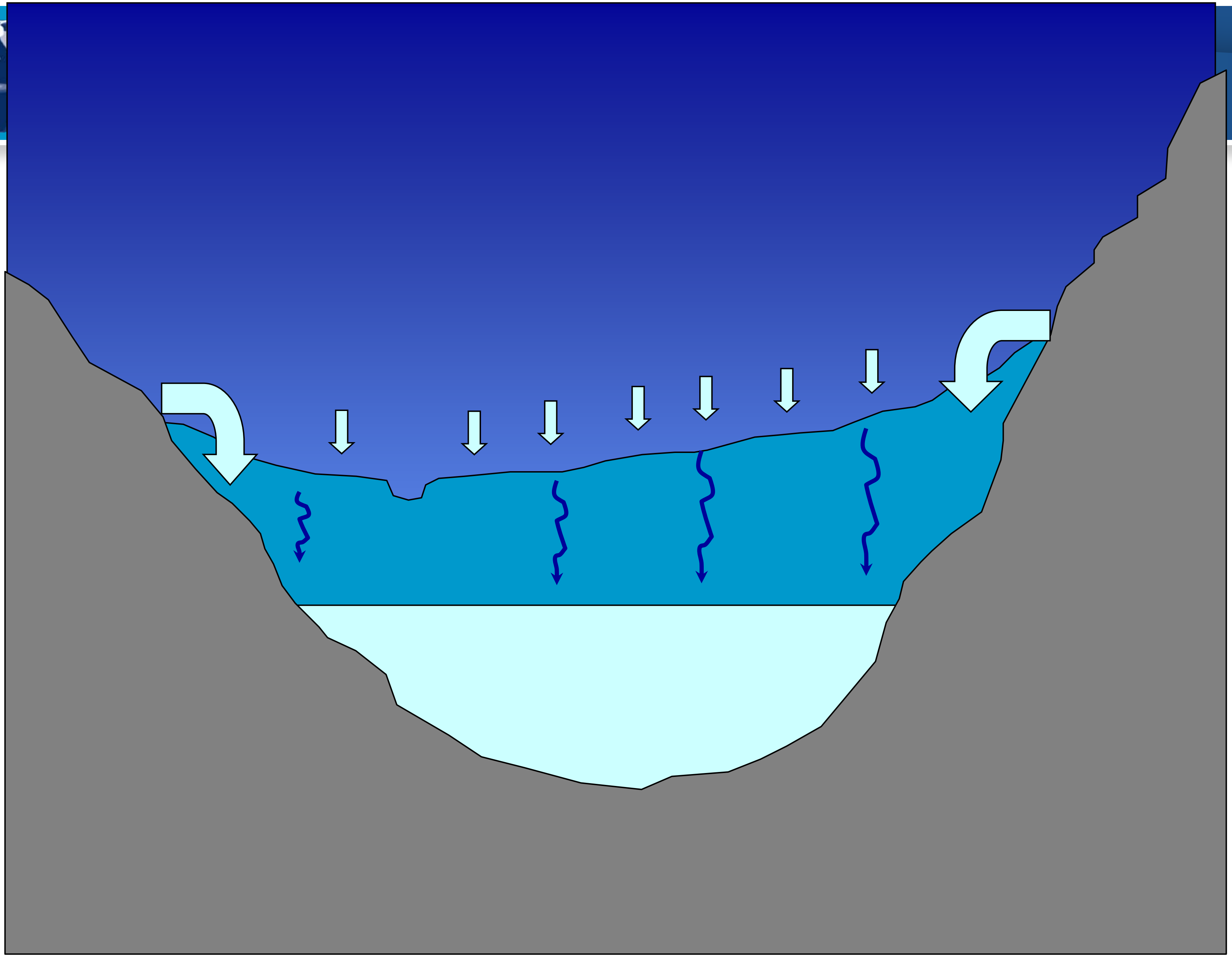
Sand and gravel aquifers of alluvial and glacial origin are north of the line of continental glaciation.

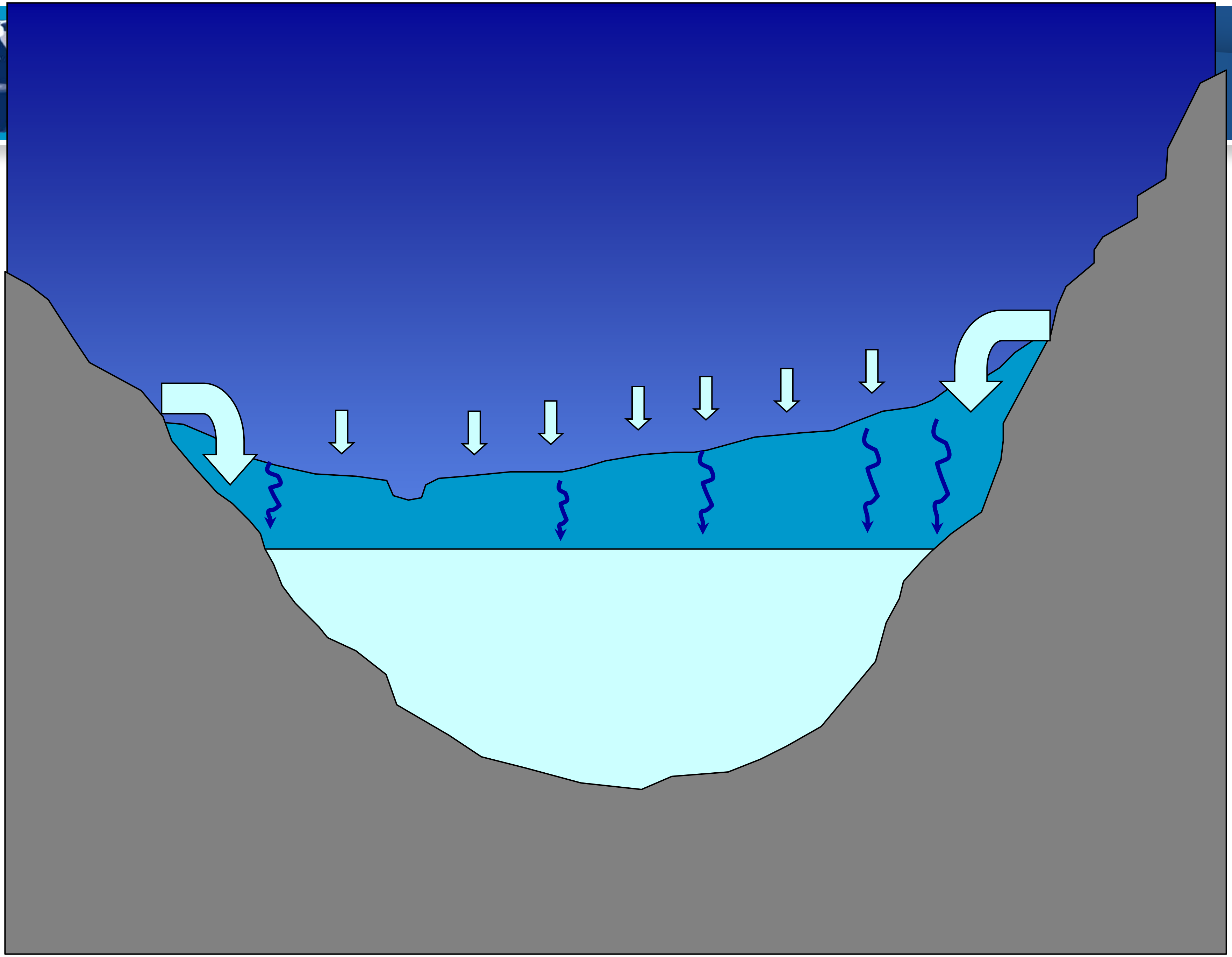
http://water.usgs.gov/ogw/aquiferbasics/uncon.html

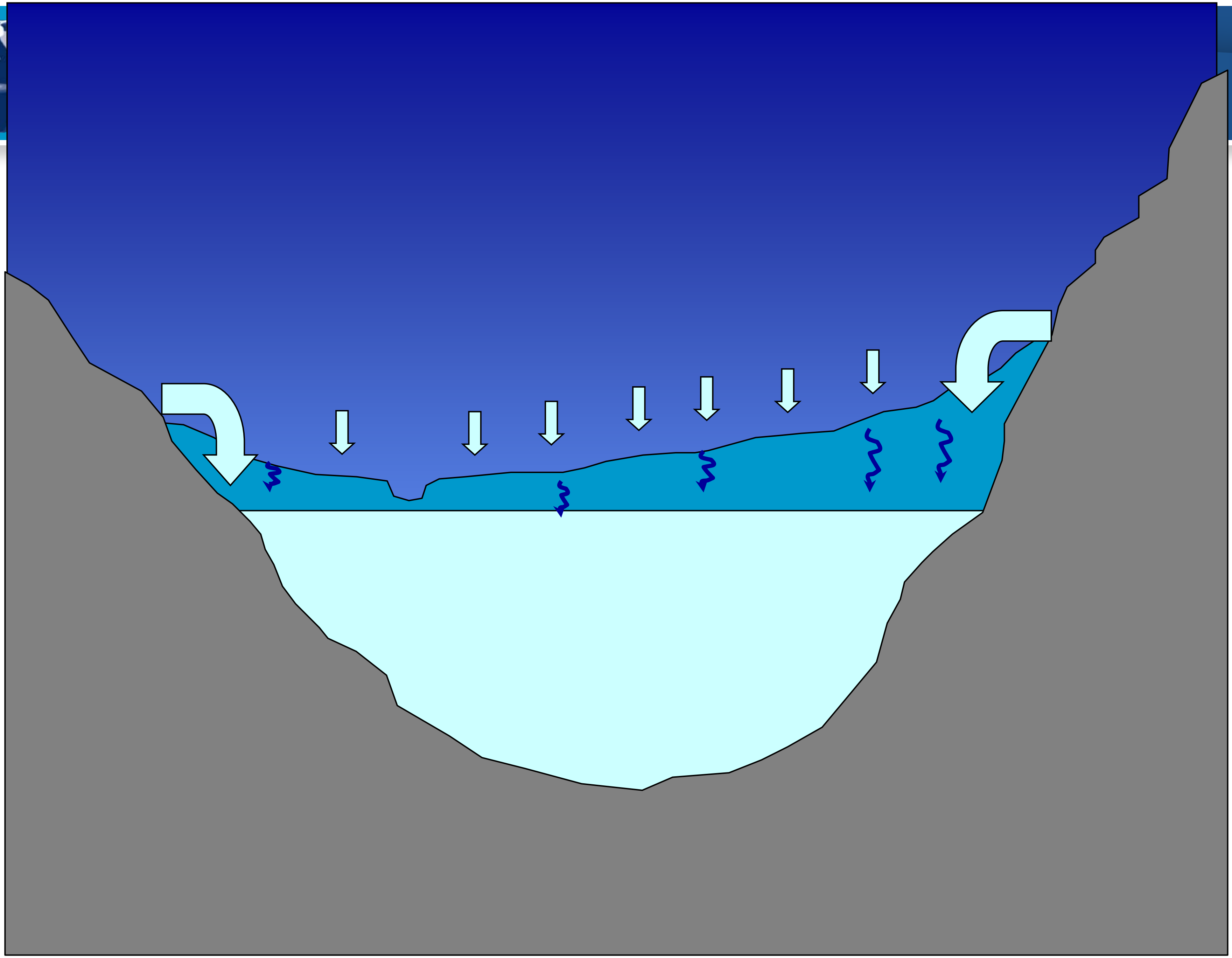

Sediments
=> result of erosion, water, wind, lake deposition, ocean bay deposition
fractured bedrock of California’s mountain ranges

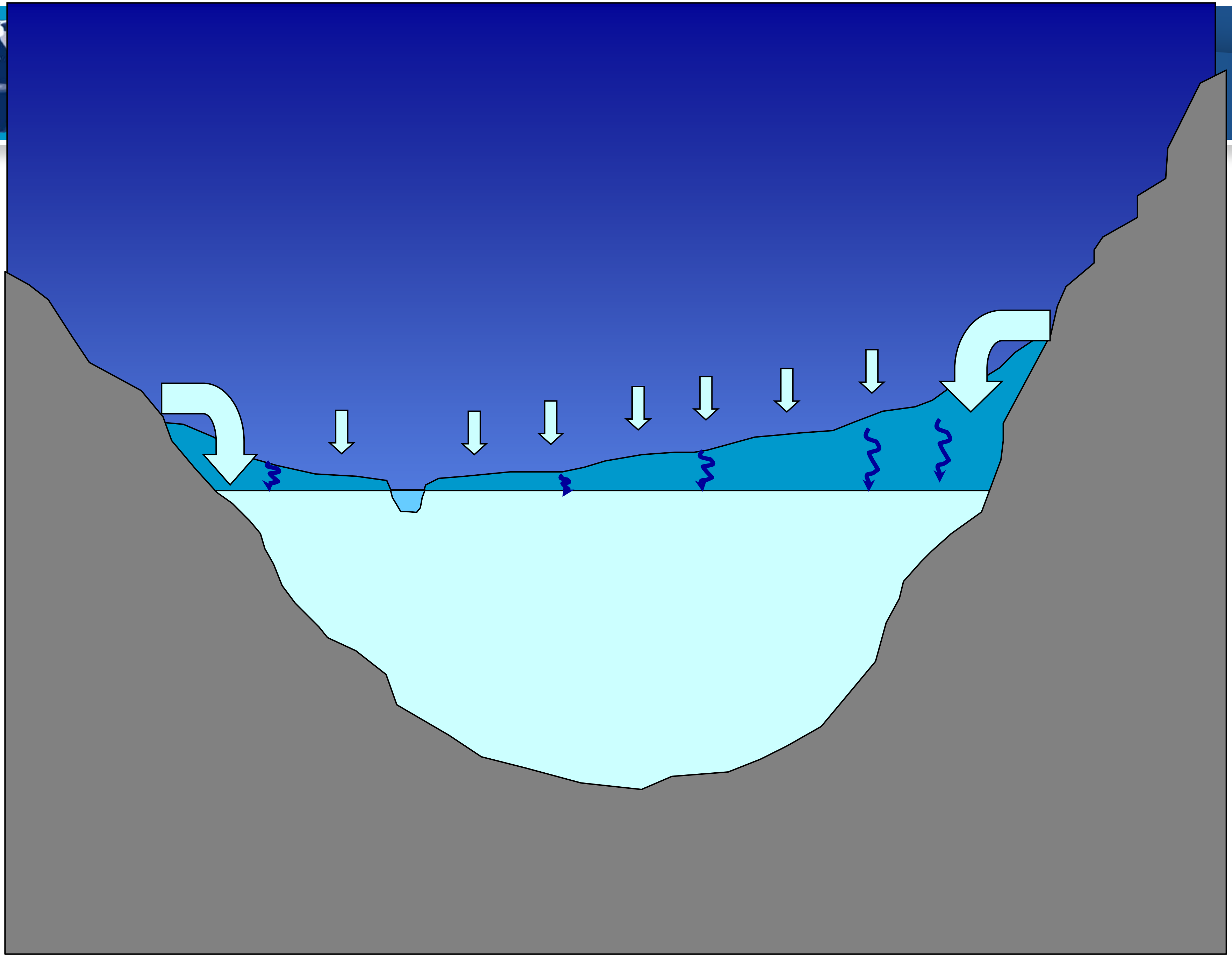


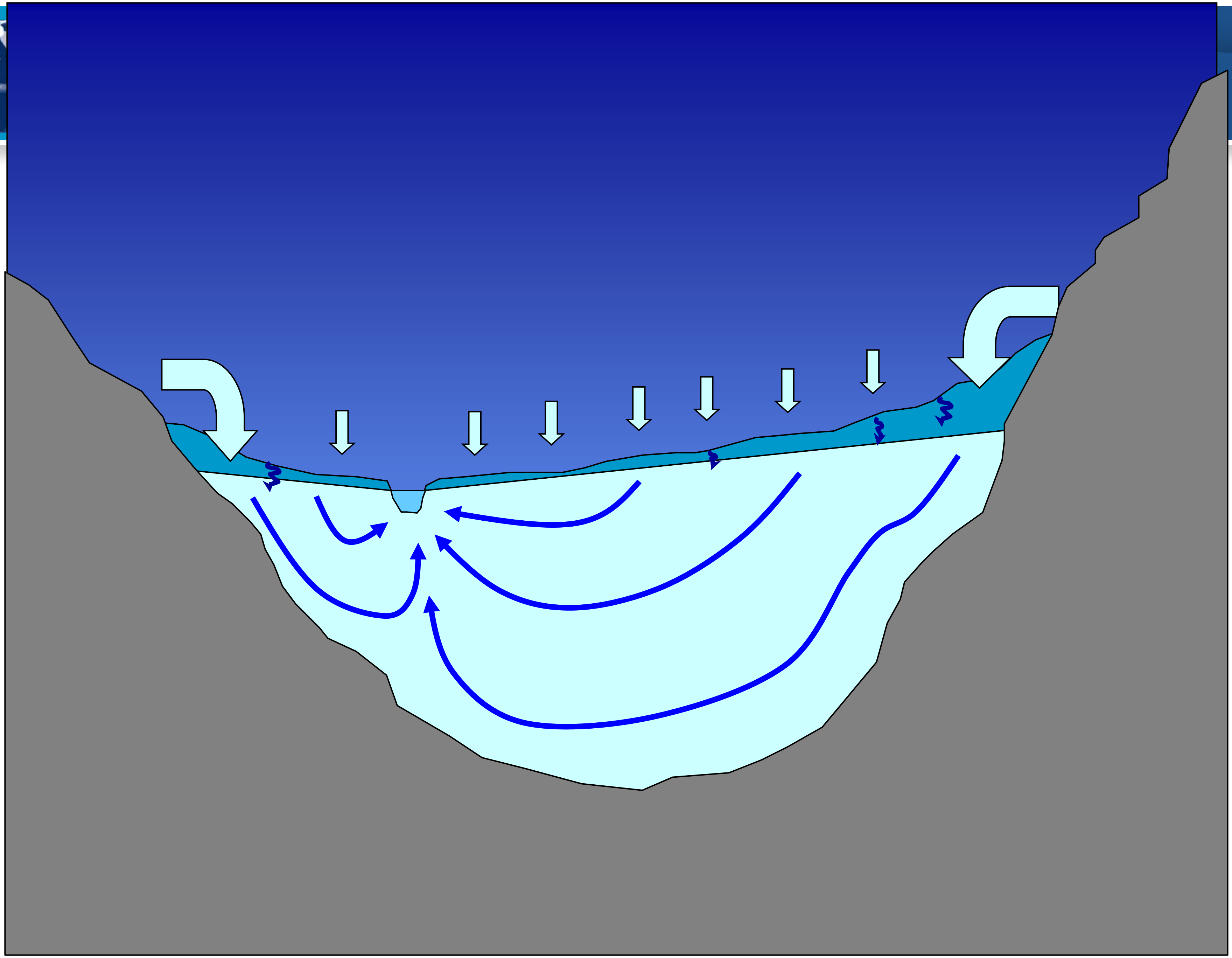






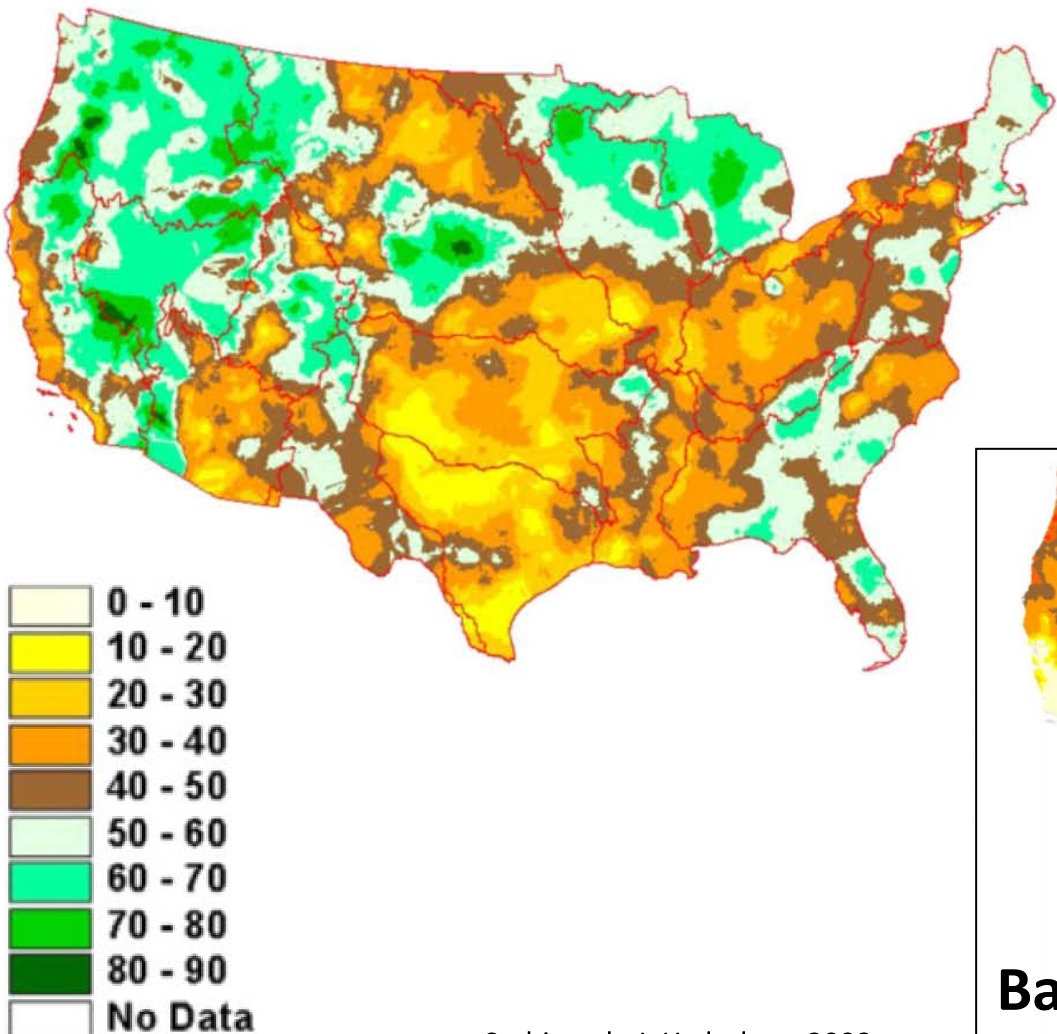






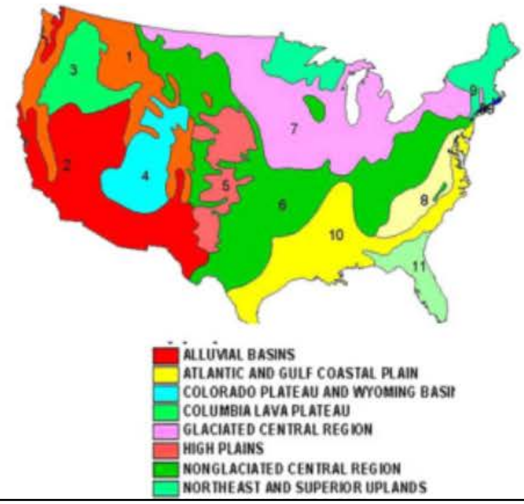
Groundwater Contribution to Streamflow: Baseflow

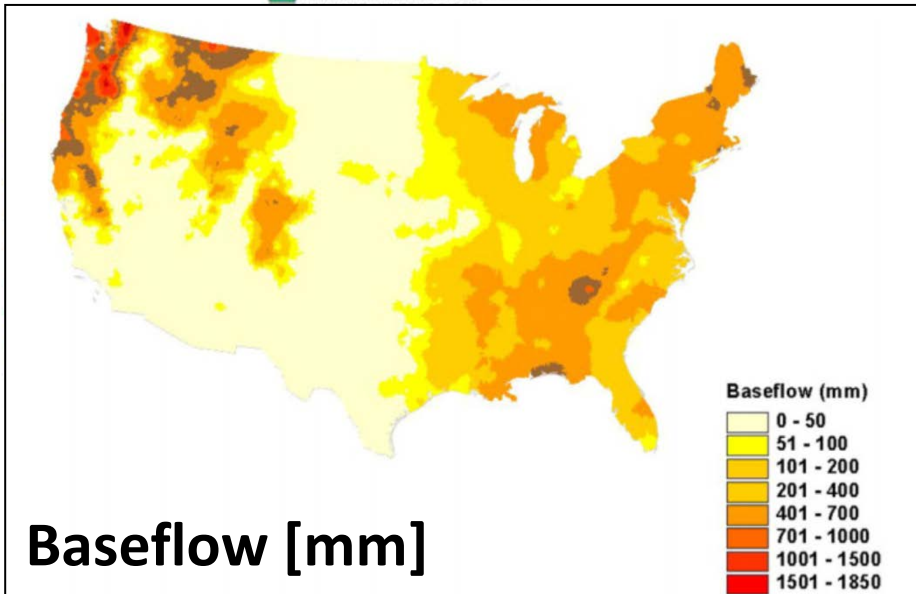
Baseflow (% of Streamflow)

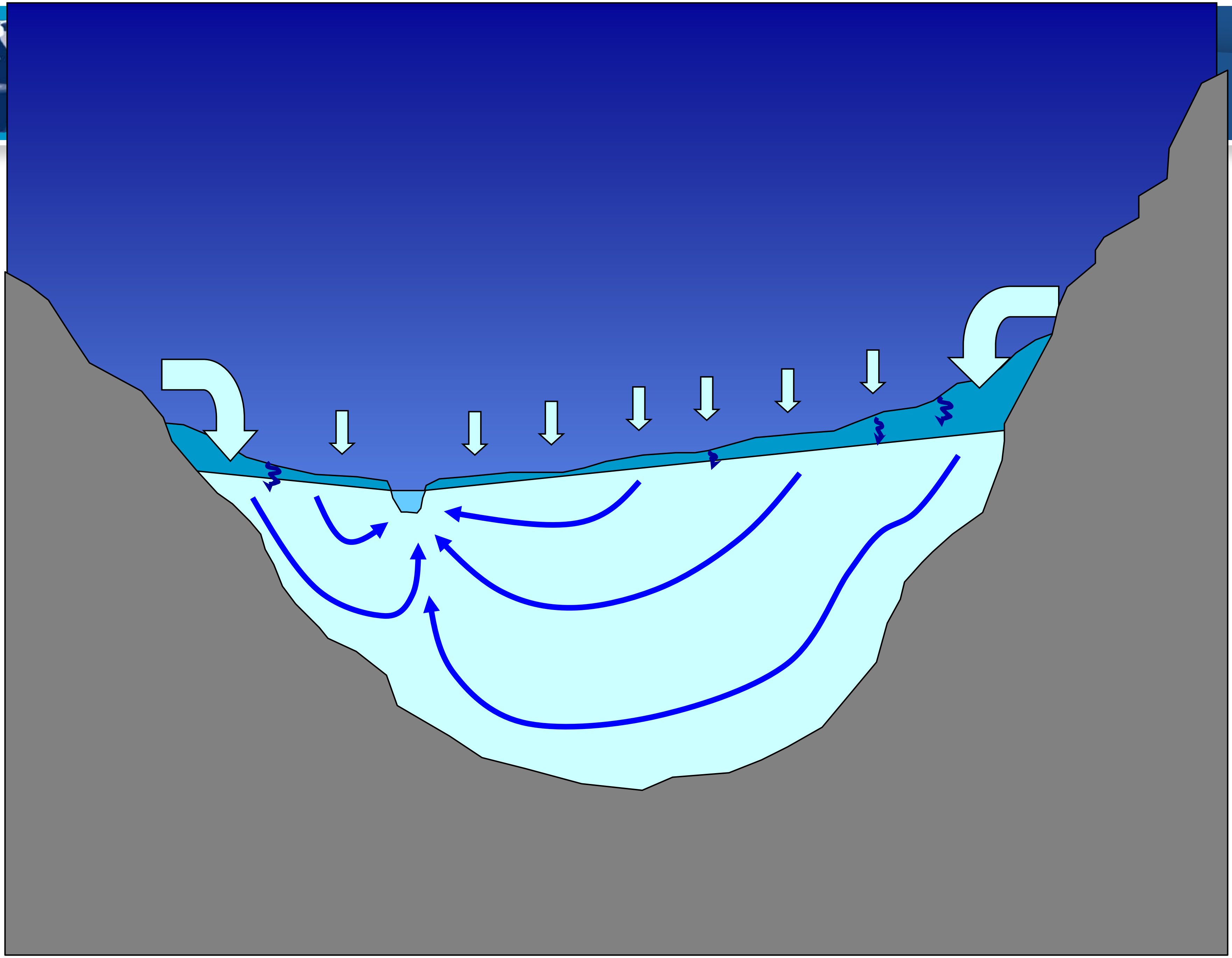


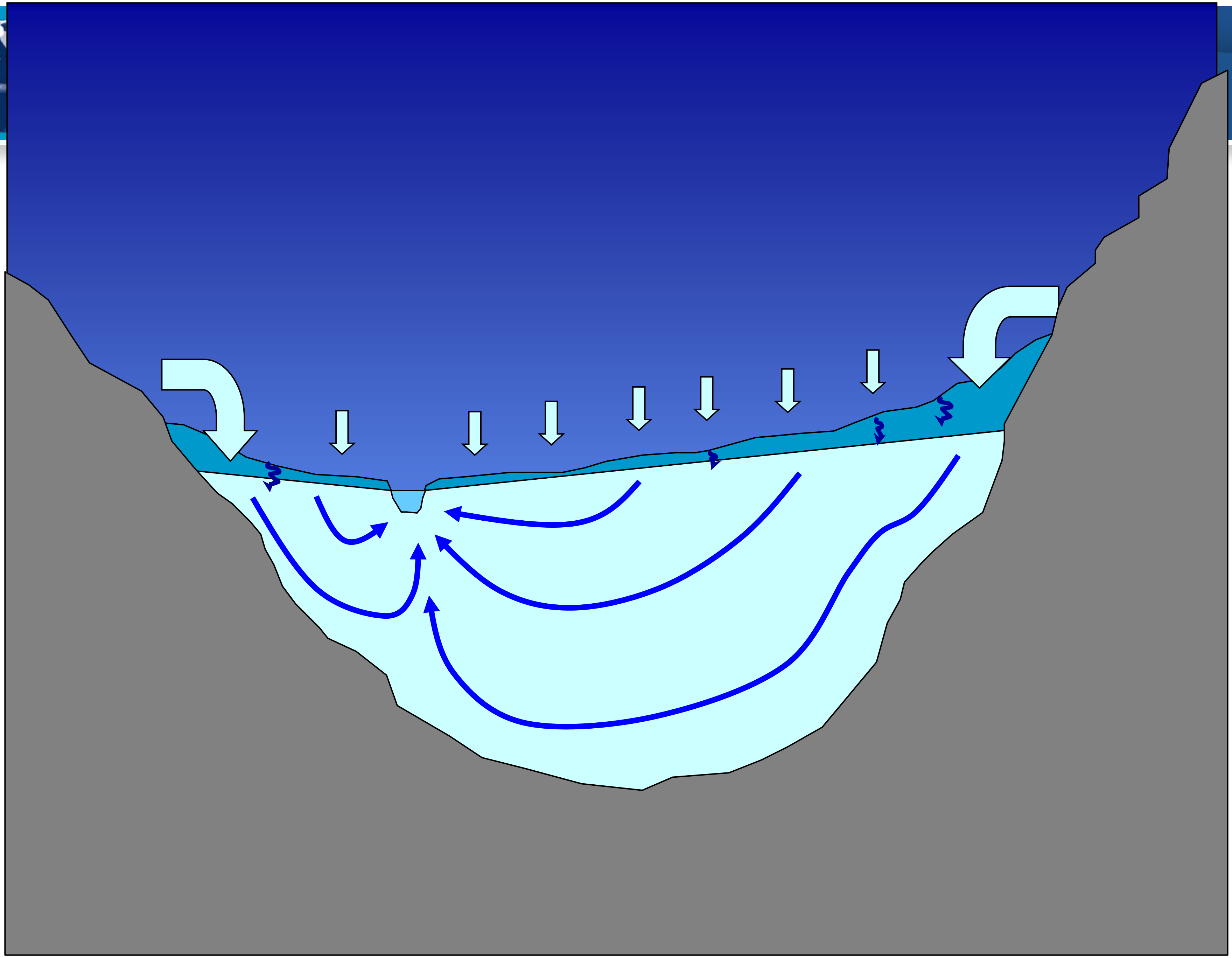
Sethi et al., J. Hydrology, 2008

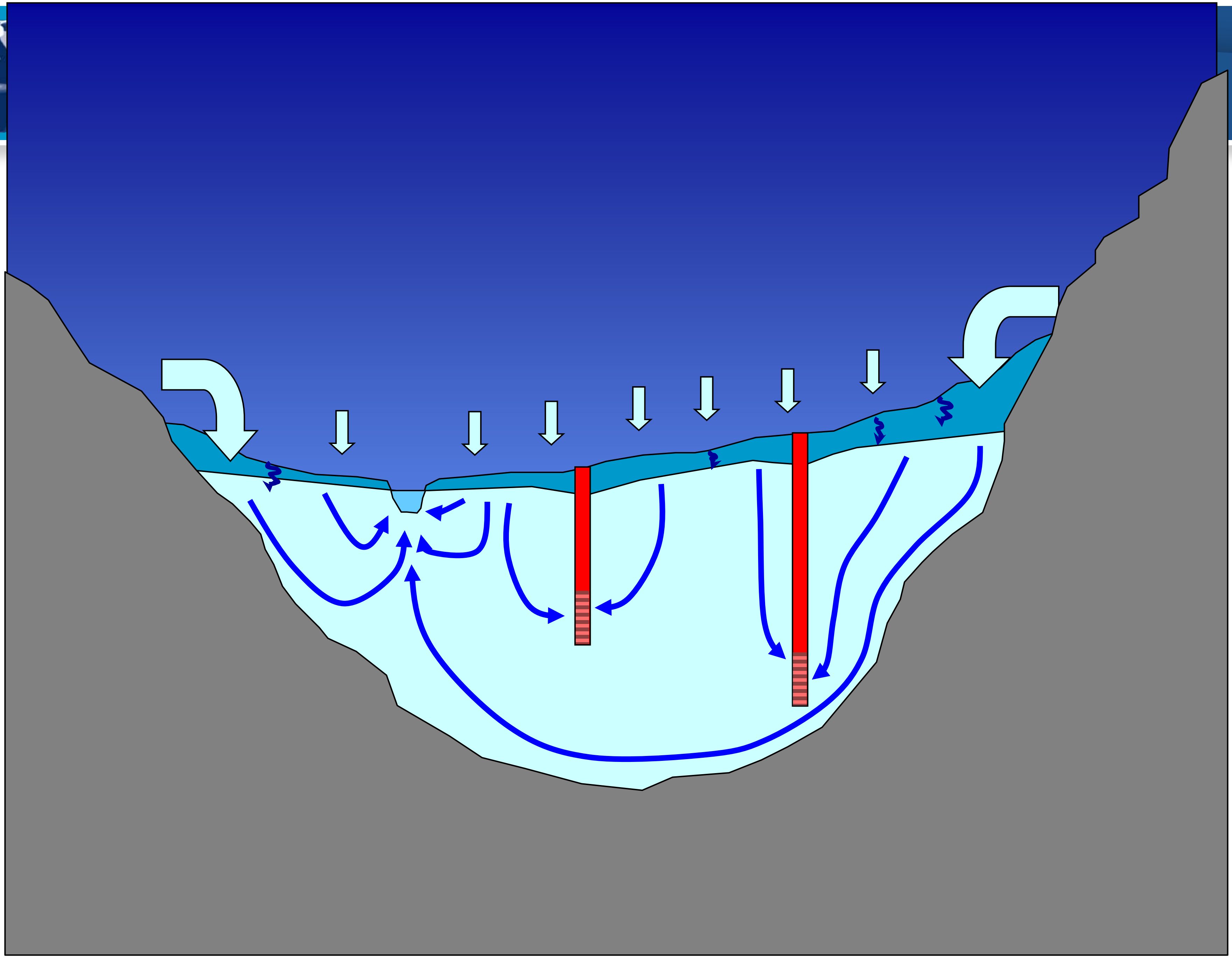
Ground Water Regions (Heath, 1984)

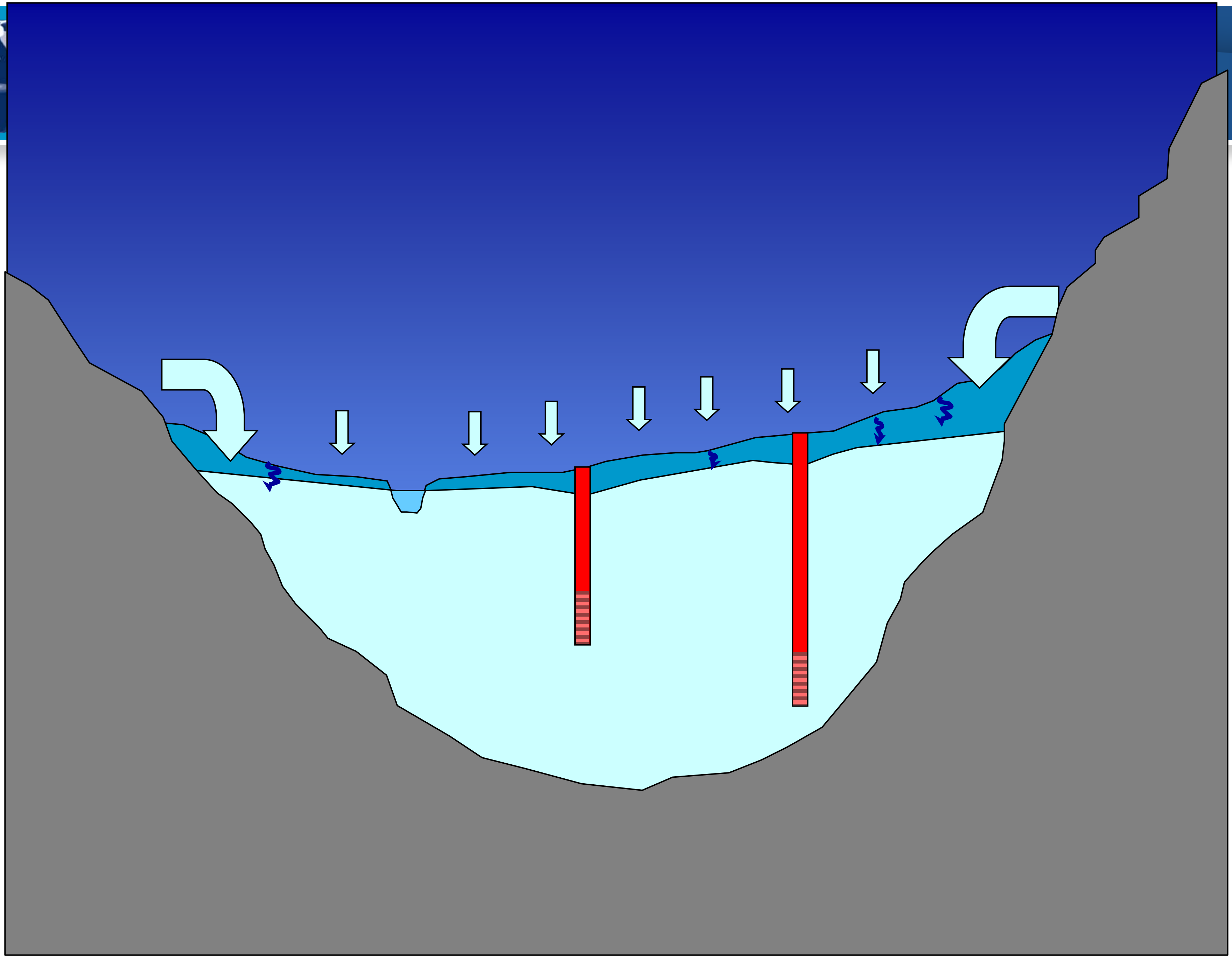


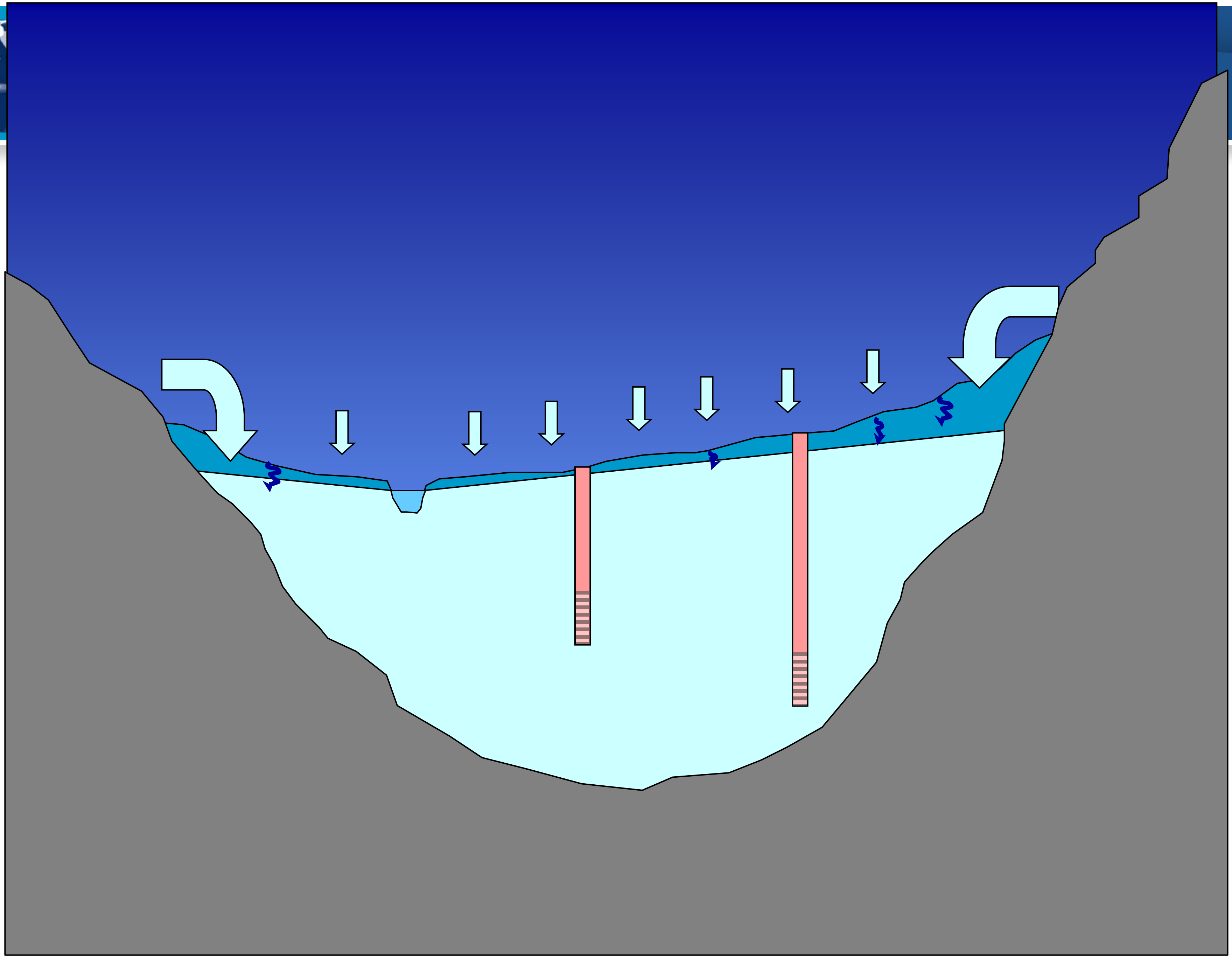


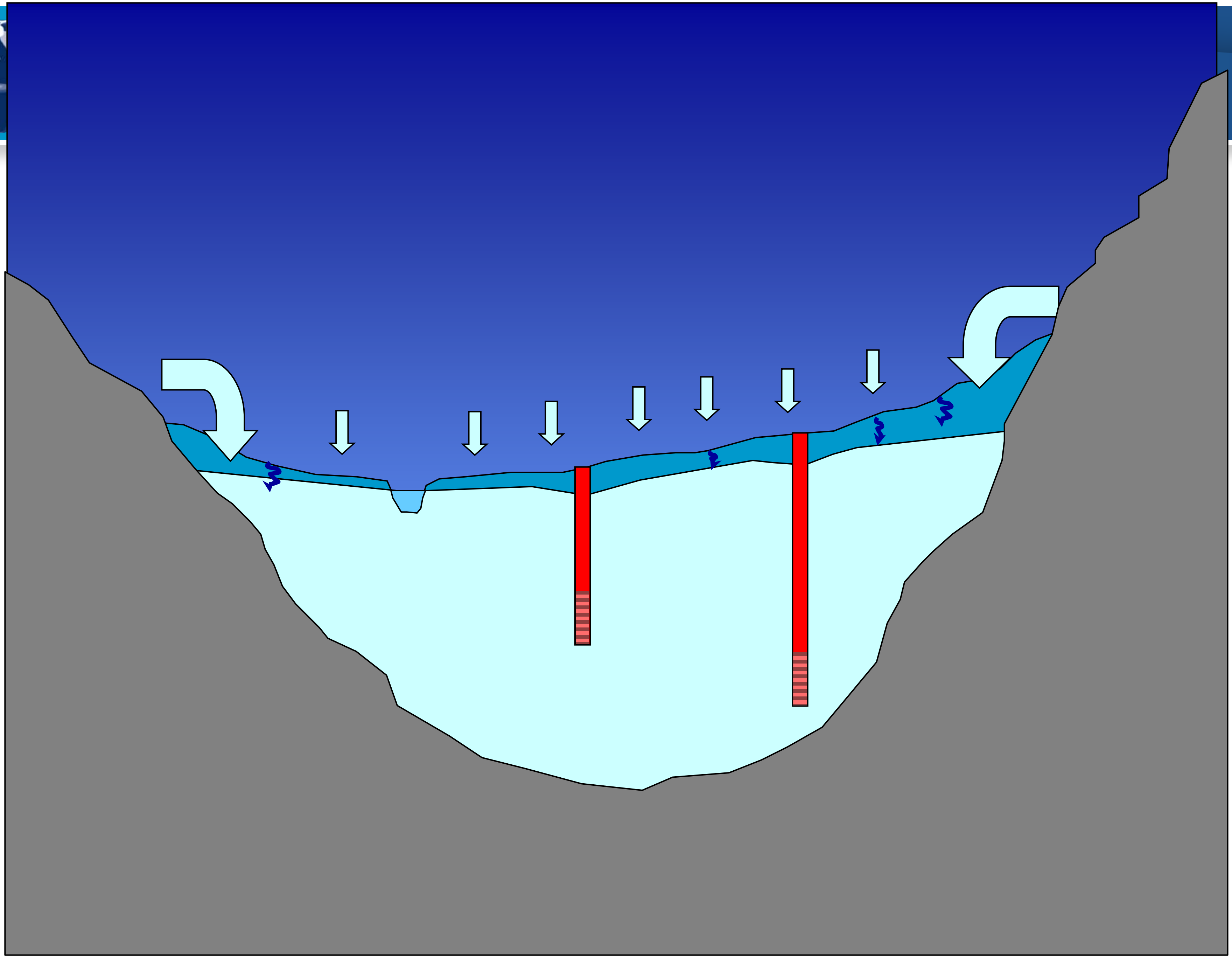


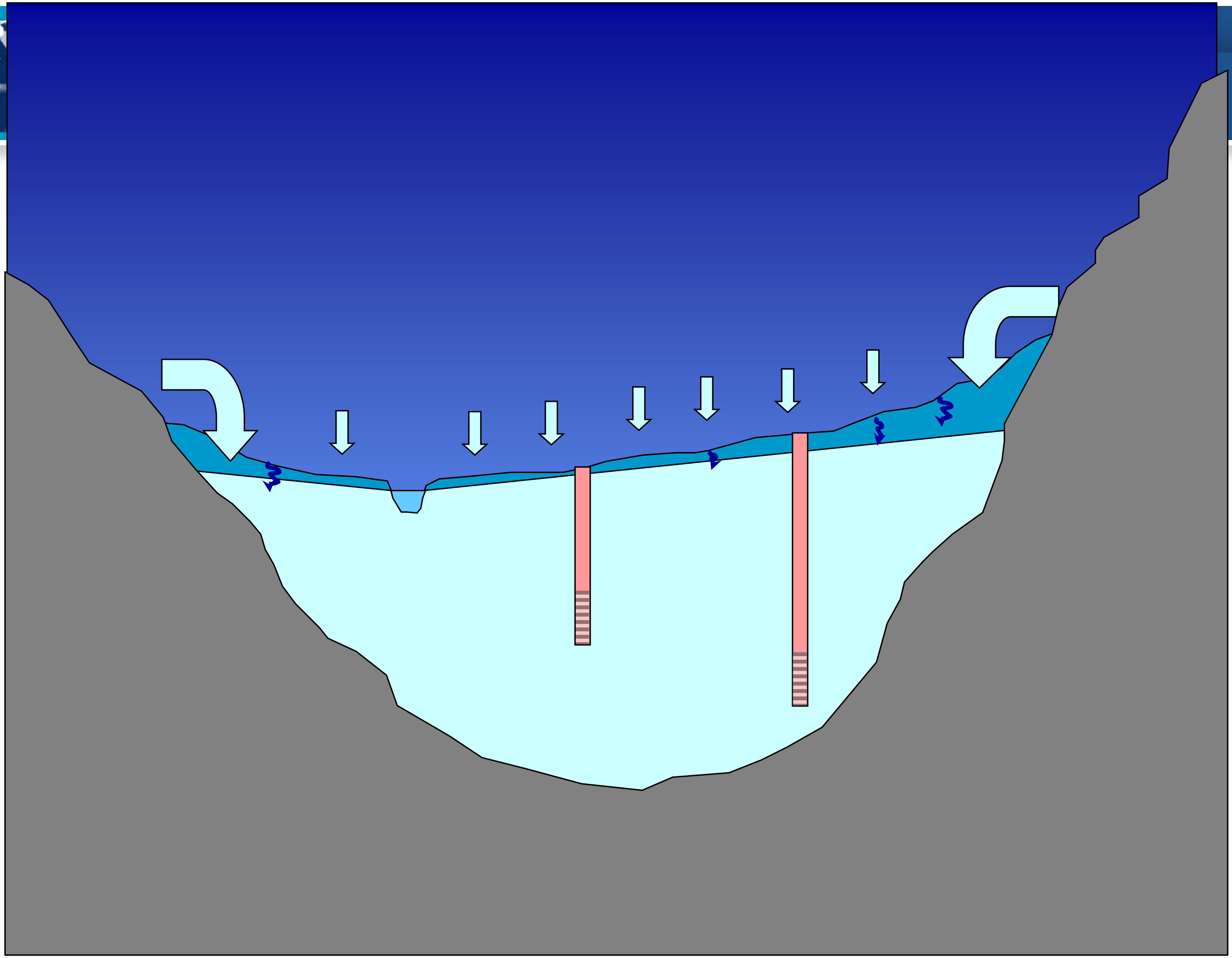


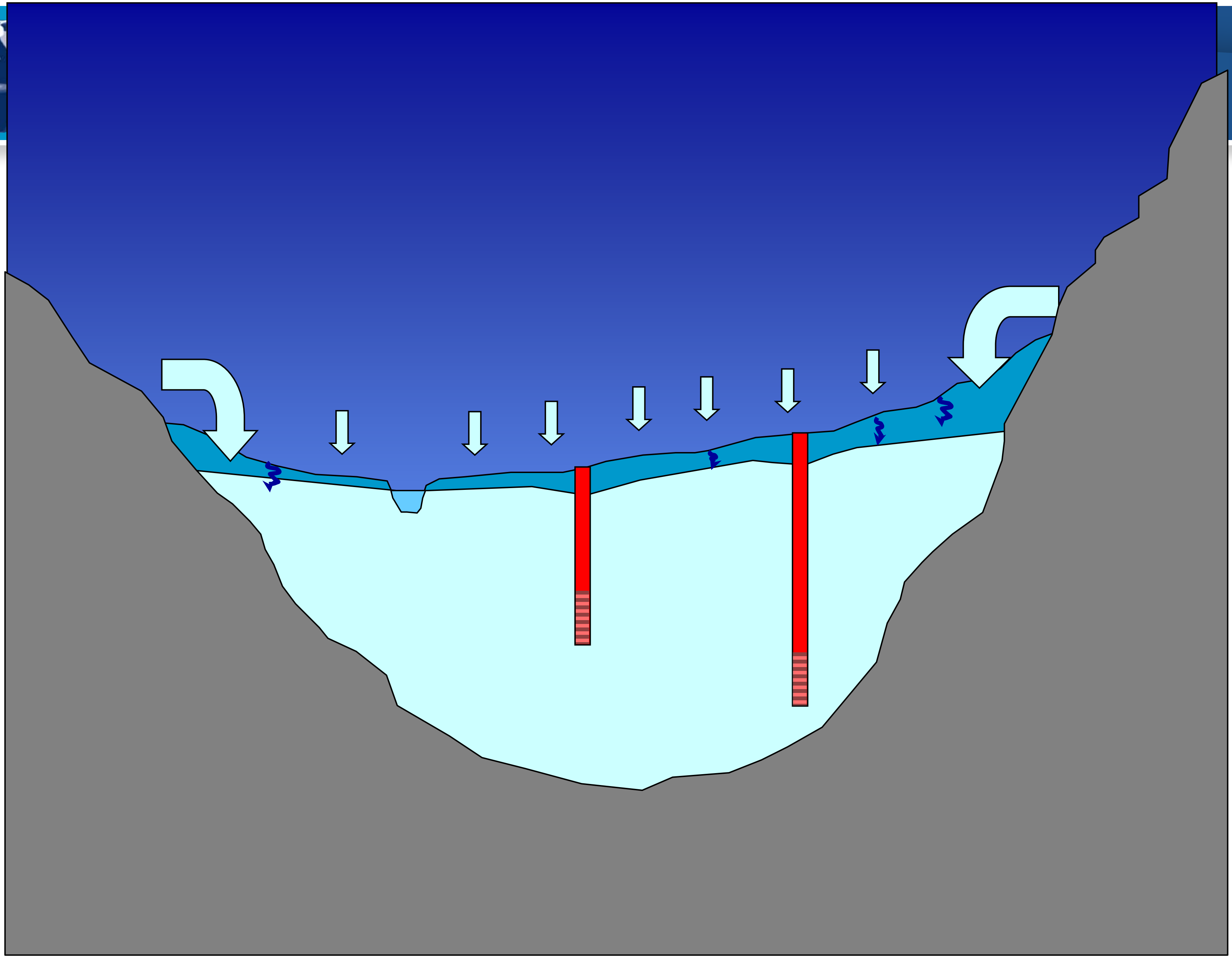


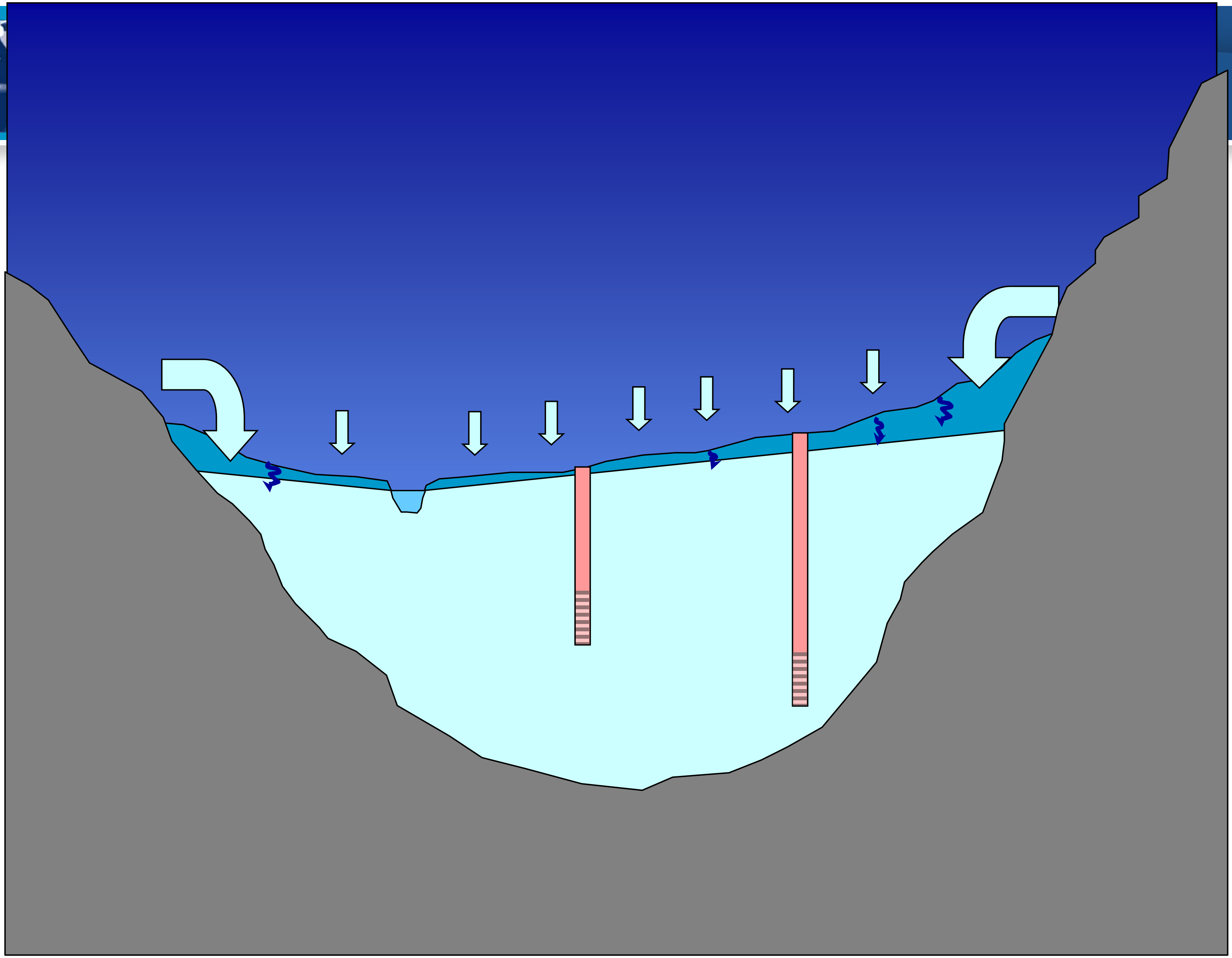


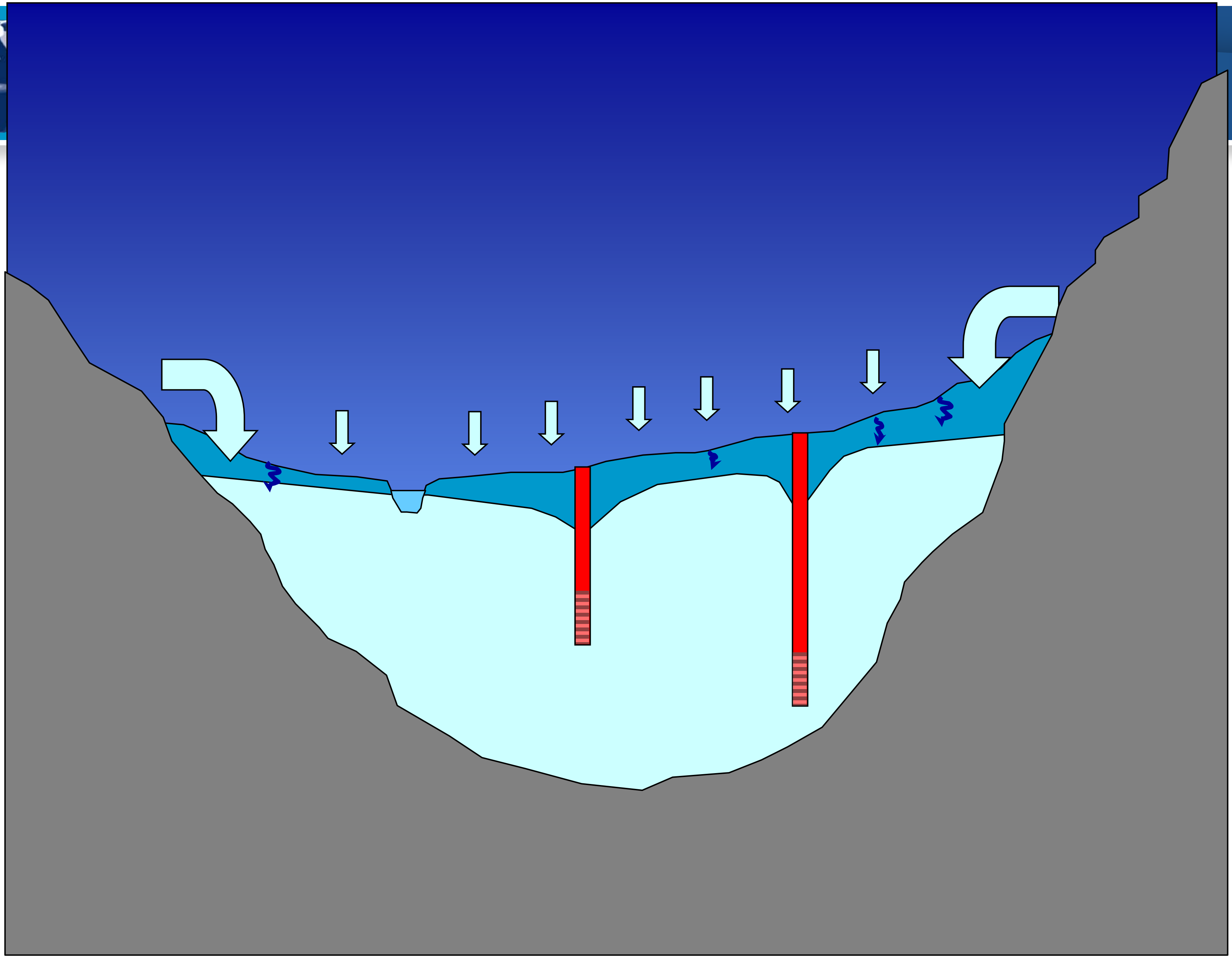


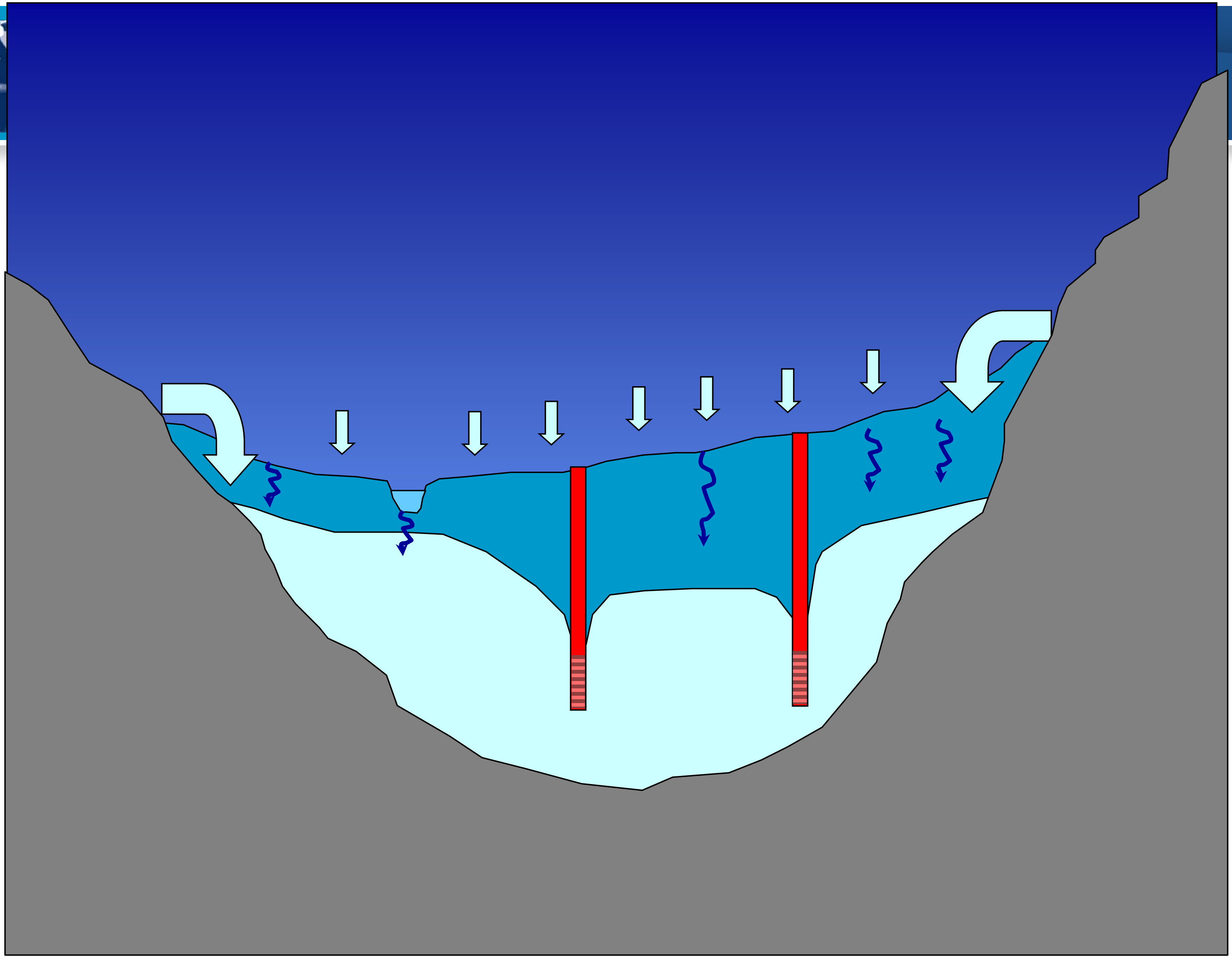


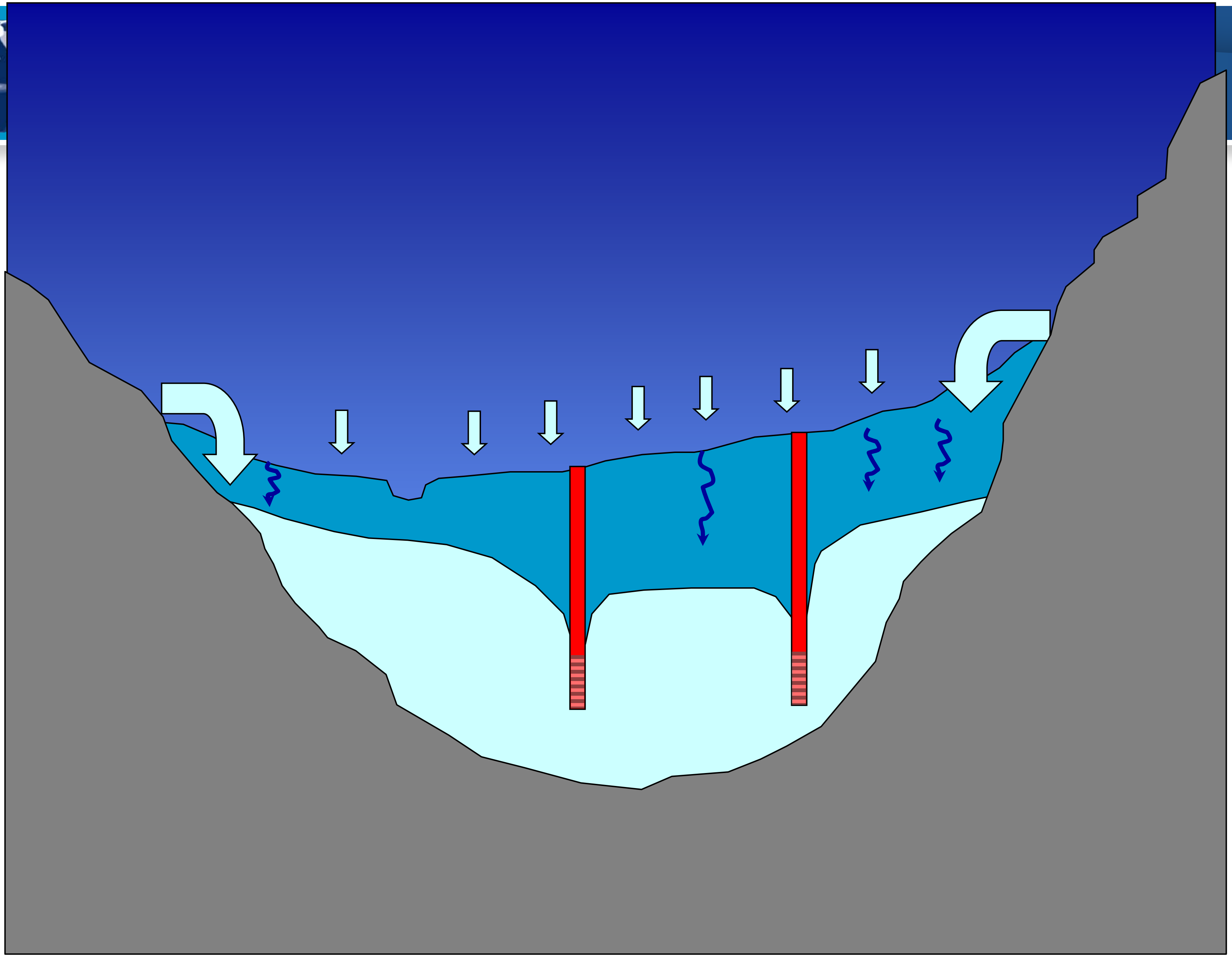




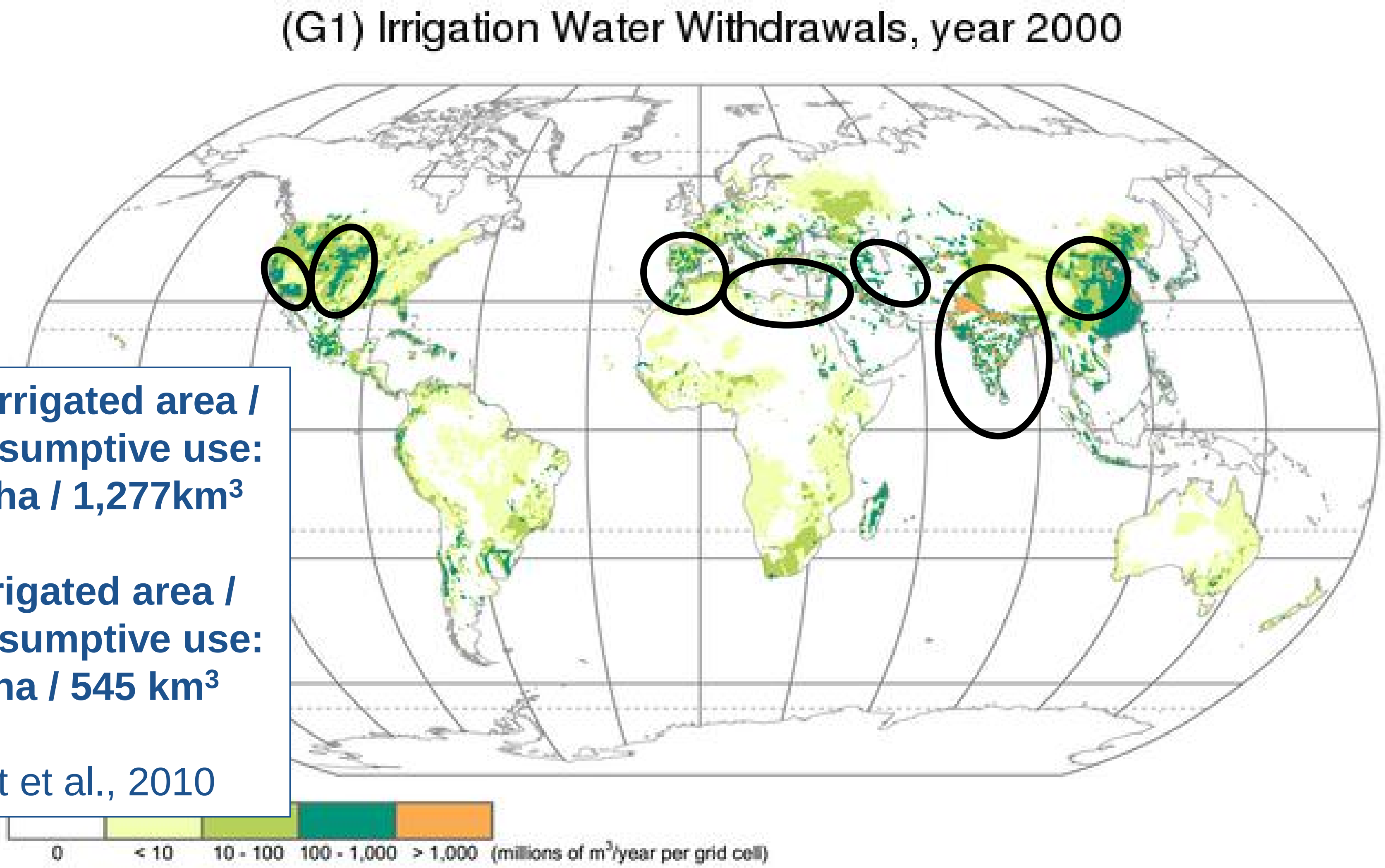








Groundwater for Irrigation



Total irrigated area / consumptive use: 300 Mha / 1,277km³

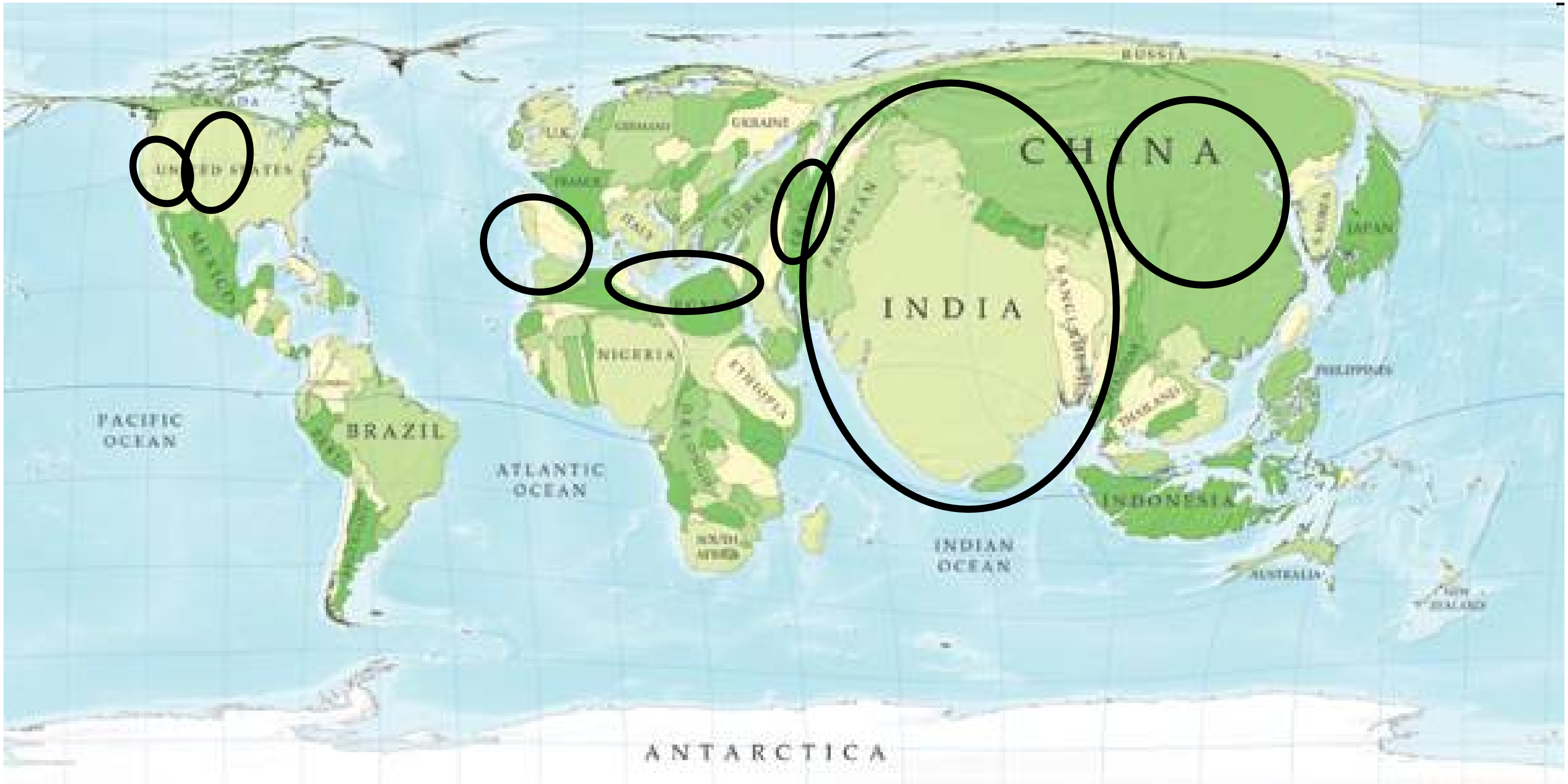
GW irrigated area / consumptive use: 112 Mha / 545 km³

Siebert et al., 2010

UN World Water Development Report II, 2006

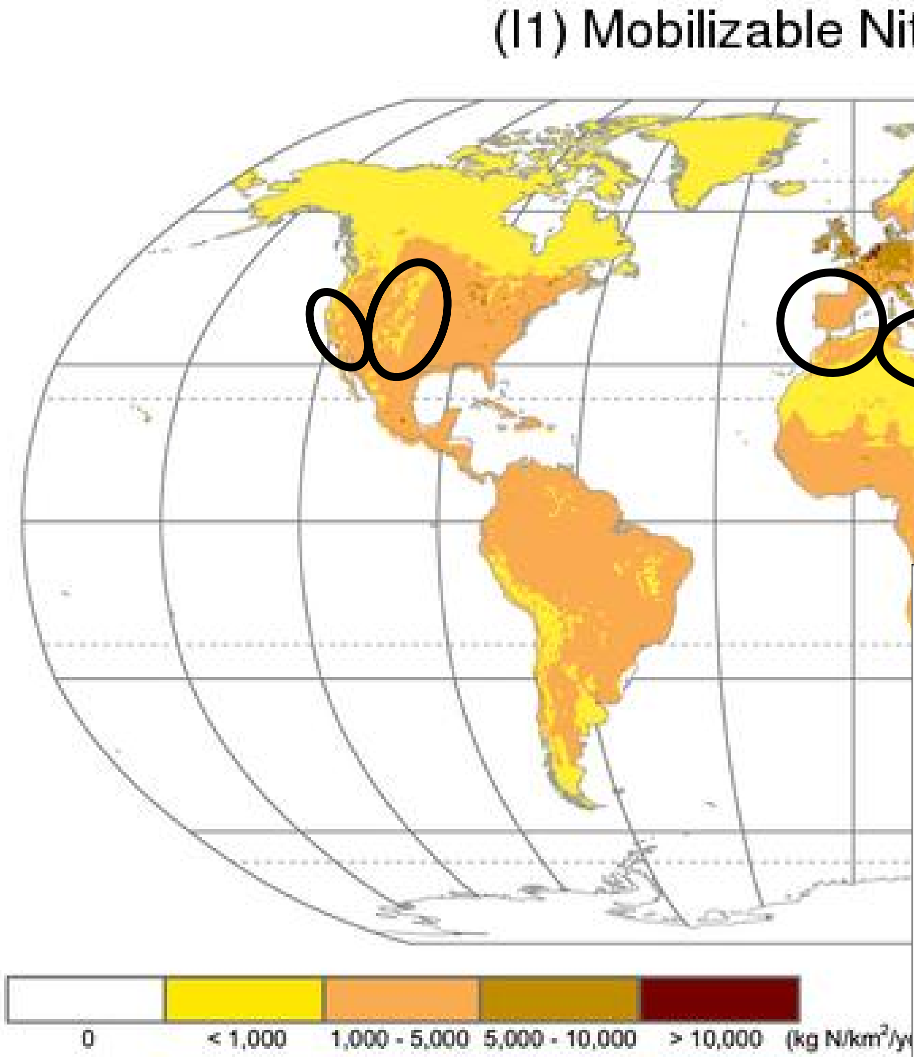
Shah, Villholth, Burke, "Groundwater: a global assessment of scale and significance", IWMI, 2007

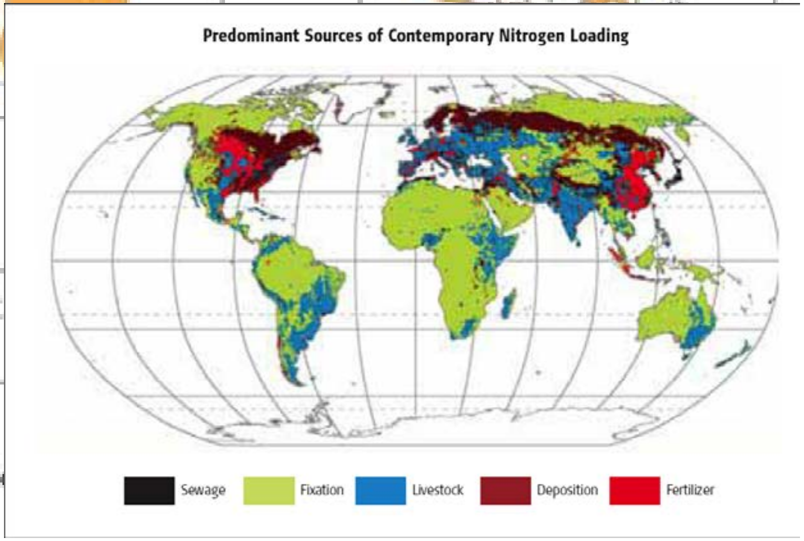
Population Map of the World & Major GW Withdrawal Centers



Modified with world population map from: *Nature* **439**, 800 (16 February 2006) **|** doi:10.1038/439800a

Example: GW Nitrate

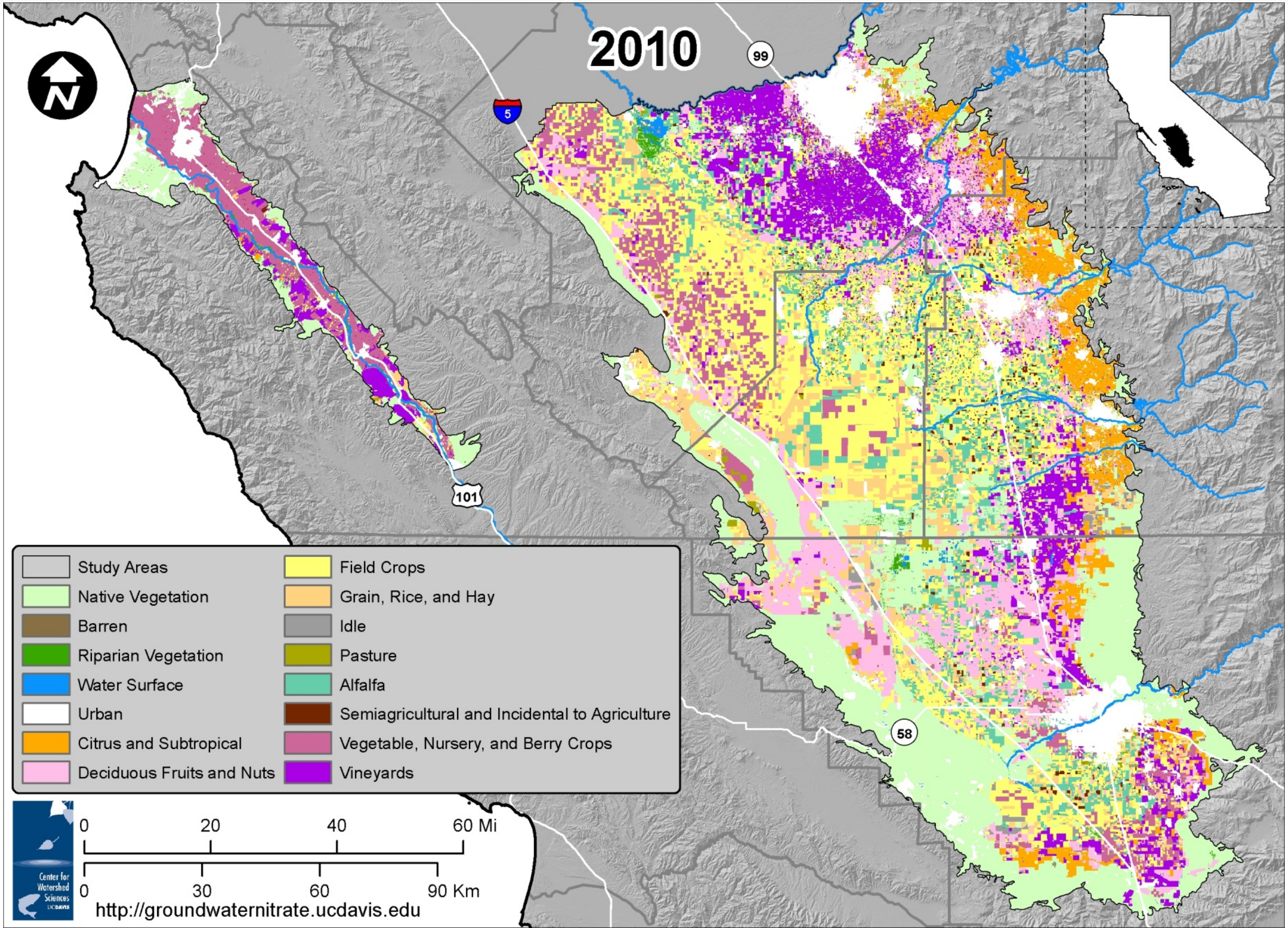




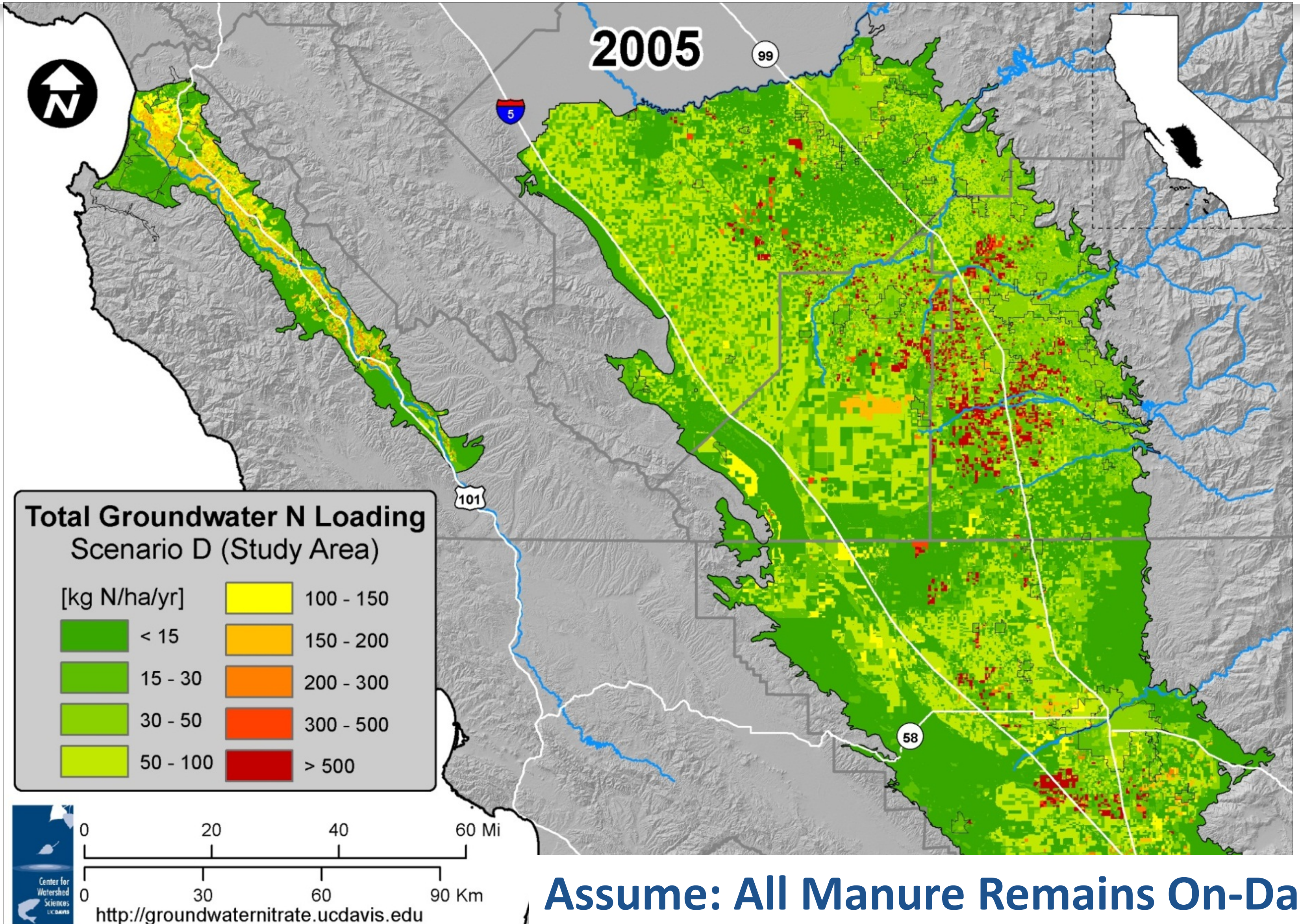
Note: 10 mg N/l = 10 kg N/km^2/yr for each 1 mm/yr recharge

UN World Water Development Report II, 2006

Nitrate Contamination Study Area

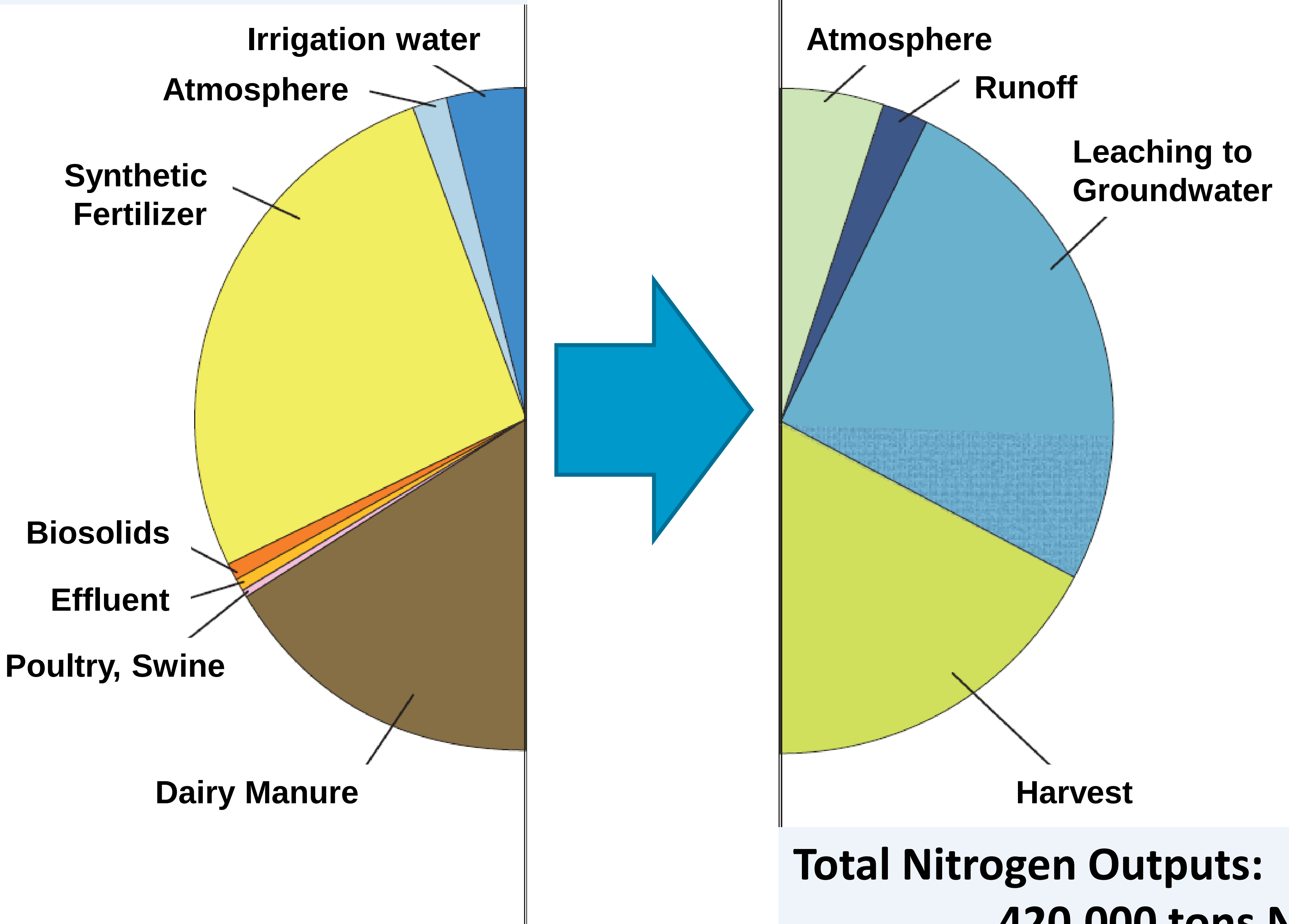


Estimated Groundwater Nitrate Loading



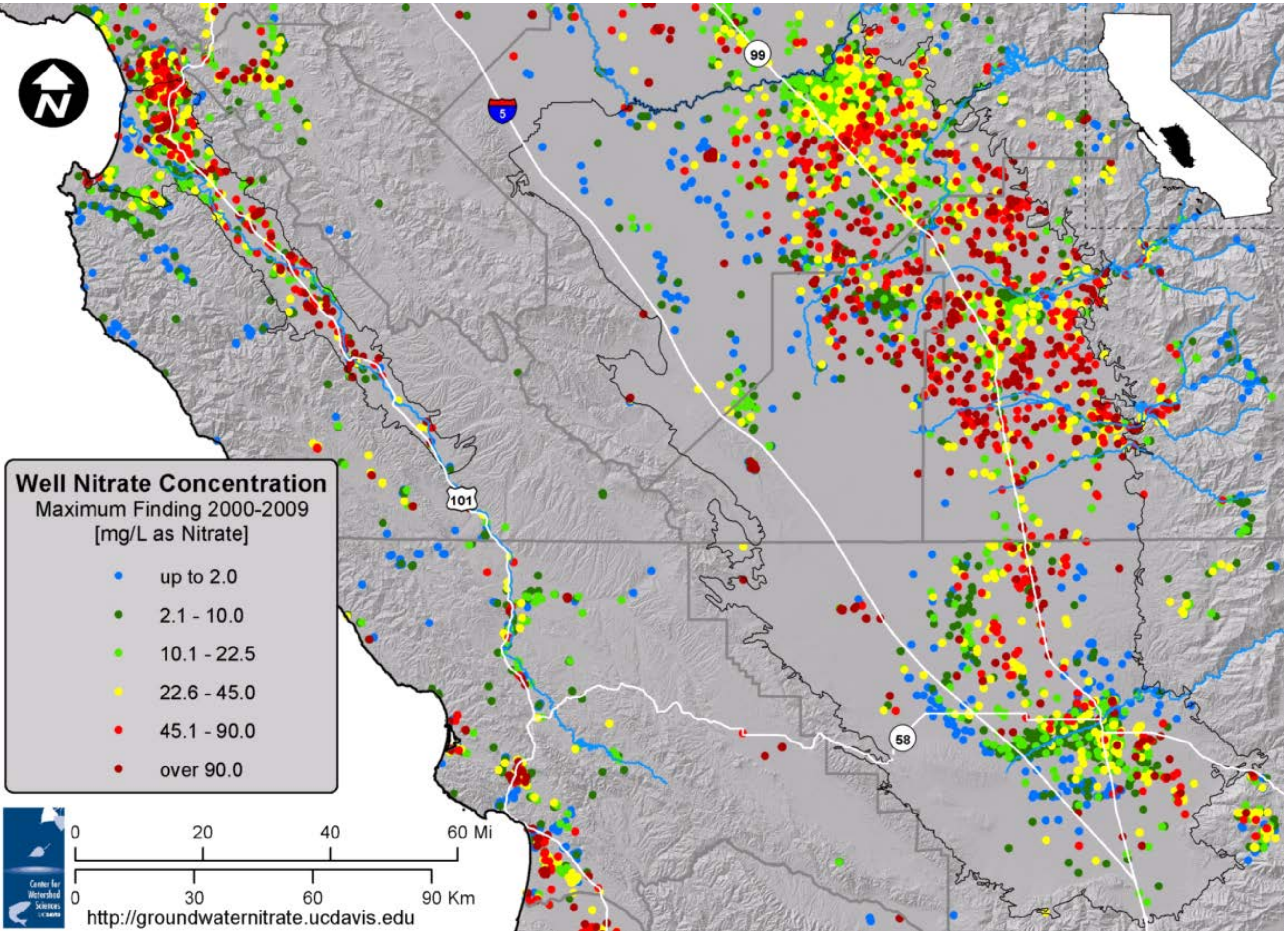
Assume: All Manure Remains On-Dairy

Total Nitrogen Inputs:
420,000 tons N/yr



Total Nitrogen Outputs:
420,000 tons N/yr

Nitrate Contamination Will Persist

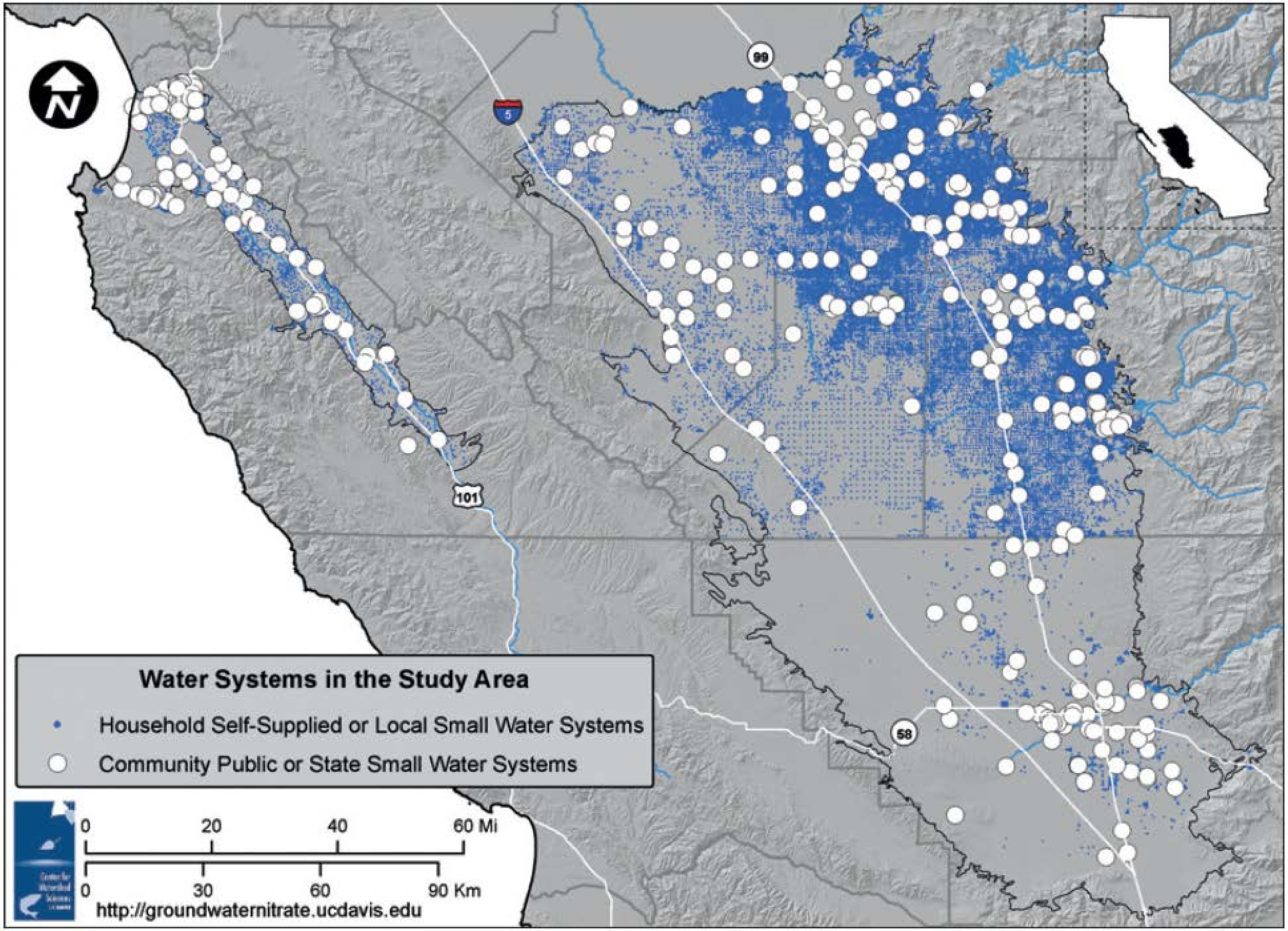


- Nitrate contamination will worsen for years/decades
- Direct remediation of groundwater is extremely costly

RED: ABOVE THE NITRATE MCL (45 mg/L)

DARK RED: ABOVE TWICE THE NITRATE MCL (90 mg/L)

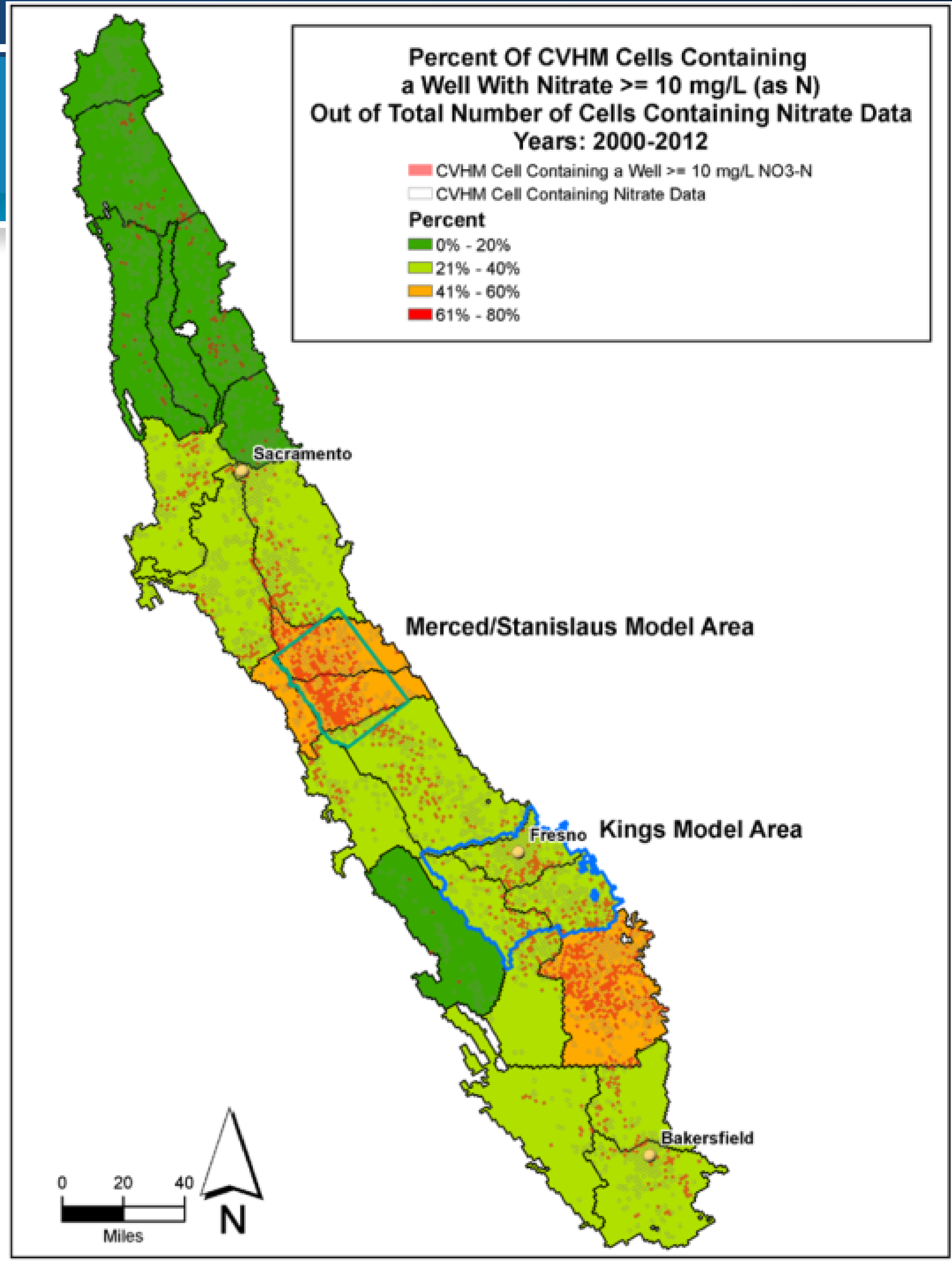
All Water Systems



Estimated locations of the area's roughly 400 regulated community public and state-documented state small water systems and of 74,000 unregulated self-supplied water systems. Source: Honeycutt et al. 2012; CDPH PICME 2010.

within the Central Valley

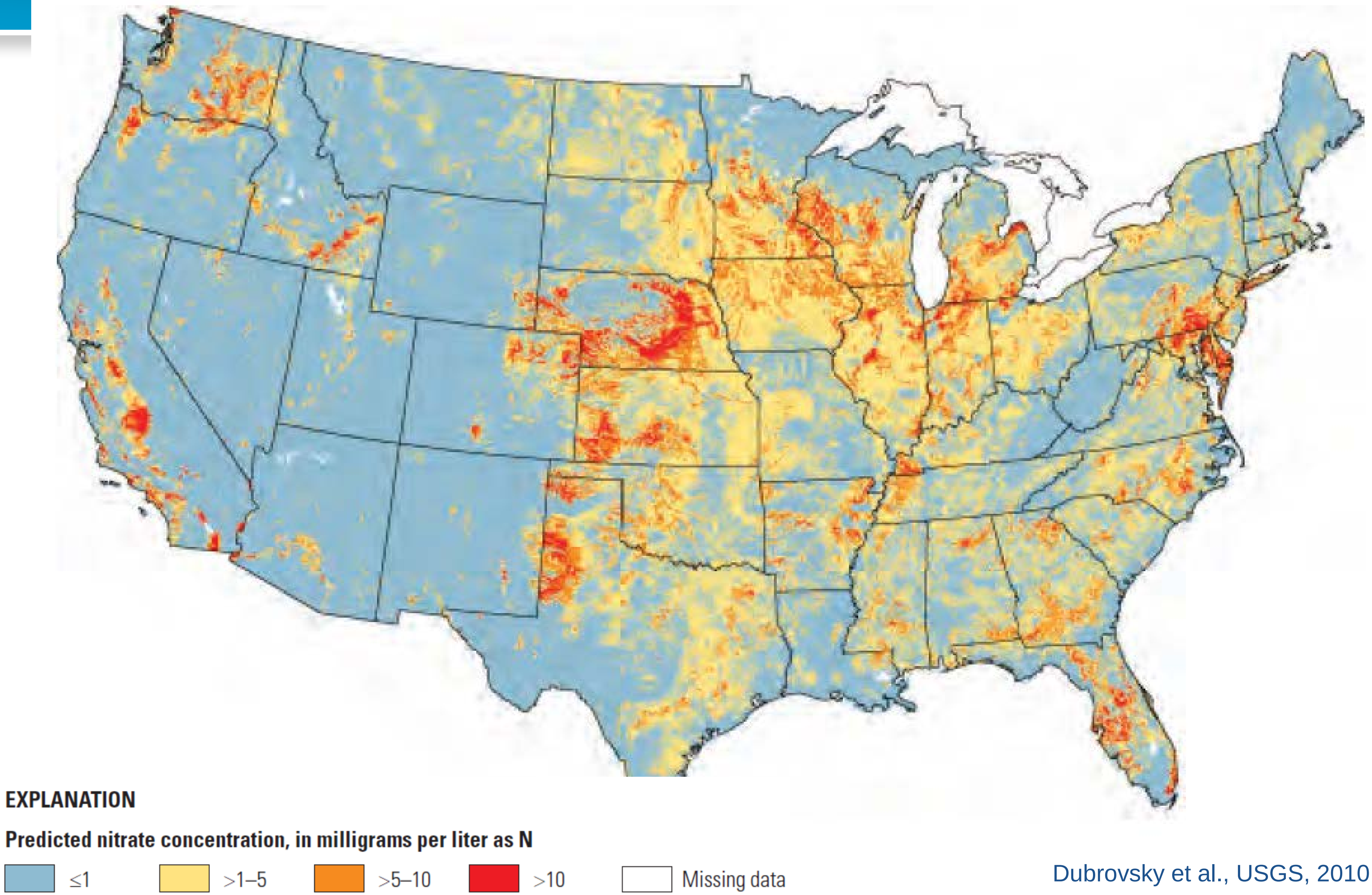
red dots: wells above MCL for nitrate



CVSALTS, Tasks 7 and 8 – Salt and Nitrate Analysis for the Central Valley Floor Final Report, December 2013

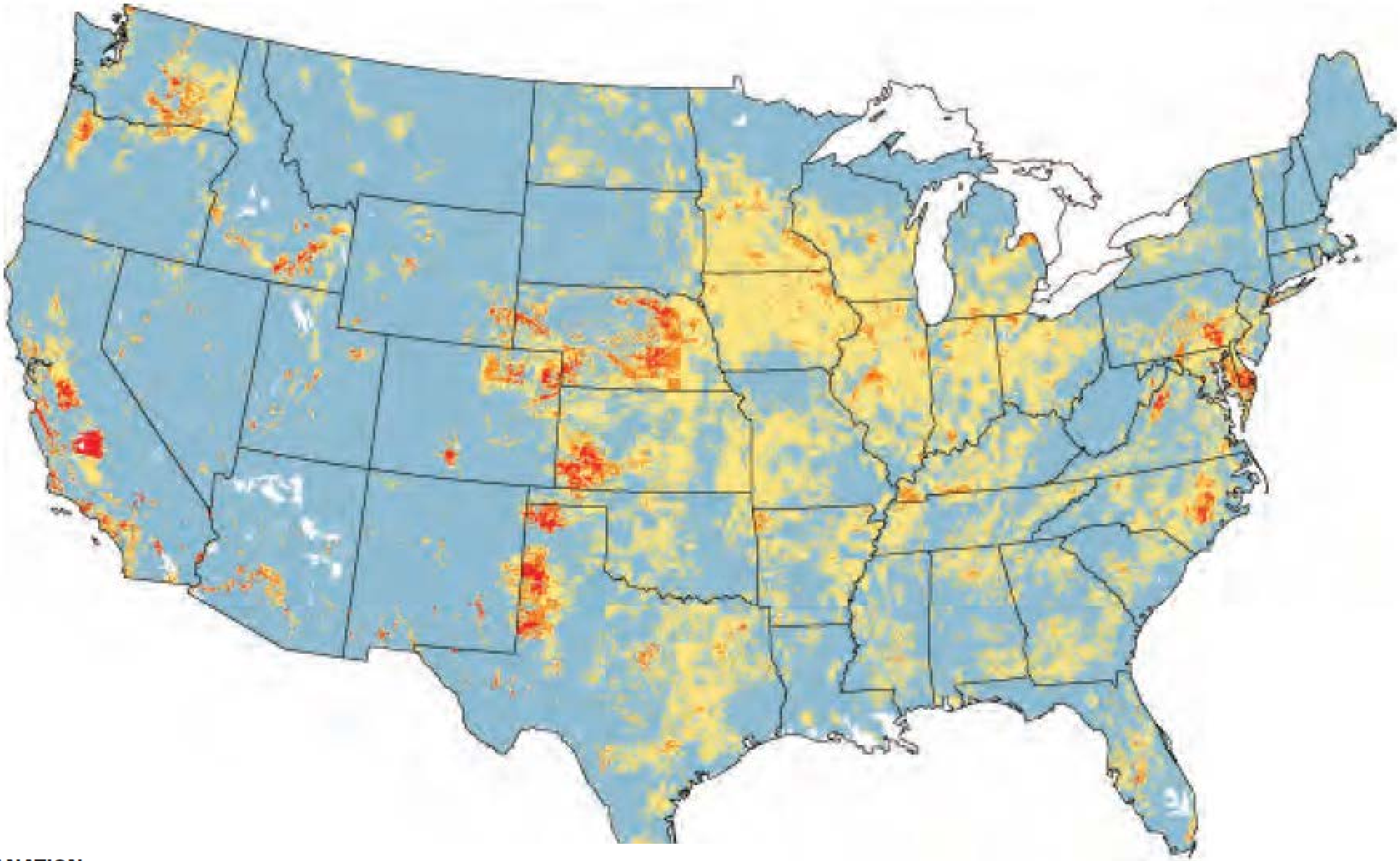
Figure 7-14

Model for shallow groundwater



Dubrovsky et al., USGS, 2010

Model for deep groundwater used as drinking water (50-m simulation depth)



EXPLANATION

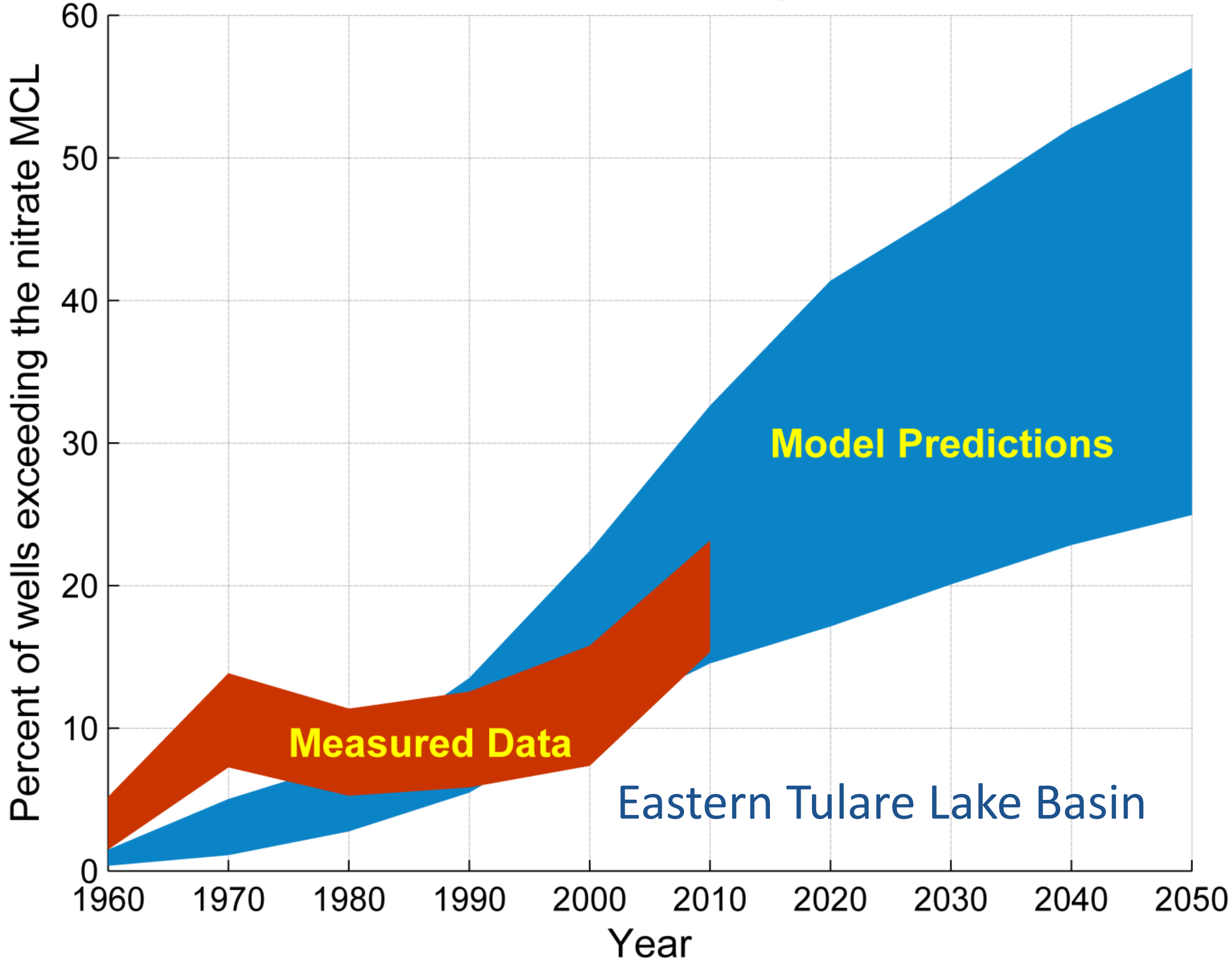
Predicted nitrate concentration, in milligrams per liter as N

≤1 | >1–5 | >5–10 | >10 | Missing data

Dubrovsky et al., USGS, 2010

Predictions Using Groundwater Nitrate Loading

Exceedance Probability, Nitrate above 45 mg/L (MCL)



Background

- Groundwater v watersheds
- **Dairy and groundwater impacts**
- Regulations
- Monitoring

Farm Sources of Diffuse GW Pollution: Example - Dairies

Sources of N:

- Feedlot
- Lagoon
- Storage areas
- Manured fields
- Fertilized fields
- Various crops
- Septic system

Dairy Manure Annual Salt Loading to Groundwater

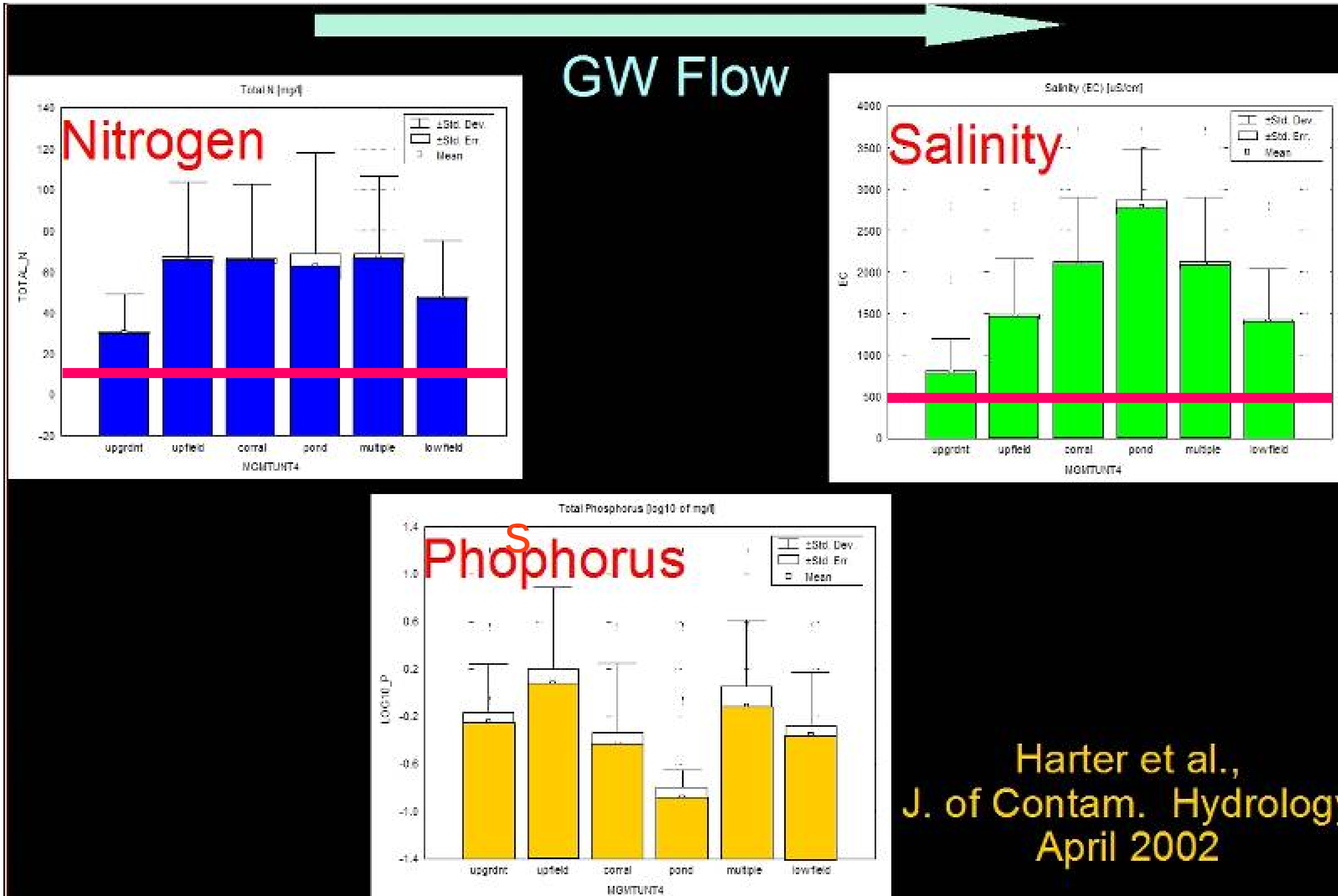
Irrigation Water Source	Salt Input, kg ha^{-1}		Annual Salt Loading kg ha^{-1}
	Winter Forage	Summer Corn	
East Side Sources	86	310	404
Wastewater + East Side	1356	2284	3615
West Side Sources	828	2983	3794
Wastewater + West Side	2000	4792	6452

130 – 220 µS/cm

1,200 – 1,900 µS/cm

Computed using "Watsuit" Model. Crop uptake is considered. Agronomic manure application rates. Scenario: Annual Summer Corn/Winter Forage Double Cropping with 250 and 150 lbs per acre of N inputs, respectively; annual water inputs are rainfall 12 inches ((30.48 cm), winter irrigation 10 inches (25.4 cm), and summer irrigation 36 inches (91.44 cm); and leaching fraction is 0.3. (UC Committee of Consultants Report, UC ANR Communications, 2007; http://anrcatalog.ucdavis.edu/DairyCattle/9004.aspx).

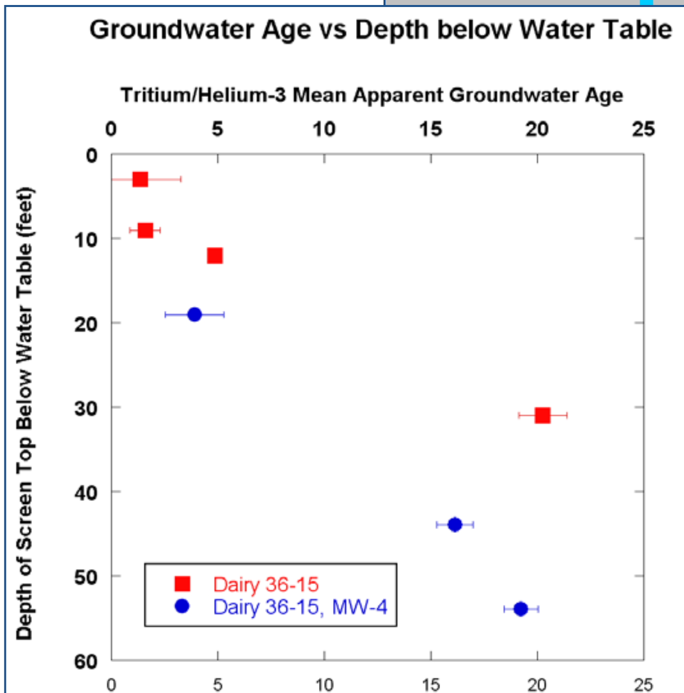
Pollutants by Dairy Management Unit

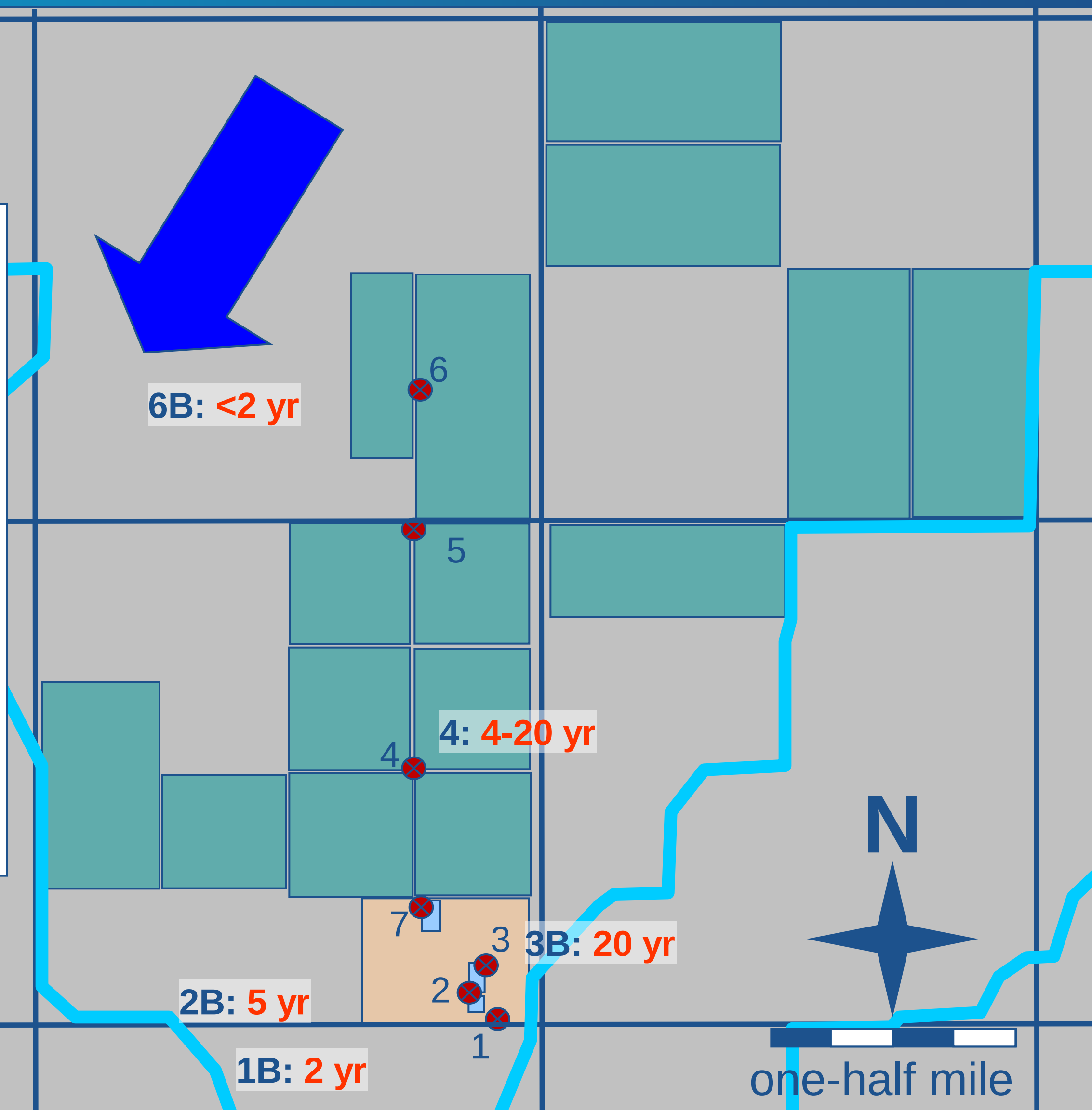


Measured Groundwater Age in Multilevel Groundwater Wells

Tritium/Helium-3 Groundwater Age (2-20 yrs)

The Dairy
- **DTW:** 80-120 ft bgs
- **Wells:** multi-level

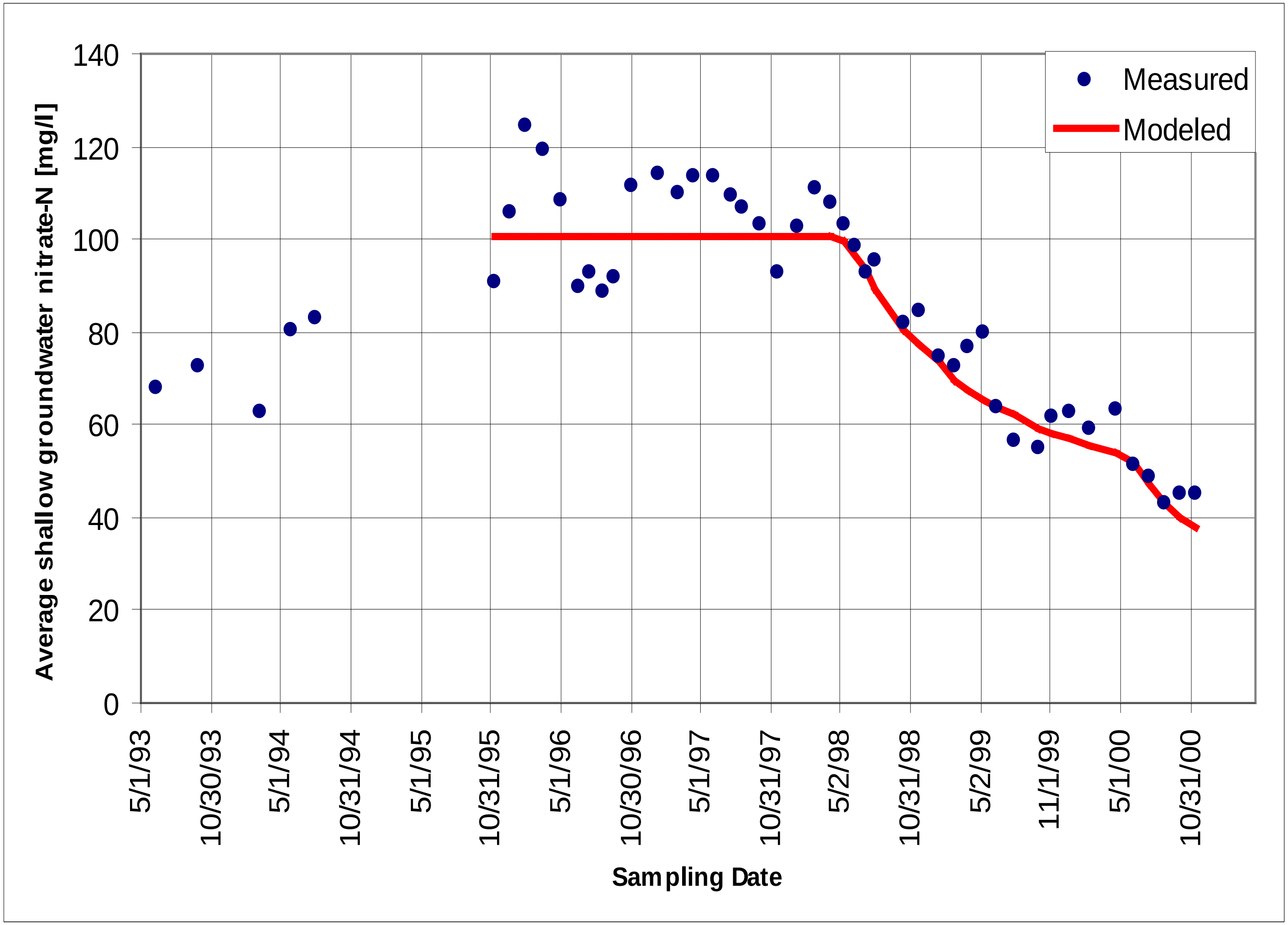




Observations
- Young groundwater present
- Age increases with depth in both multi-level wells & across the site
- No significant saturated-zone denitrification in monitor wells

Courtesy, Brad Esser & Jean Moran, LLNL, 2009

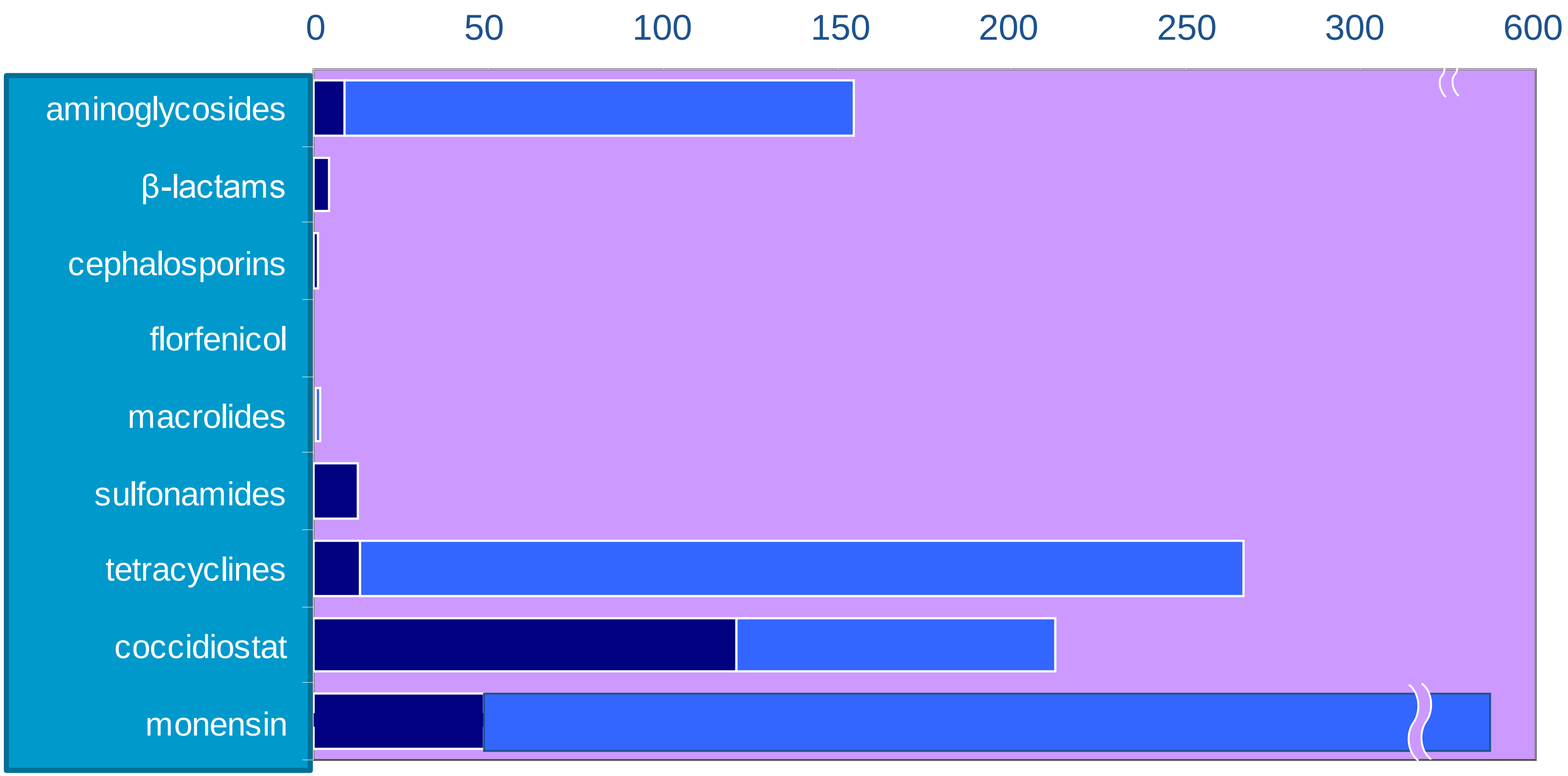
Assessment: Field Trials & Modeling Transport and Fate of Nitrate and Salts
=> improved management practices



VanderSchans et al., Ground Water, 2009

for further publications: http://groundwater.ucdavis.edu/gw_201.htm

Dairies: Antibiotic Use – By Primary Class



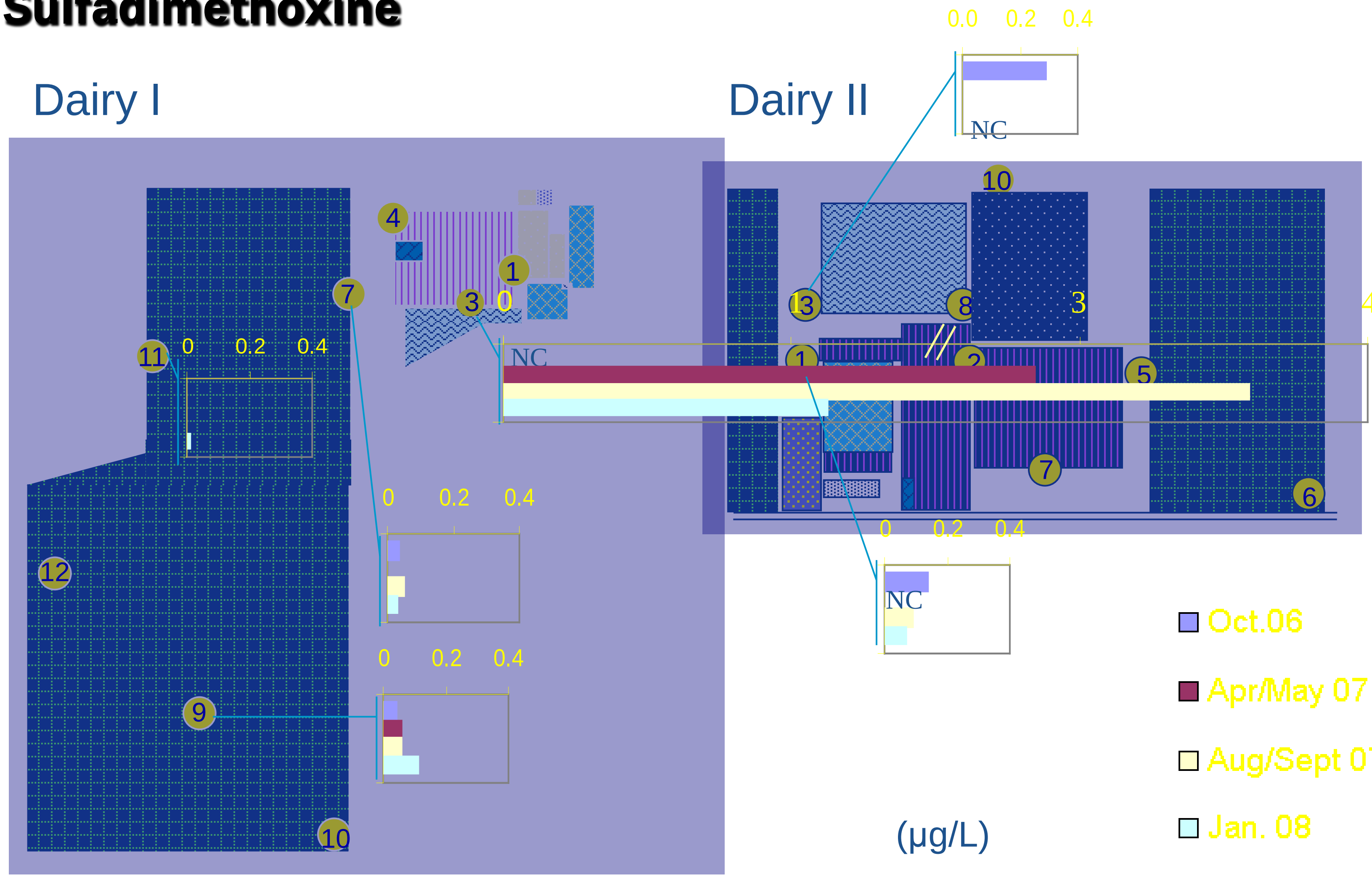
Estimated amount by primary classes of antibiotics

Light blue shows the maximum amount i.e. if used on all the heifers and cows every day.

Watanabe et al., Env.Sci.Tech, 2010

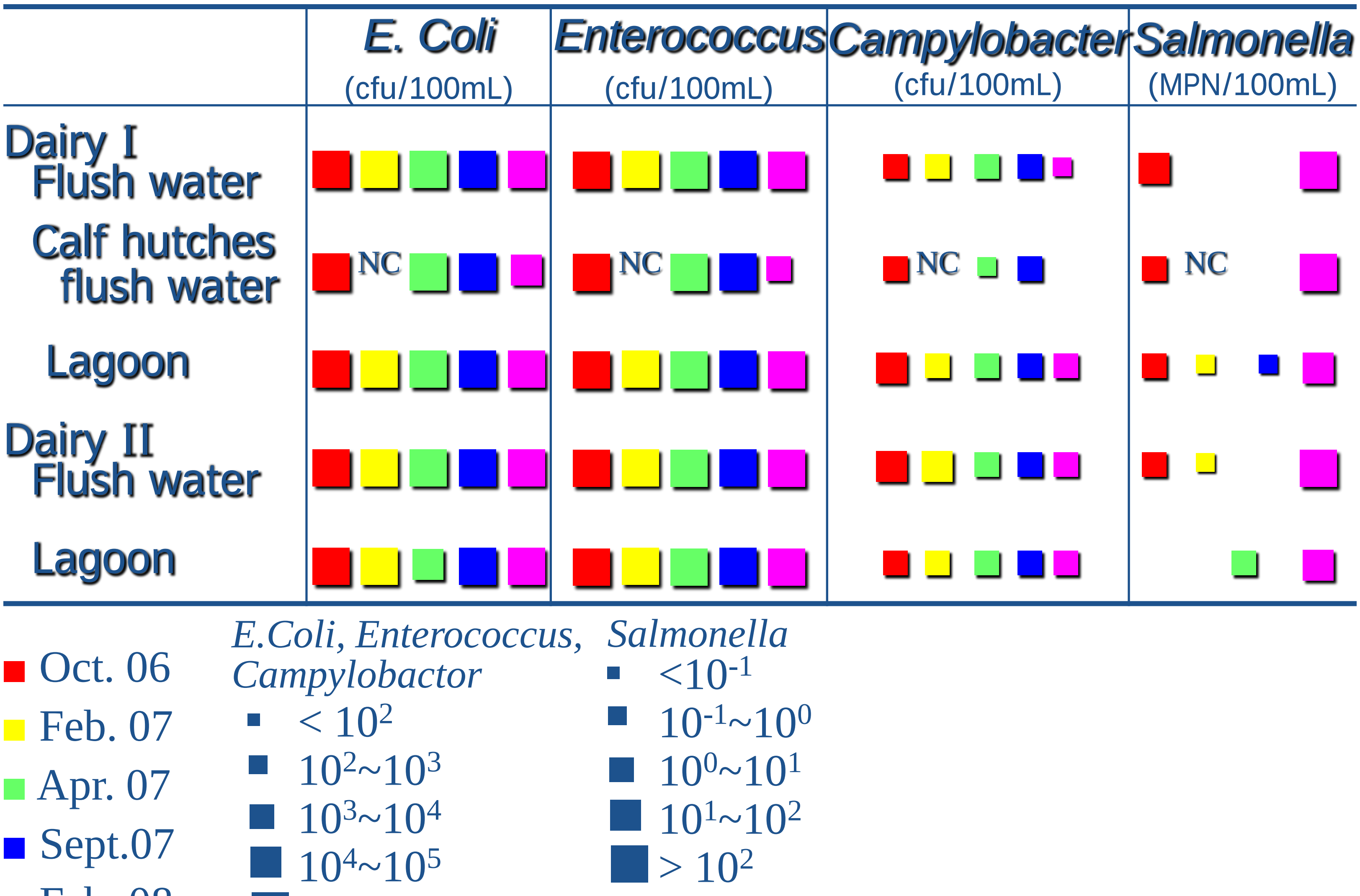
Groundwater occurrence

Sulfadimethoxine



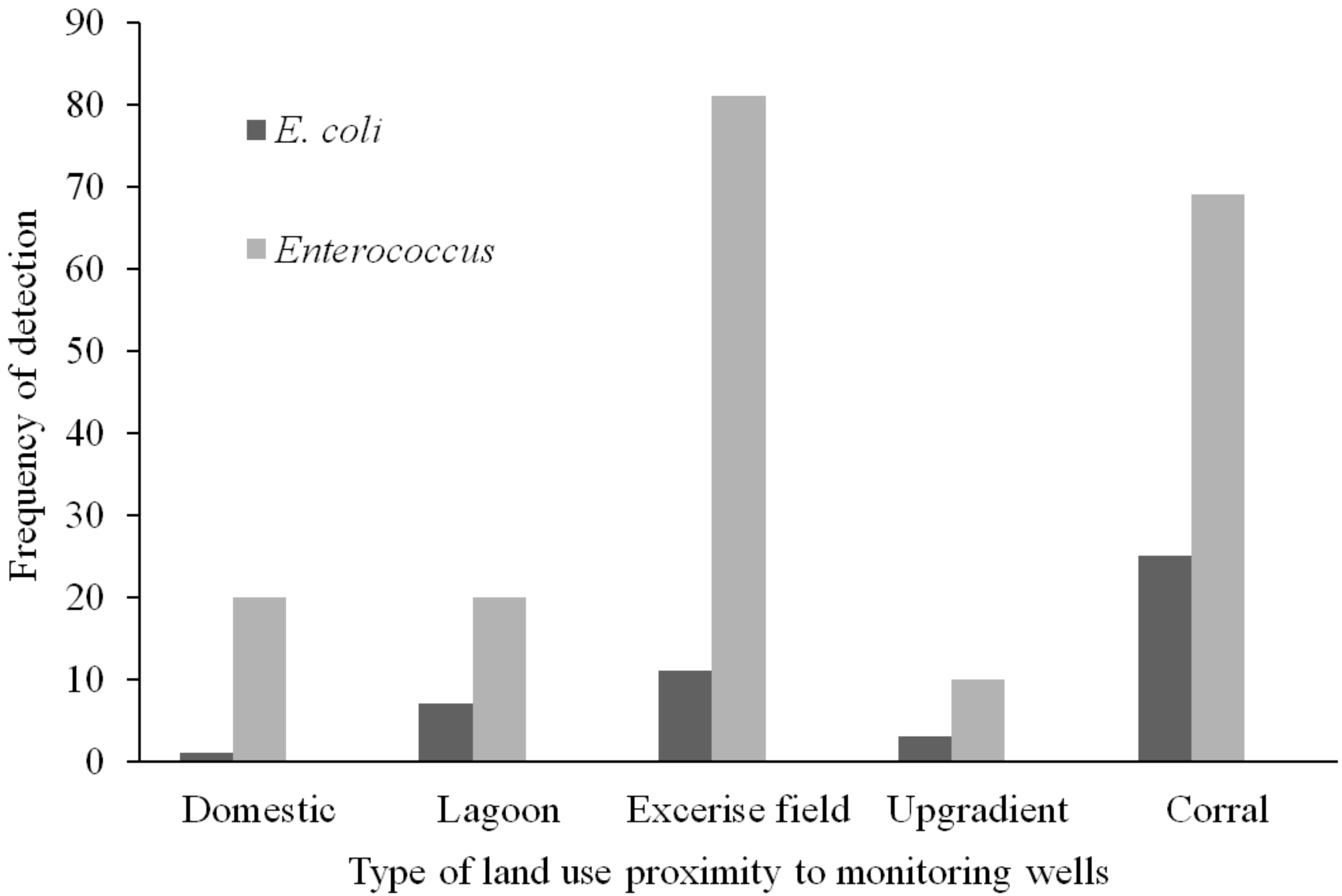
Watanabe et al., Env.Sci.Tech, 2010

Microbes in Wastewater



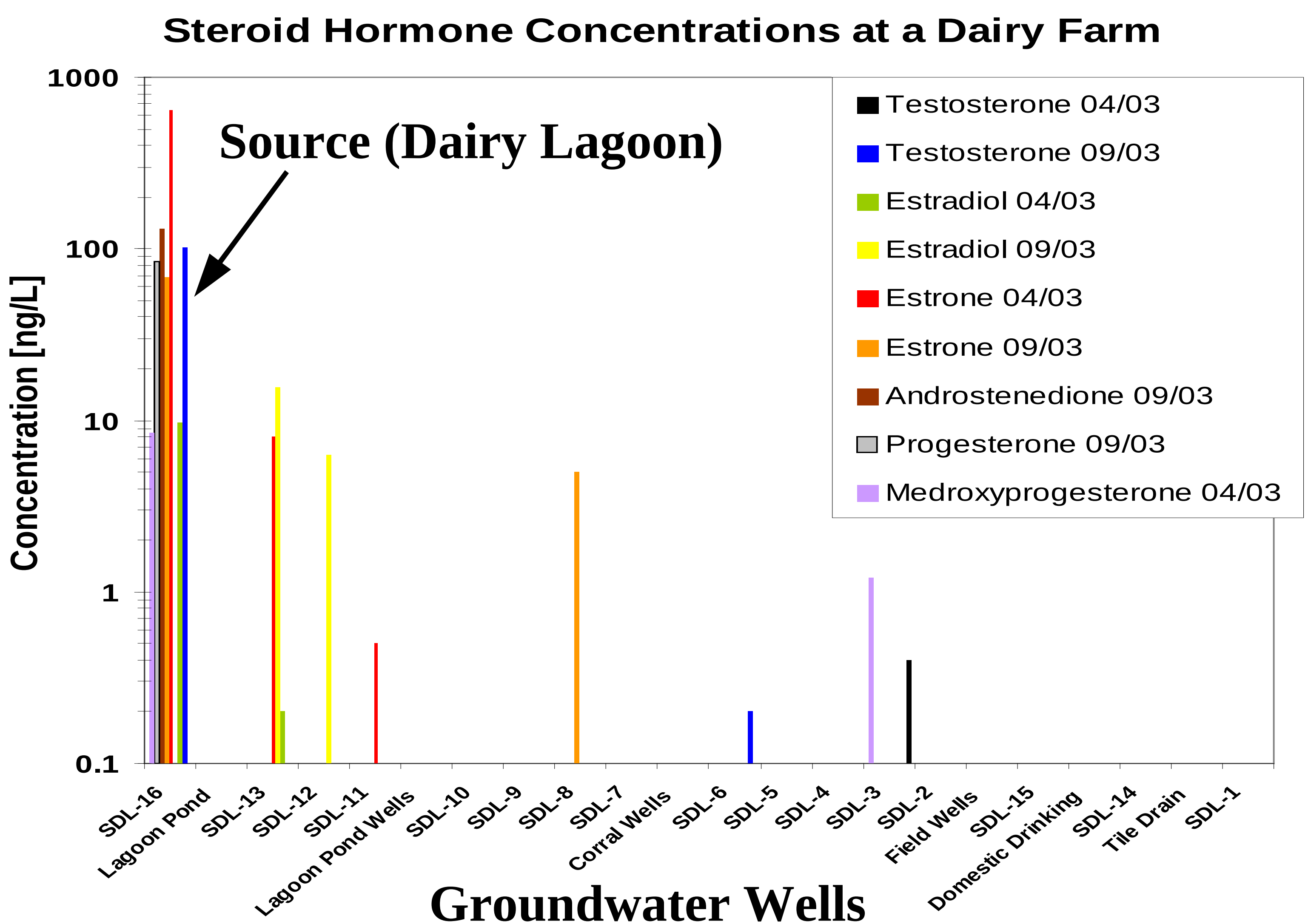
Li, Watanabe et al., in prep., 2011

Frequency of Indicator Bacteria in Dairy Groundwater



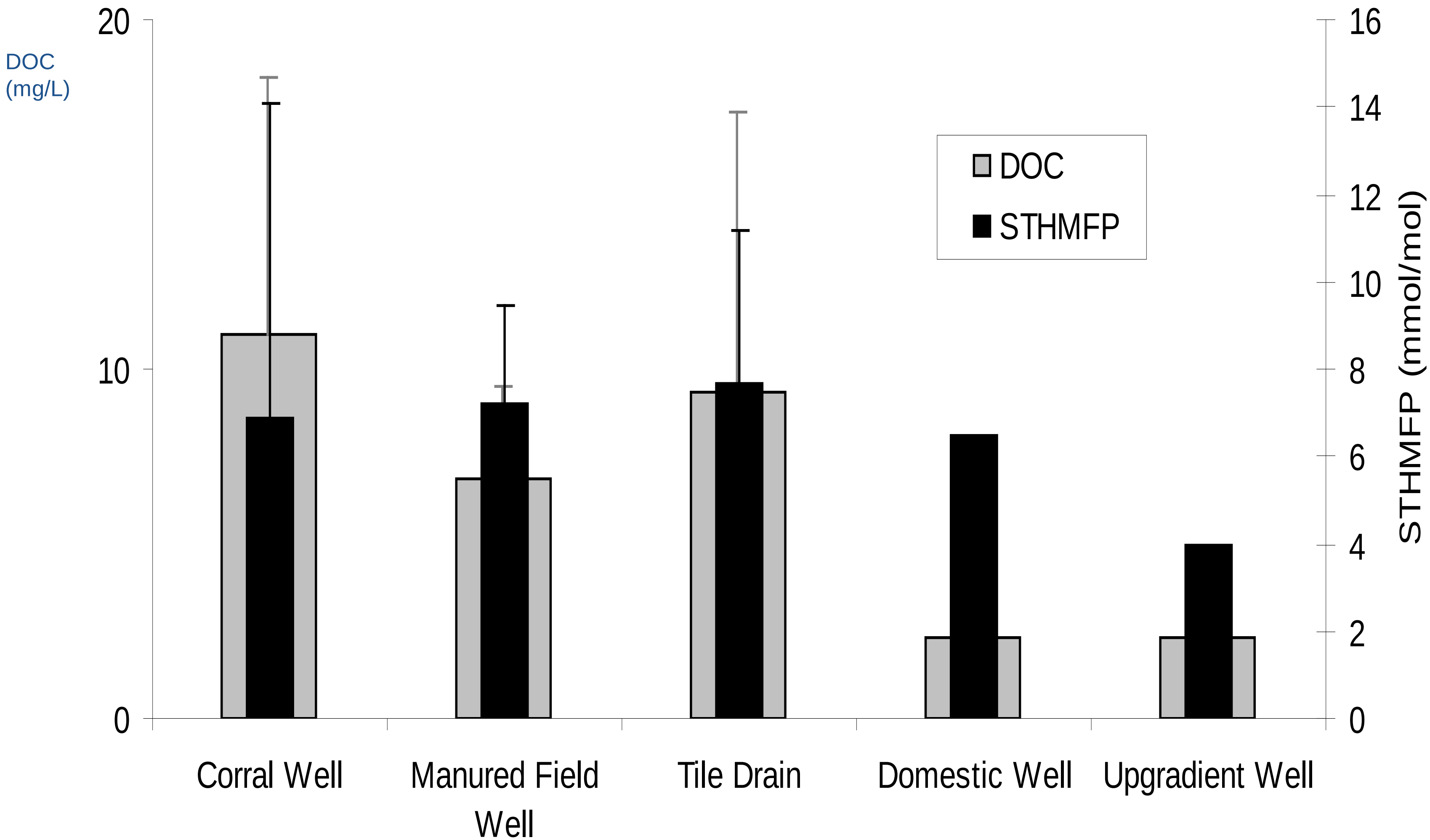
Harter et al., 2014; Li et al, 2015 (in preparation)

Steroid Hormones



Kolodziej et al., Env.Sci.&Tech., 2004

DOC and DBP-forming Potential

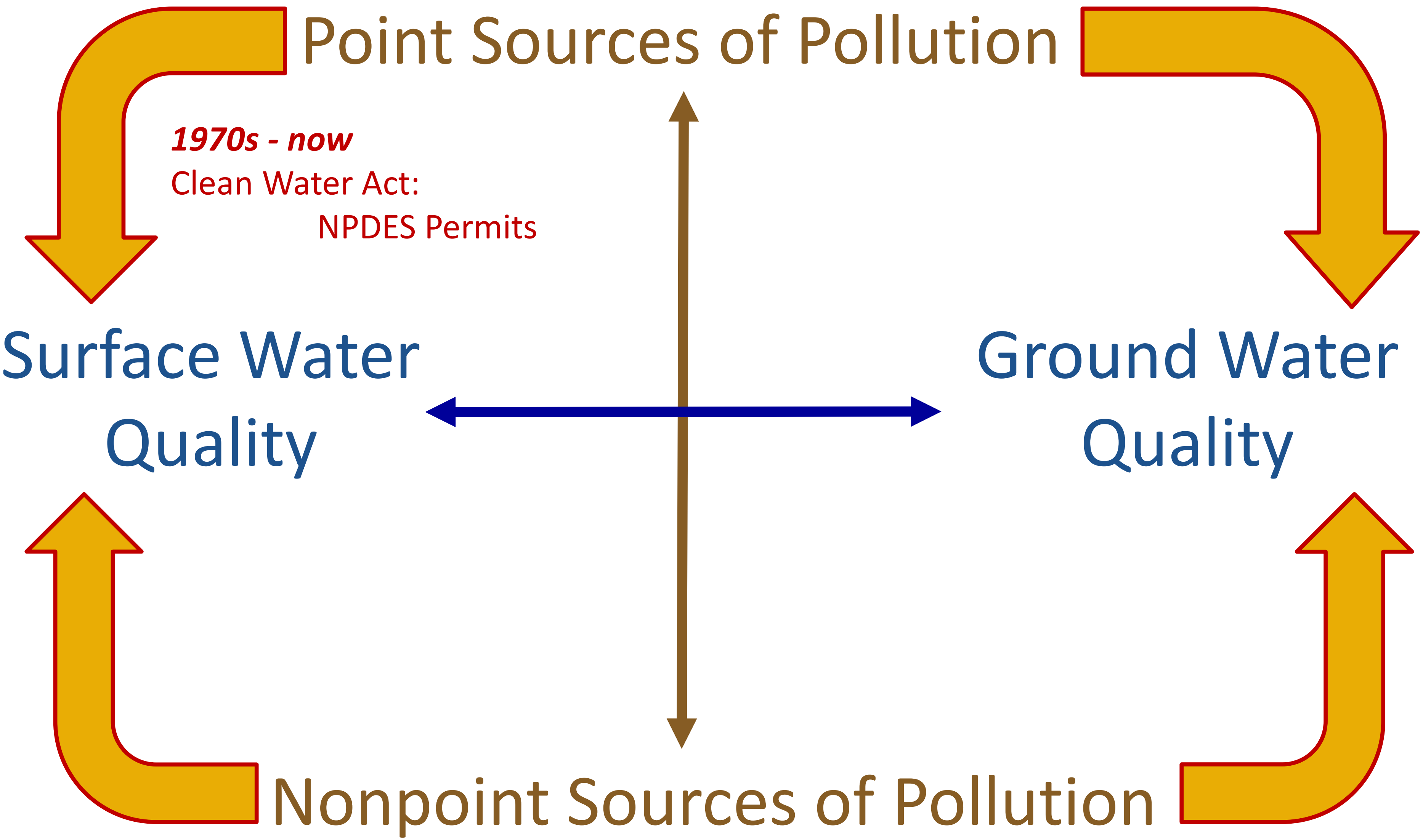


Chomycia et al., J.Env.Qual., 2007

Background

- Groundwater v watersheds
- Dairy and groundwater impacts
- **Regulations**
- **Monitoring**

Regulating Water Pollution Sources



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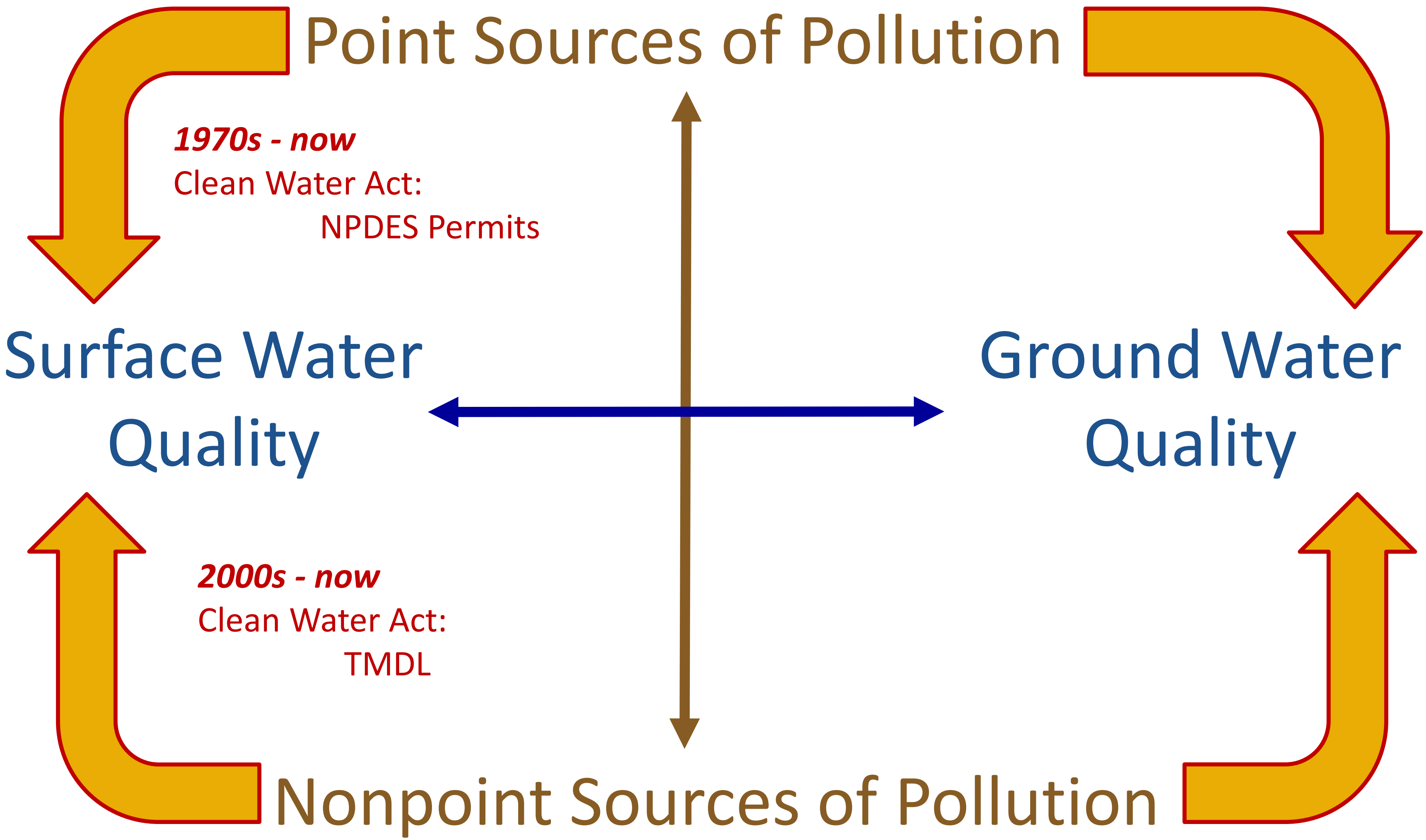

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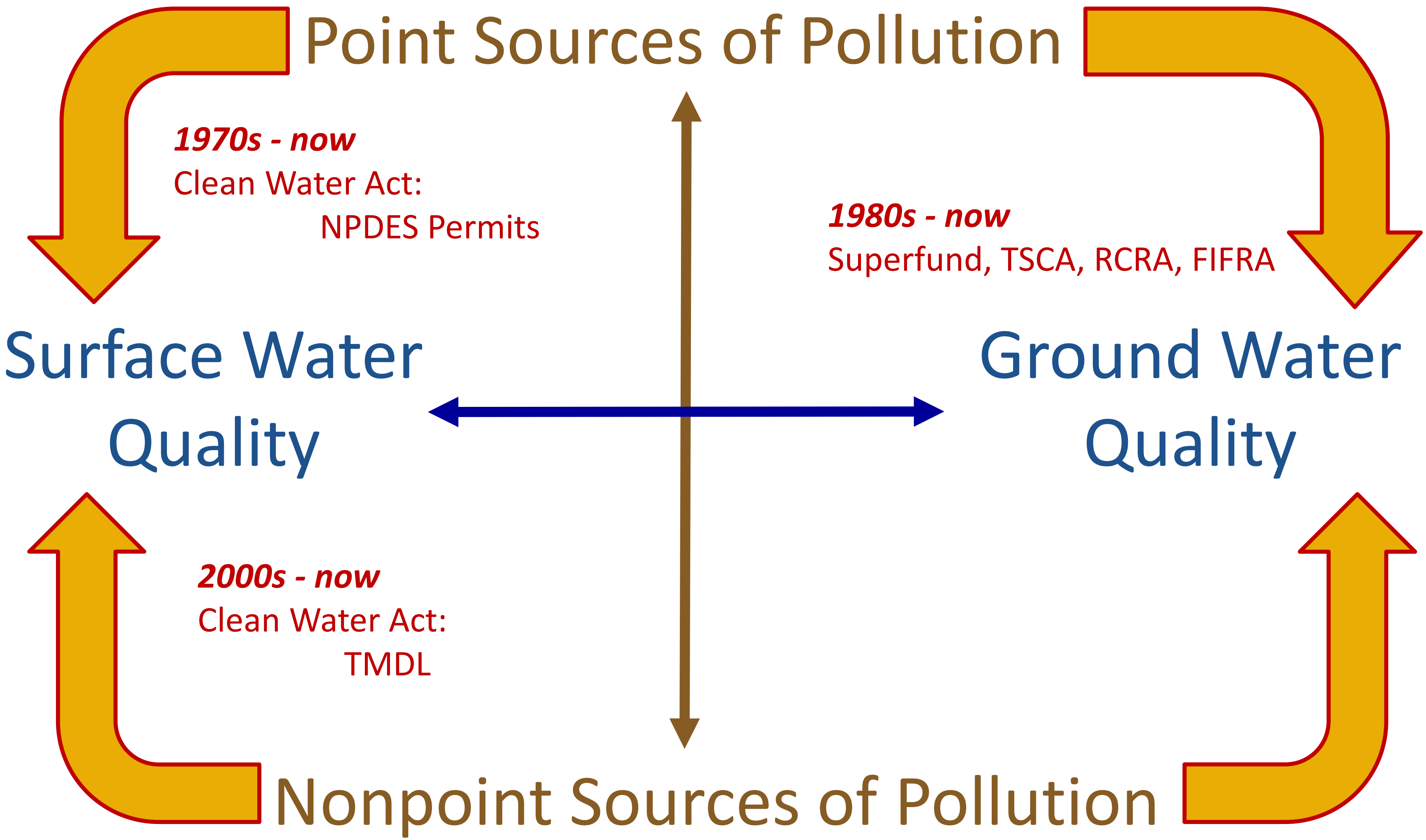
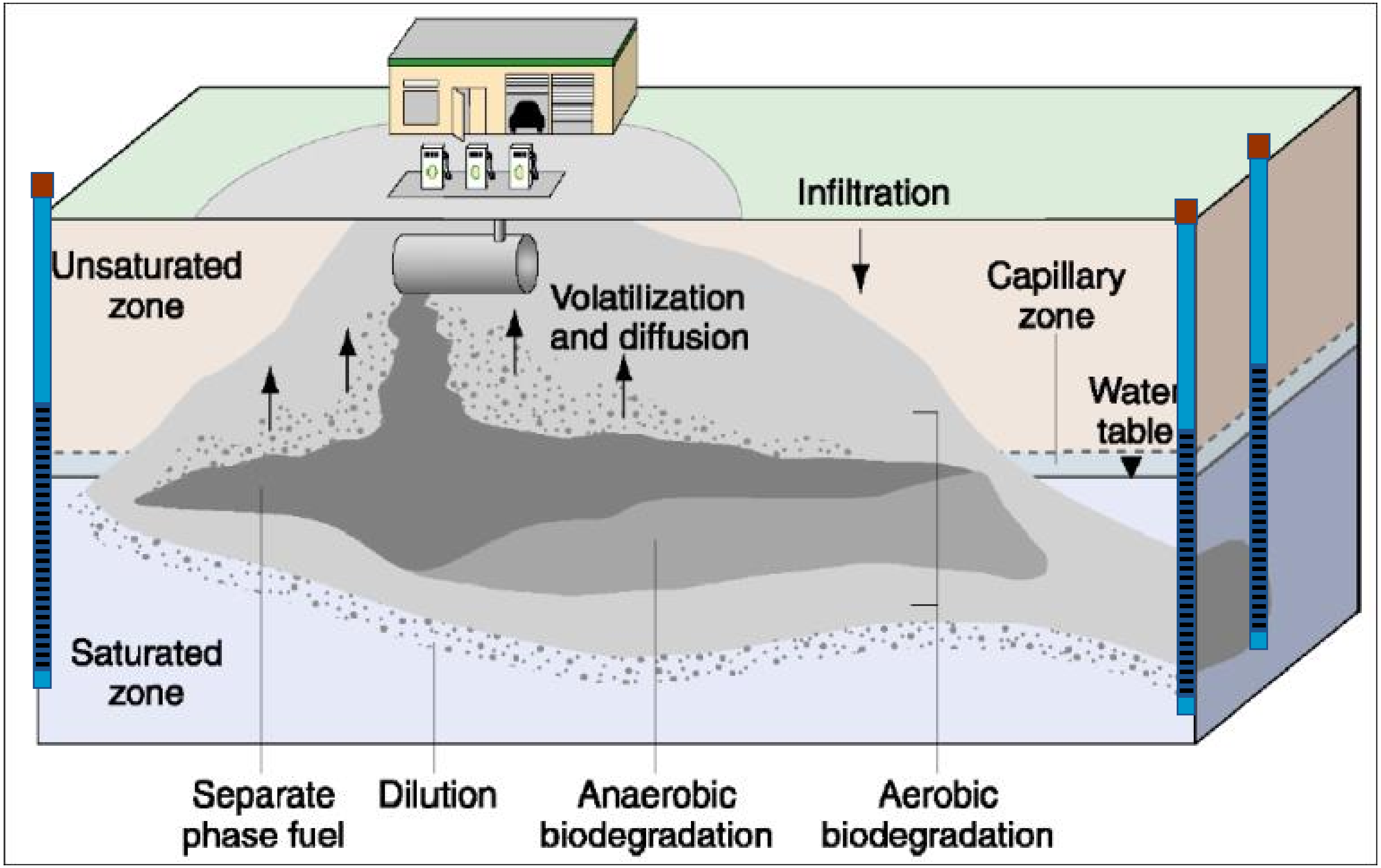


RCRA Groundwater Monitoring

- Affected parties:
  - TSDFs (transport, storage, and disposal facilities)
    - Permitted facilities vs. Interim facilities (existed prior to RCRA rules)
  - MSWFs (municipal solid waste landfills
- Detection monitoring
  - 1 or more monitoring wells upgradient
  - 3 or more monitoring wells downgradient
  - Objective: SSI (statistically significant increase)?
- Compliance monitoring / Assessment monitoring
  - Objective: groundwater protection standards exceeded?
- Corrective Action
  - Treatment
  - Clenaup
  - Cease and desist

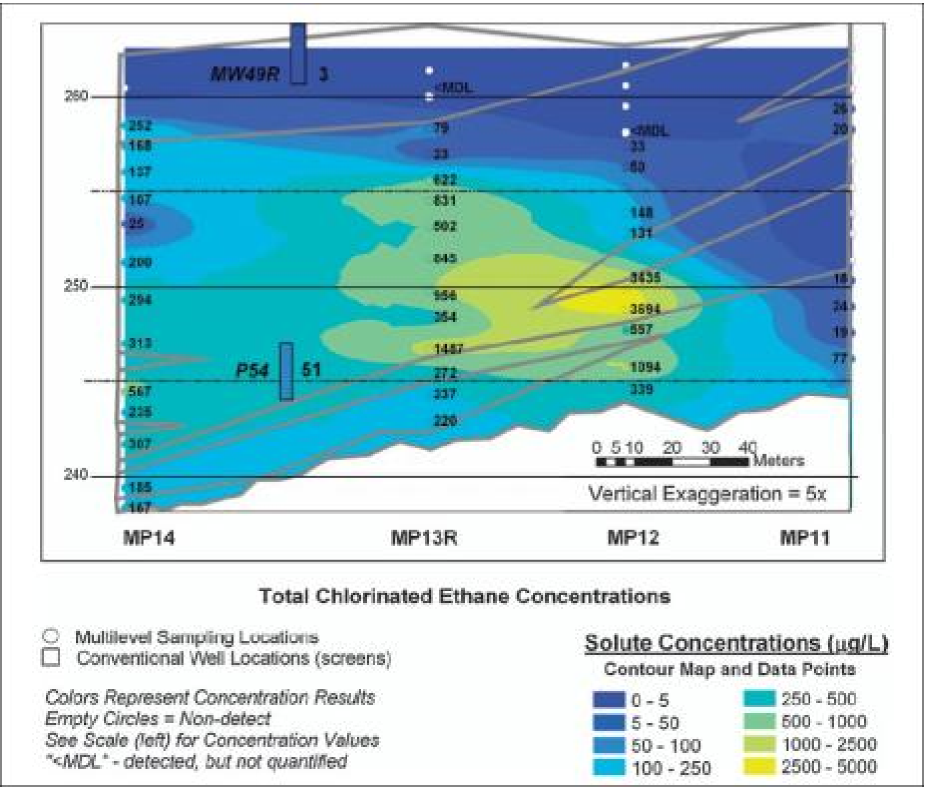
http://www.epa.gov/osw/hazard/tsd/td/ldu/financial/gdwater.htm
http://www.epa.gov/solidwaste/nonhaz/municipal/landfill/financial/gdwmswl.htm

Regulatory Approaches to Groundwater Protection and Monitoring

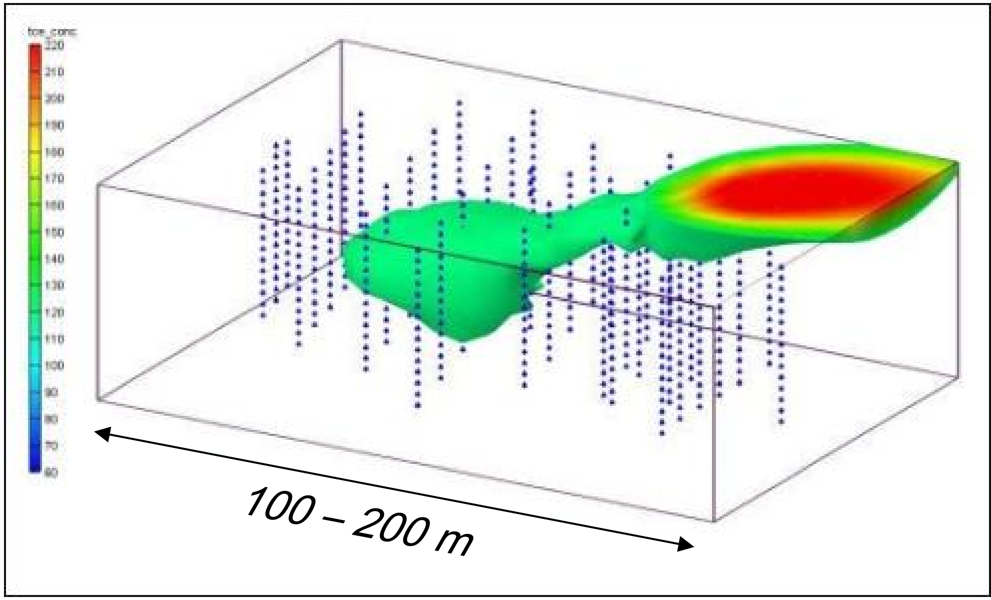


Modified from: EOS, Transactions, AGU 2001

Regulatory Approaches to Groundwater Monitoring

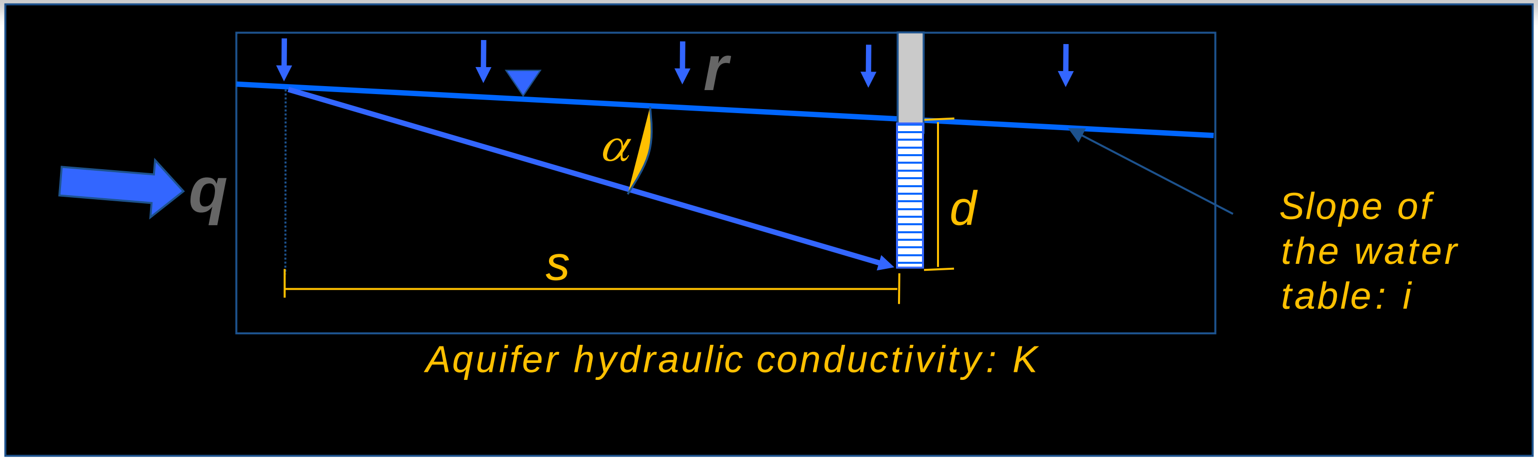


from: Parker, Beth L., Cherry, John A. & Swanson, Benjamin J., 2006. A Multilevel System for High-Resolution Monitoring in Rotasonic Boreholes. Ground Water Monitoring & Remediation 26 (4), 57-73. doi: 10.1111/j.1745-6592.2006.00107



from: http://www.ems-i.com

What Does a Monitoring Well Monitor in Irrigated Agriculture?



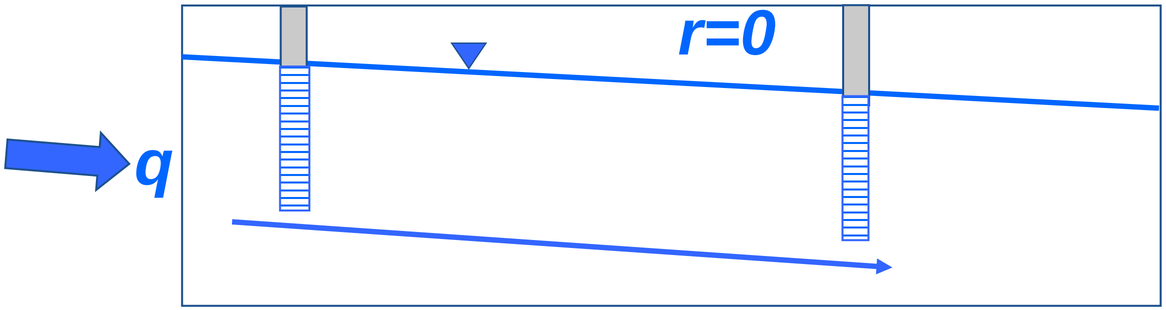
*Horizontal flow: q = K * i (Darcy's law)*

Vertical flow: r (recharge)

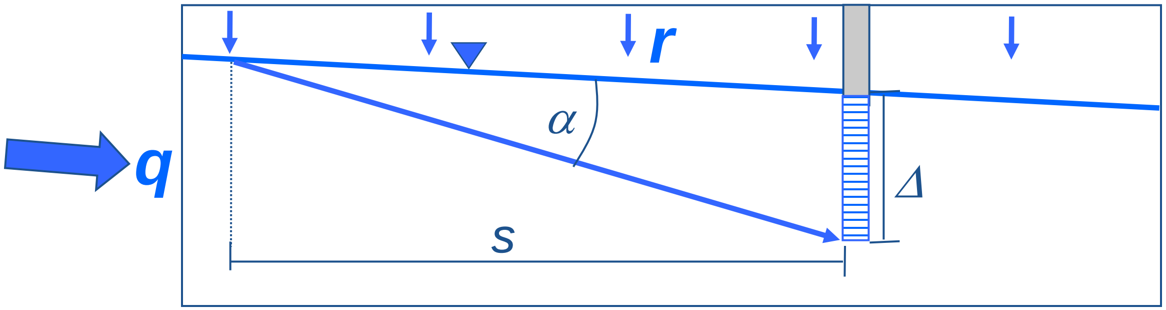
*Monitored source length, s = d * q/r*

Monitoring Well: Source Area Recharging vs. Non-Recharging Source

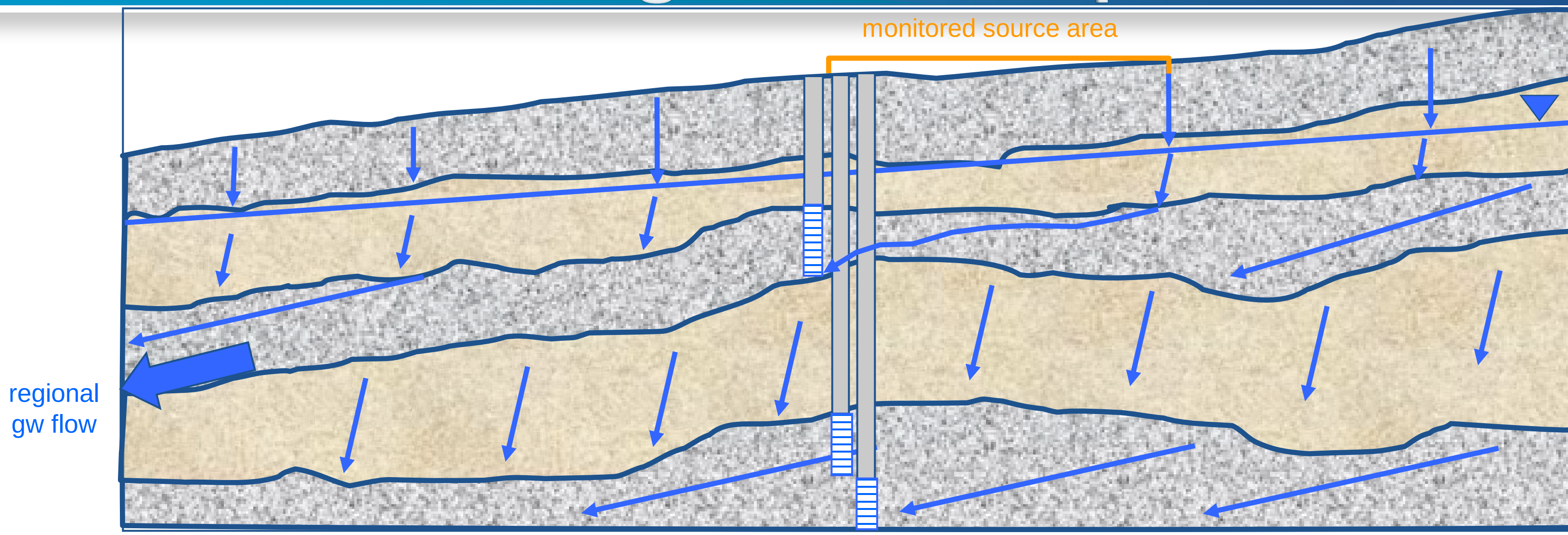
Non-recharging source



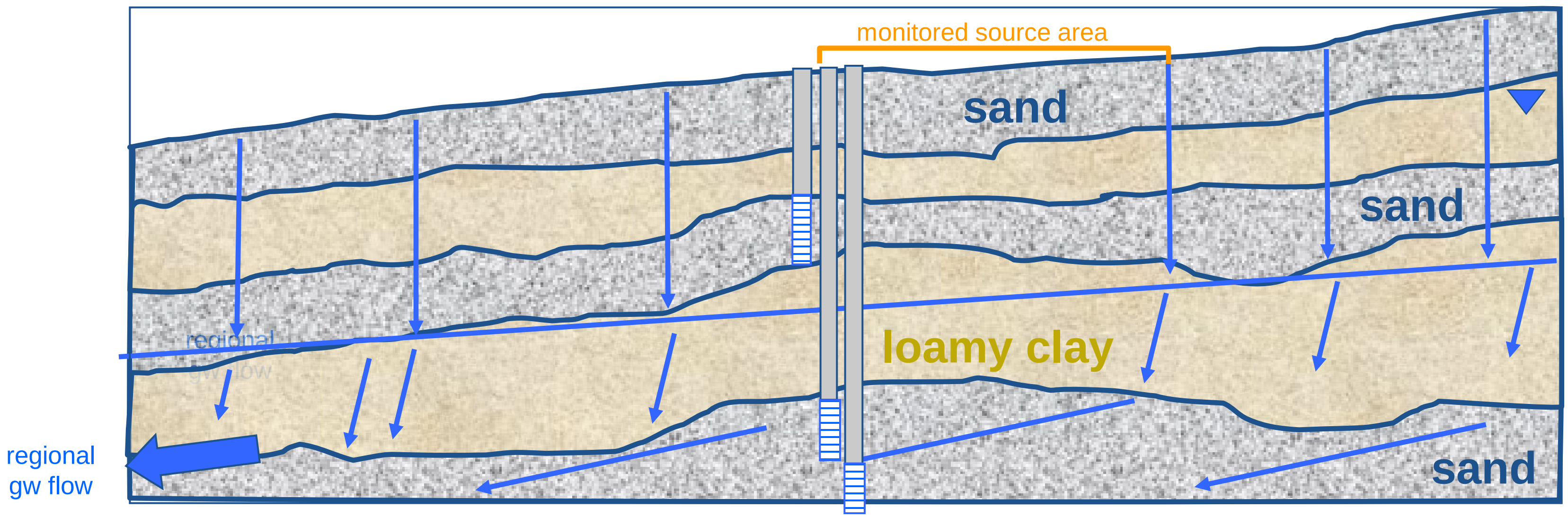
Recharging source



MW Well Design: Varying Water Table in Heterogeneous Aquifer

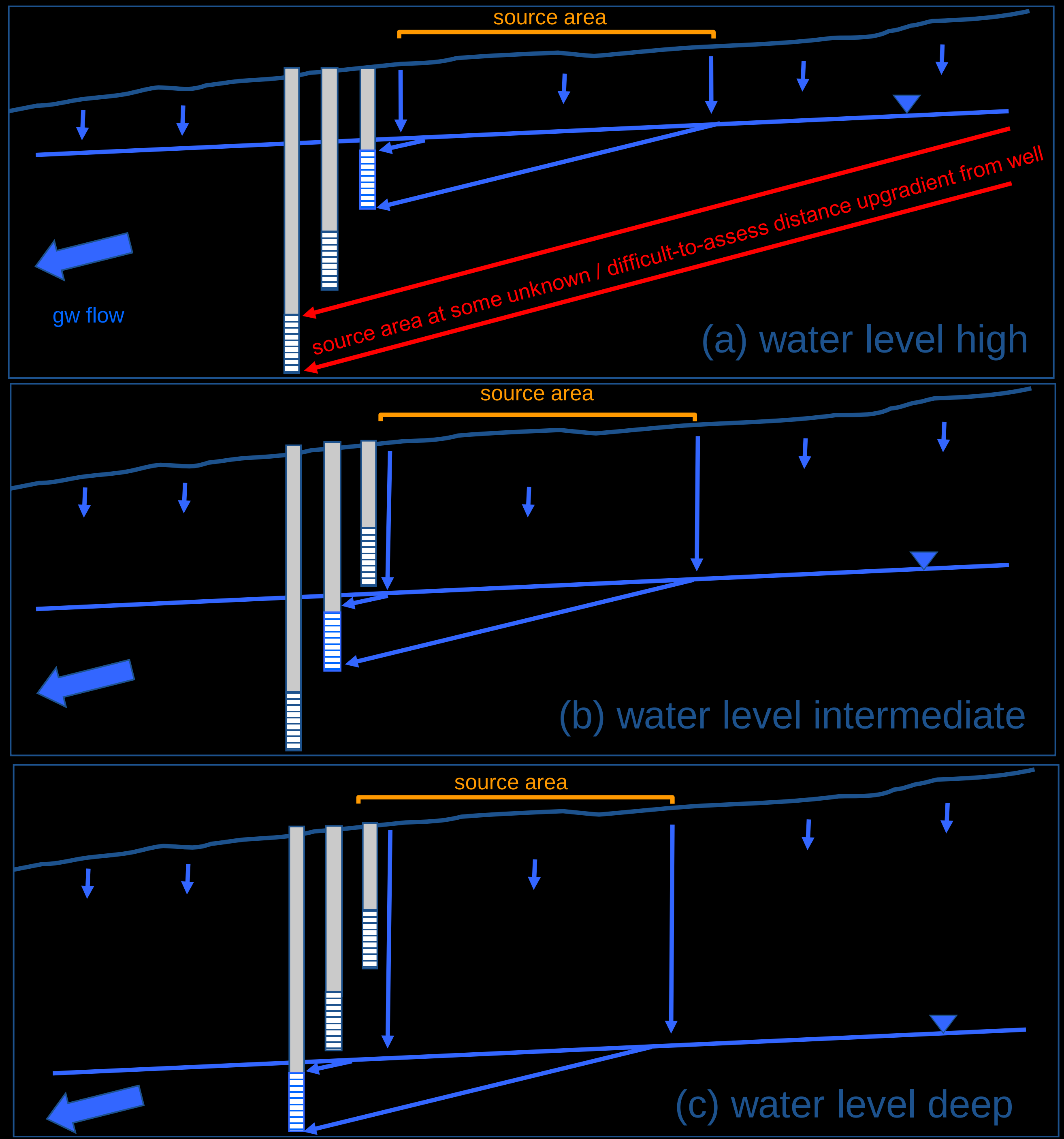


(a) Screen (length ~ 20’) located at water table, but not intersecting sand layer



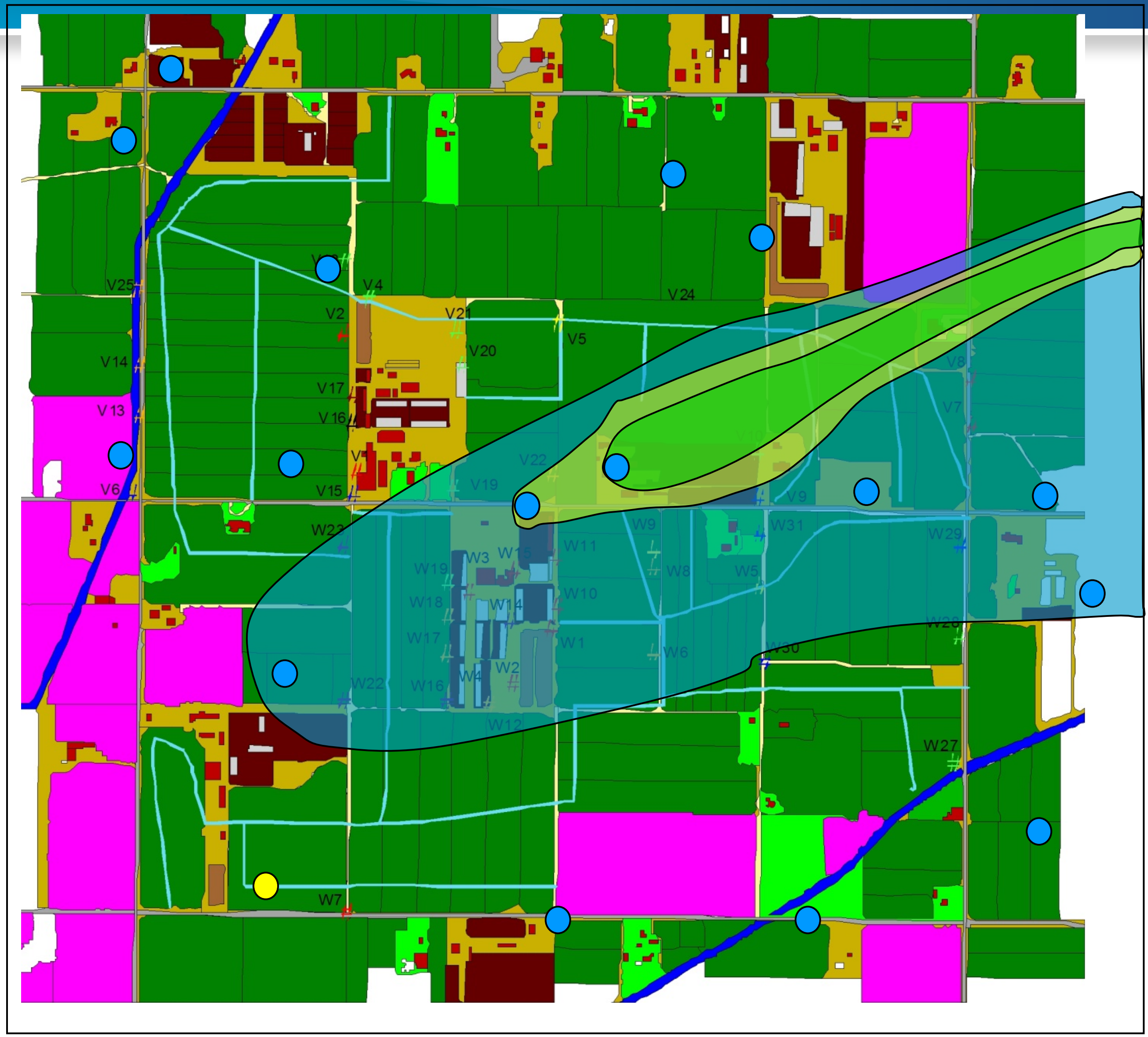
(b) Screen (length ~ 20’) located in sand layer

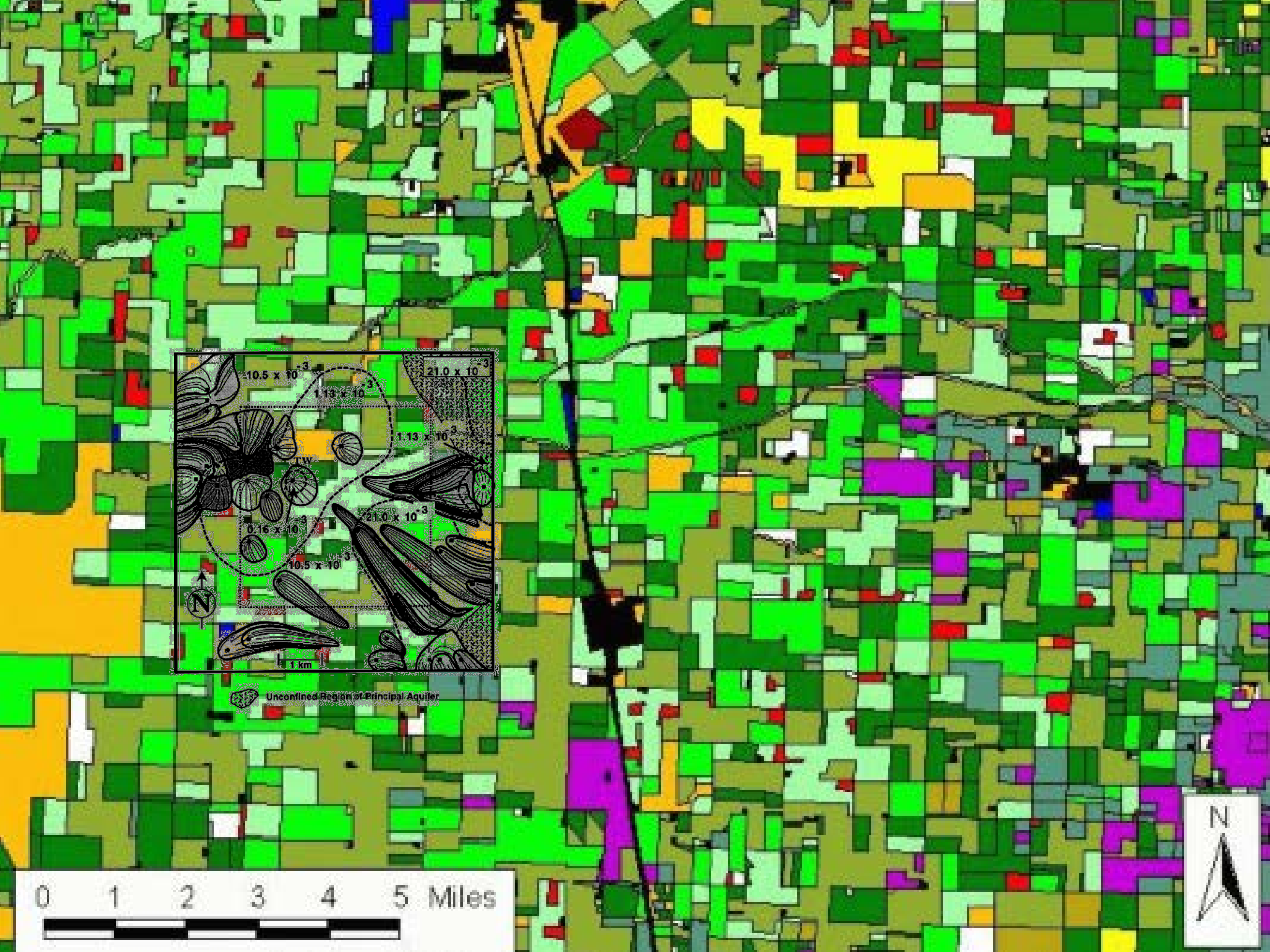
Monitoring Design for Varying Water Table Depth



UC Davis Multilevel Well Design

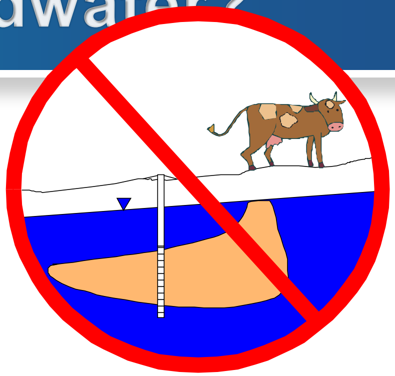
Source Area of a Barn / Irrigation Well





10.5 x 10^-3
1.13 x 10^-3
21.0 x 10^-3
1.13 x 10^-3
TW
0.16 x 10^-3
21.0 x 10^-3
10.5 x 10^-3
N
1 km
Unconfined Region of Principal Aquifer
0 1 2 3 4 5 Miles
N

Why is Nonpoint Source Pollution Different from Point Source Pollution of Groundwater?



- Scale
  - Millions of acres vs. 1-10 acres
- Intensity
  - Within ~1 order magnitude above MCL vs. many orders of magnitude above MCL
- Hydrologic Function
  - Recharge vs. non-leaky
- Frequency
  - Ongoing/seasonally repeated vs. incidental
- Heterogeneity & Adjacency

Focus: Enforcement Monitoring

Example of Working with a Regulation: Speed Limit

Responsible Party:
Driver

Feedback:
Speedometer

Management Tool:
Brakes

Enforcement:
Radar Controls

Focus: Enforcement Monitoring

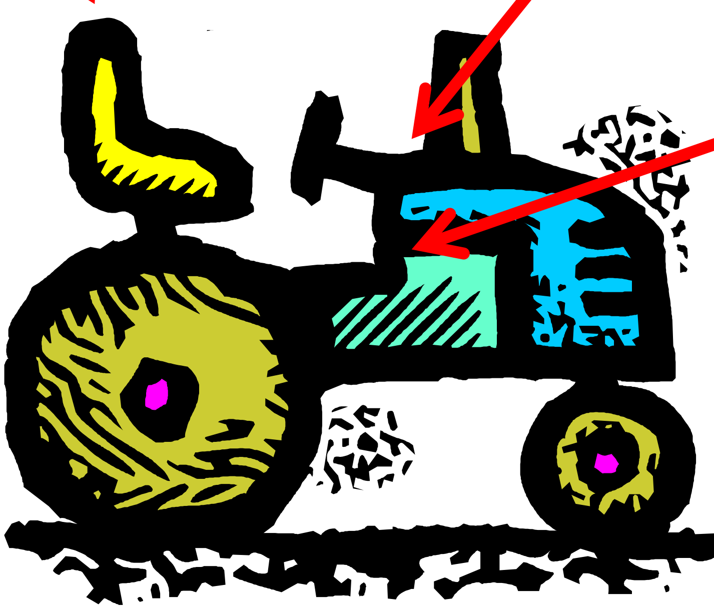
Applying Point Source Approach to Nonpoint Source:

Responsible Party:
Landowner

Feedback:
missing

Management Tool:
$$$ “agronomic”

Enforcement:
Monitoring Wells



Focus: Enforcement Monitoring

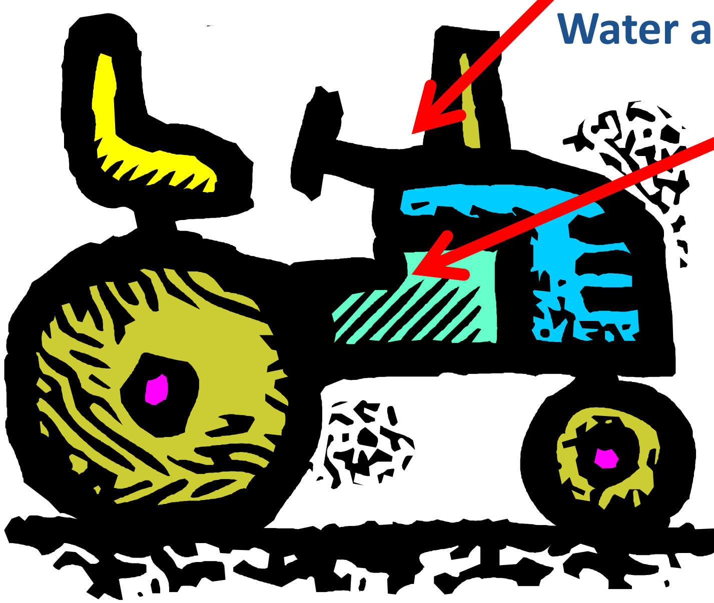
Alternative Monitoring Approach to Nonpoint Source:

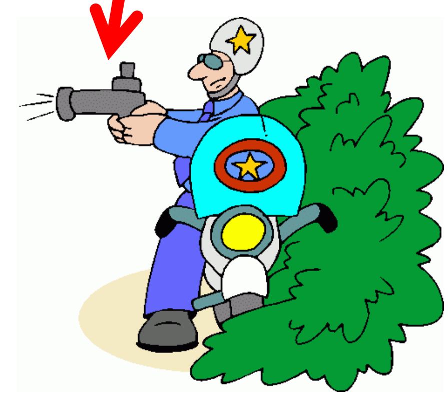
Responsible Party:
Landowner

Feedback:
Nutrient/Water Monitoring & Assessment

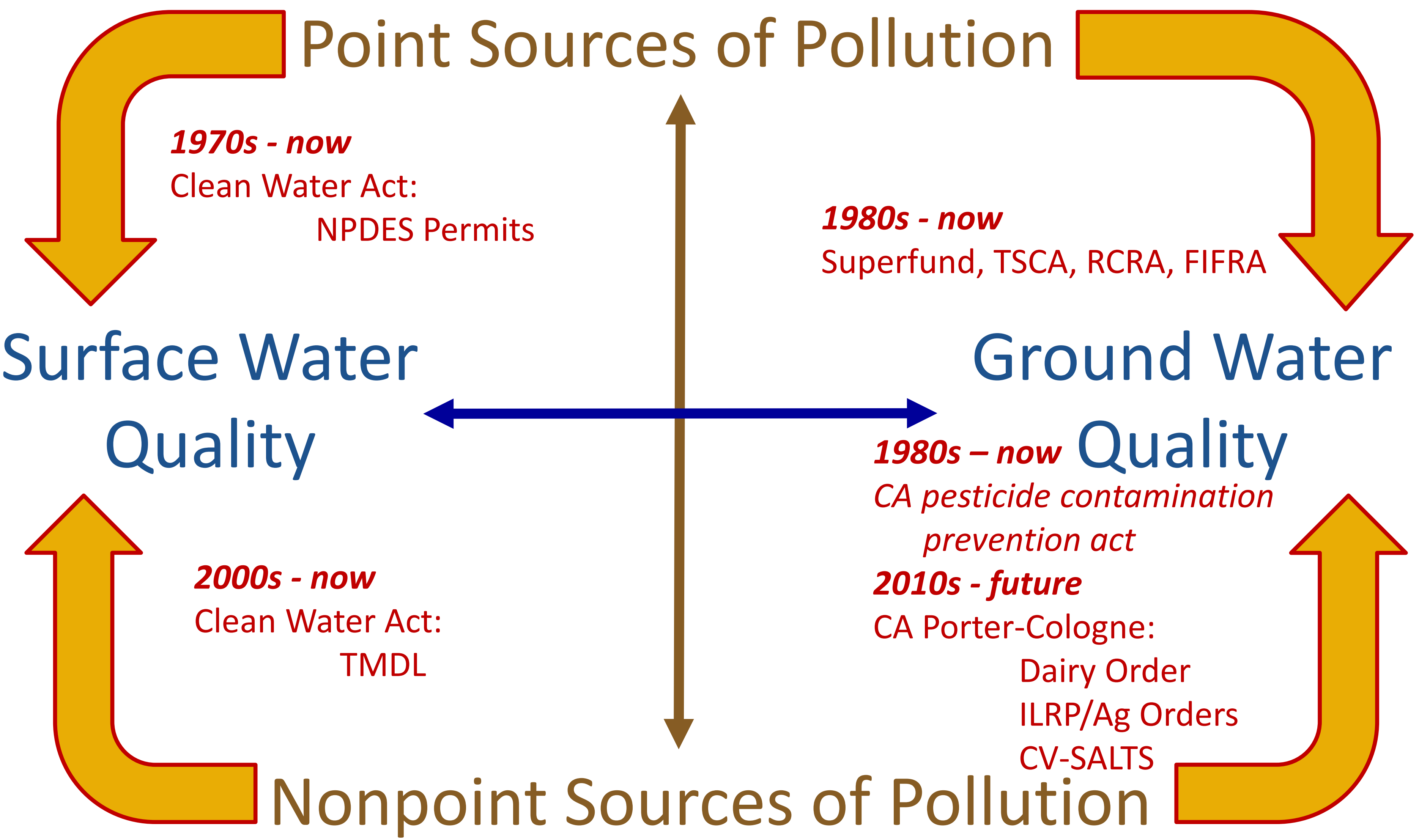
Enforcement:
Annual Nitrogen Budget
+
Management Practice Assessment
+
Regional Trend Monitoring

Management Tool:
Water and Nutrient Management





Regulating Water Pollution Sources



Areas of Research Strengths

- Soil physics, hydrogeology, fate and transport in the subsurface
- Dairy system N, P fluxes, mass balances
- Engineering of facility isolation (liners)
- Monitoring well construction, sampling
- Dairy impact in alluvial aquifer systems
- Nitrate, pathogen impacts

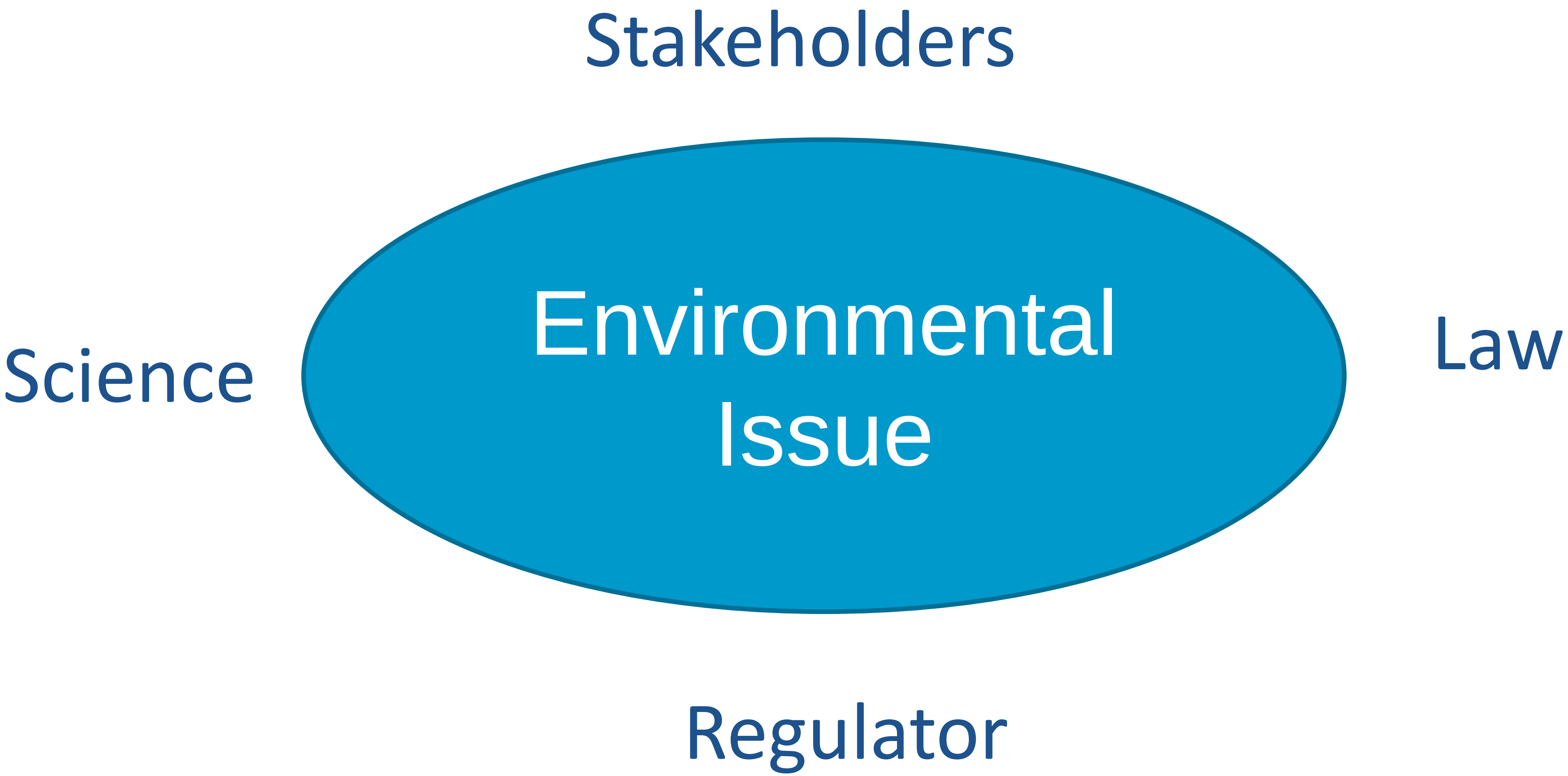
Areas of Research Weakness

- Manure/nutrient management effects on groundwater
- Dairy groundwater research in non-alluvial groundwater systems
- N: atmospheric emissions / mass balance
- Impacts from:
  - Pathogens
  - Antibiotics and other pharmaceuticals
  - Steroid hormones
  - Antimicrobial resistance
  - Salts
- Effective monitoring & reporting systems
- Groundwater overdraft & clean recharge

Key Future Research Areas

- Management practice evaluation w/ respect to groundwater
  - “waste discharge” as function of mgmt practice
- “proxy” monitoring systems (instead of groundwater monitoring)
  - Nitrogen budget
  - Management practice evaluations
  - Soil / deep root zone monitoring
- Impacts from non-N contaminants in vulnerable systems
- Remediation / pump & fertilize / drinking water treatment
- Integration part of all of the above

Understanding Challenges to Sustainable Dairy Management



Vision for Regulating Nonpoint Sources of Groundwater

- **SCIENCE**
  - NPS source control
  - NPS pollution soil/groundwater fate, transport
  - NPS pollution assessment, monitoring
- **REGULATORY FRAMEWORK**
  - Enforcement: Paradigm shift in monitoring approaches
- **AGRICULTURE (largest NPS!)**
  - Socio-cultural change needed to work within new regulatory framework

Future of Groundwater Management in Agricultural Regions:

Opportunity for creative solutions to **simultaneously** address

- groundwater supply enhancement
- groundwater quality improvement
- drinking water protection
- economic viability of agriculture

High irrigation efficiency + High nutrient use efficiency + CLEAN groundwater recharge