WATER EDUCATION FOUNDATION

GROUNDWATER SUPPLY AND QUALITY

Water Education Foundation – Groundwater Tour
October 5-6, 2016

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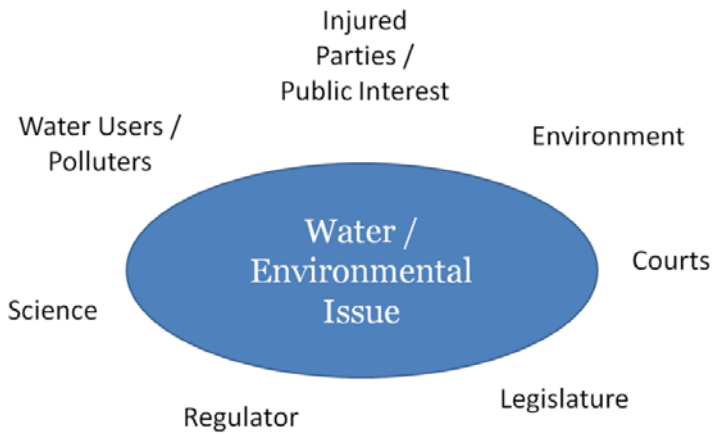
http://groundwater.ucdavis.edu

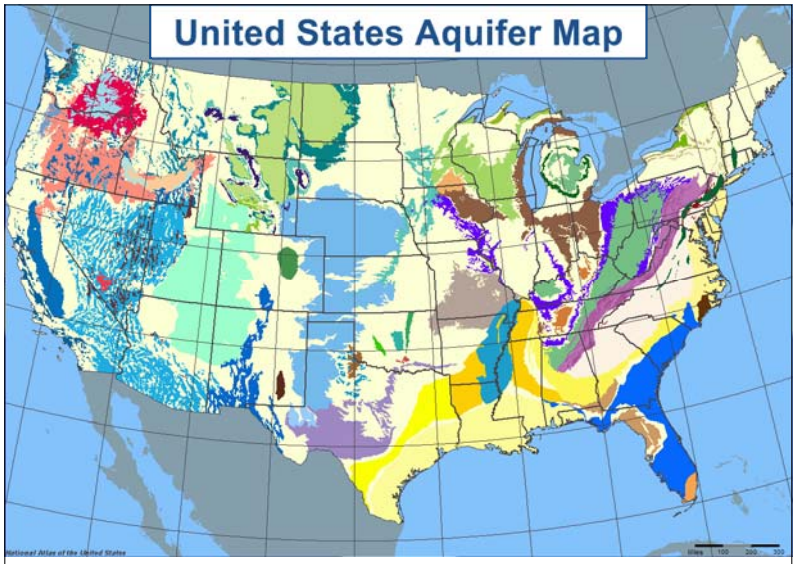
Understanding Challenges to Addressing Water Issues:



Background

- **Groundwater Supply**
- Groundwater Quality
- Regulations & Monitoring
- Dairy and groundwater impacts

United States Aquifer Map

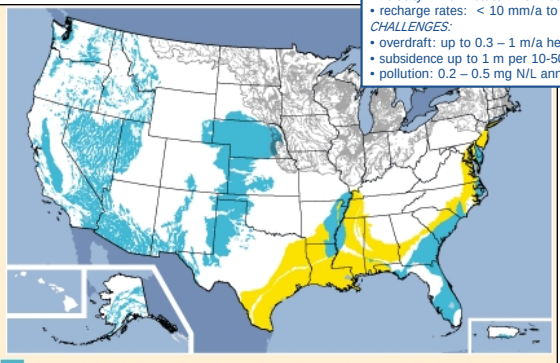


http://nationalatlas.gov/mapmaker

U.S. Sand & Gravel Aquifers

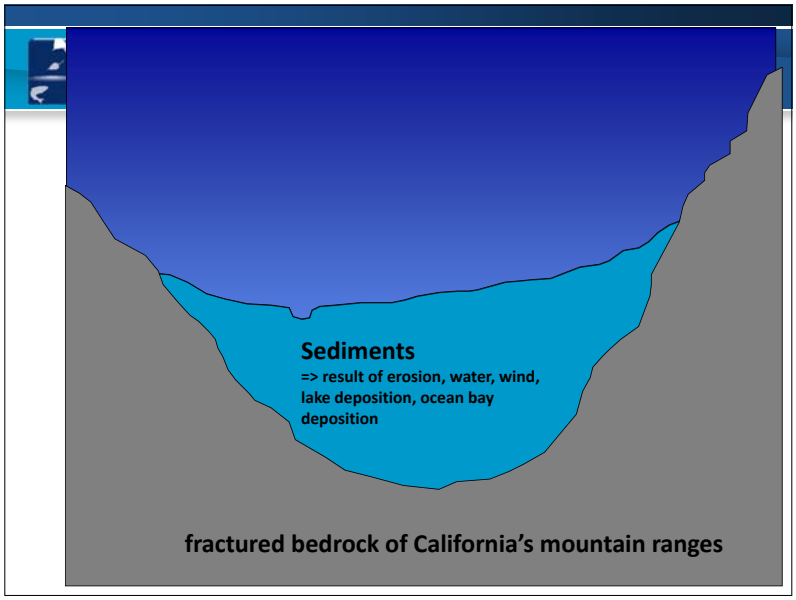
GENERAL PROPERTIES (exceptions a*re the rule!)*
- K values = 1 m/d – 100 m/d
- gradients 0.1 – 1%
- effective porosity of 5-15%
- velocity: ~10^1 m/a to ~10^3 m/a
- recharge rates: < 10 mm/a to 500 mm/a

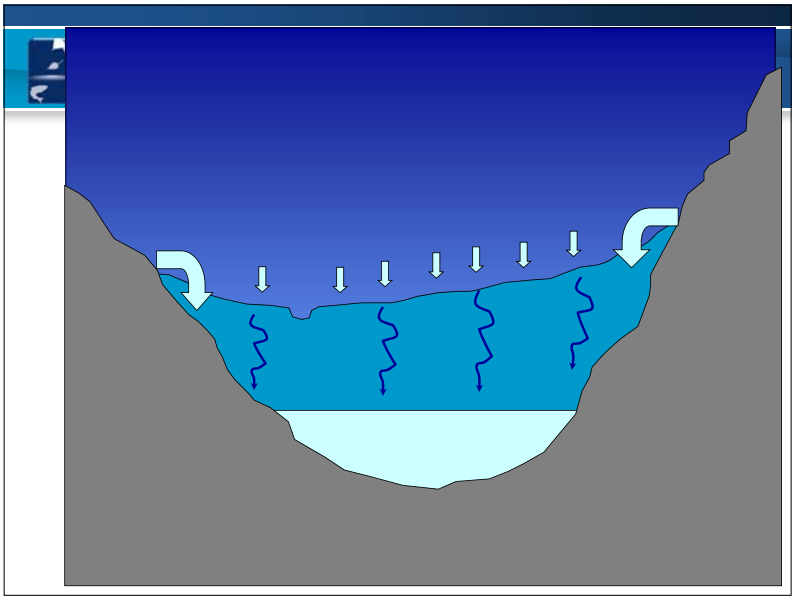
CHALLENGES:
- overdraft: up to 0.3 – 1 m/a head loss (30 – 200 mm/a gw loss)
- subsidence up to 1 m per 10-50 m drawdown
- pollution: 0.2 – 0.5 mg N/L annual increase in nitrate-N

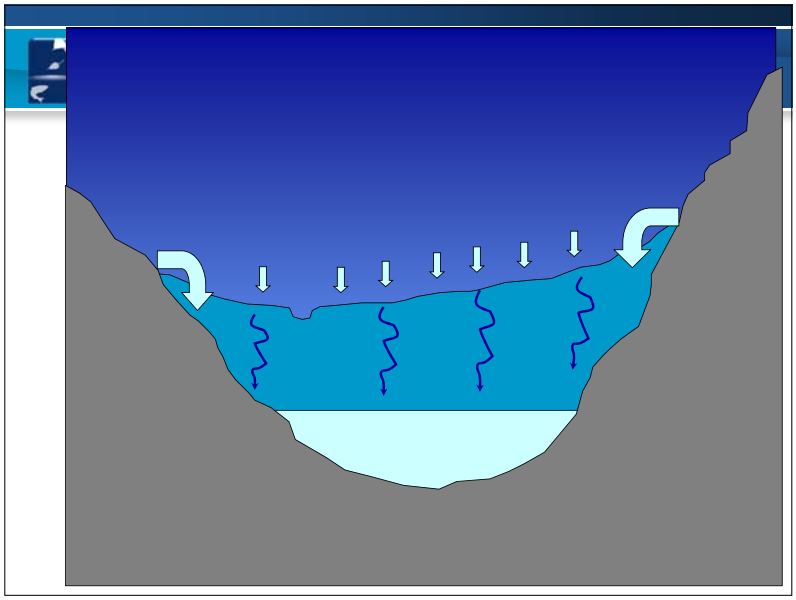


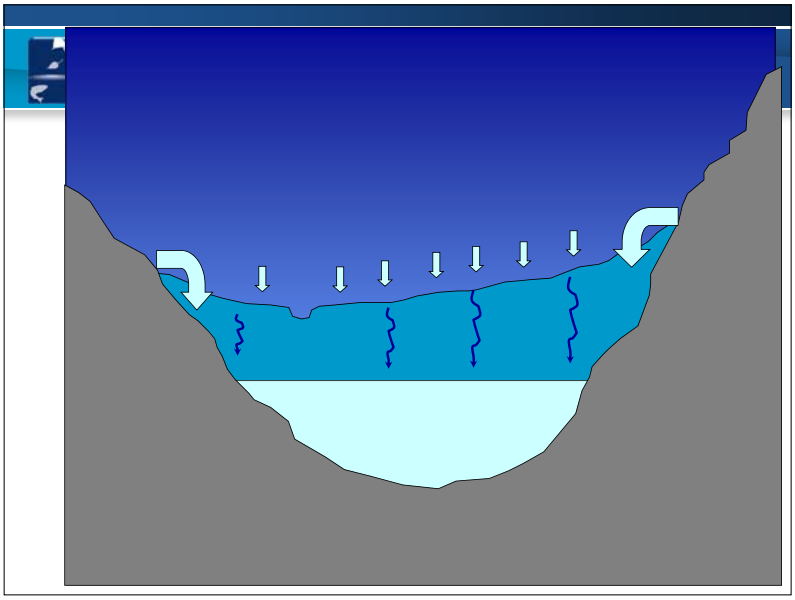
Unconsolidated sand and gravel aquifers at or near the land surface.
Semiconsolidated sand and gravel aquifers.
Sand and gravel aquifers of alluvial and glacial origin are north of the line of continental glaciation.

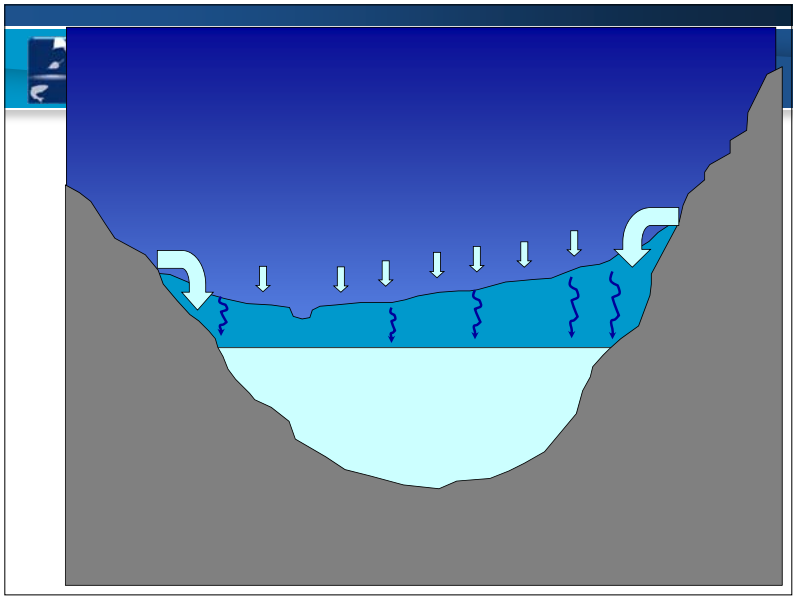
http://water.usgs.gov/ogw/aquiferbasics/uncon.html

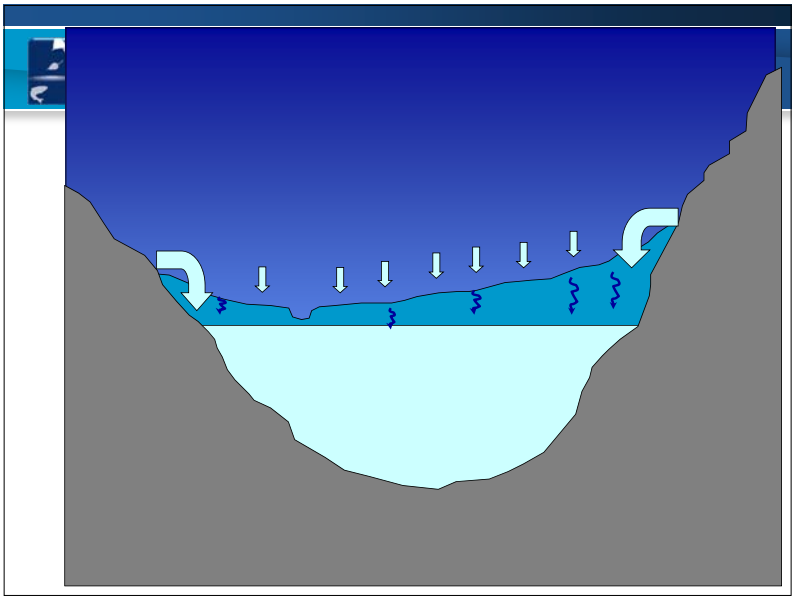


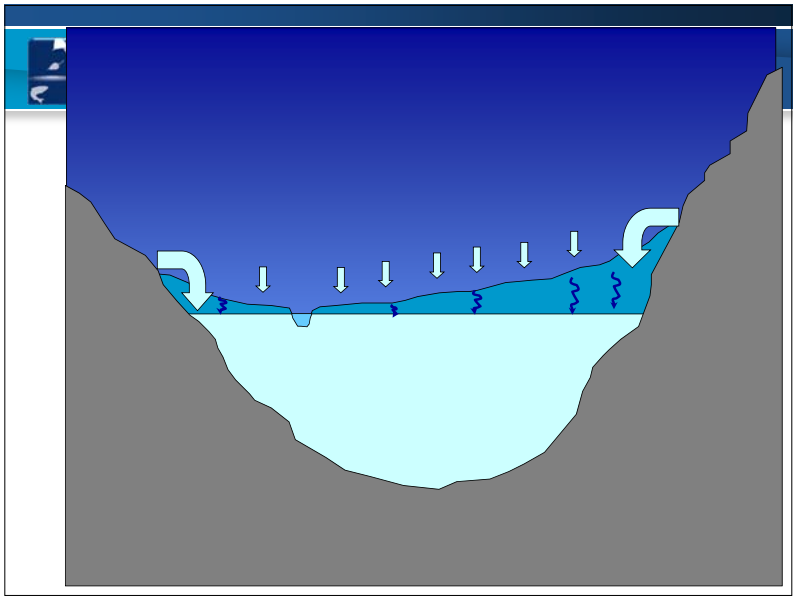


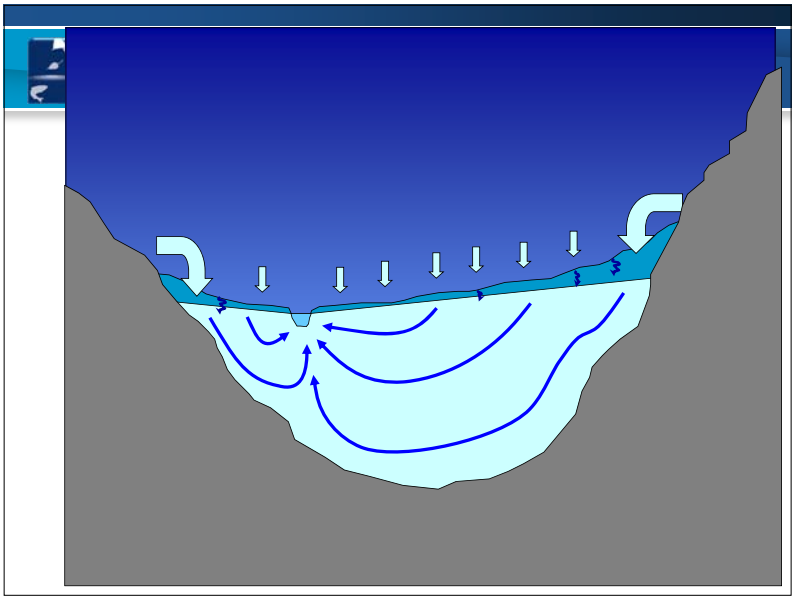


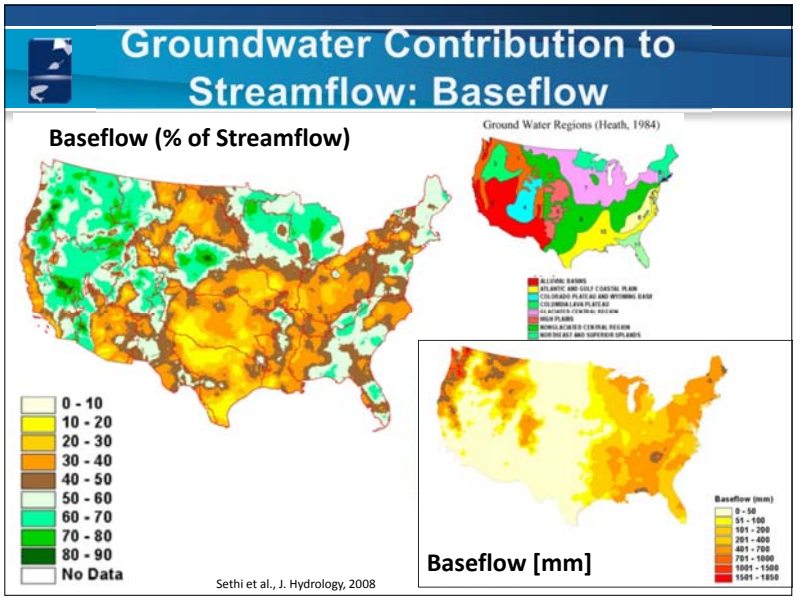


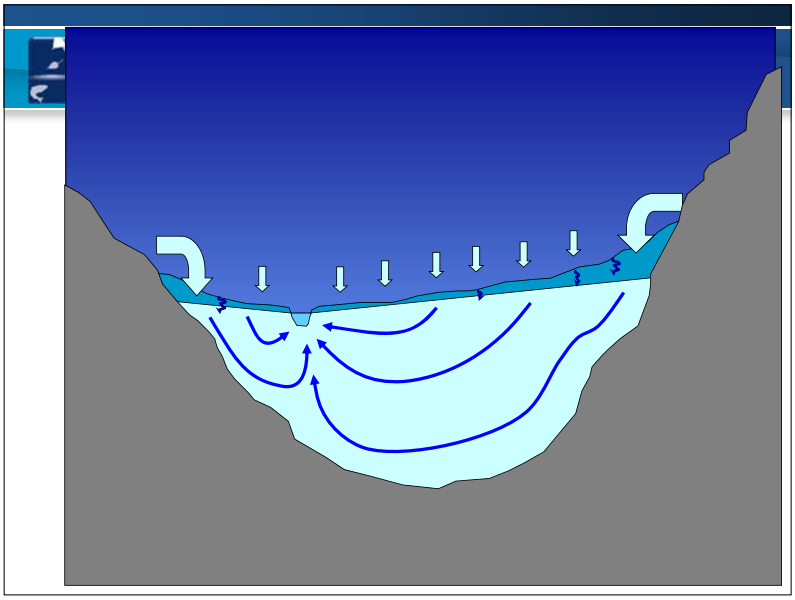


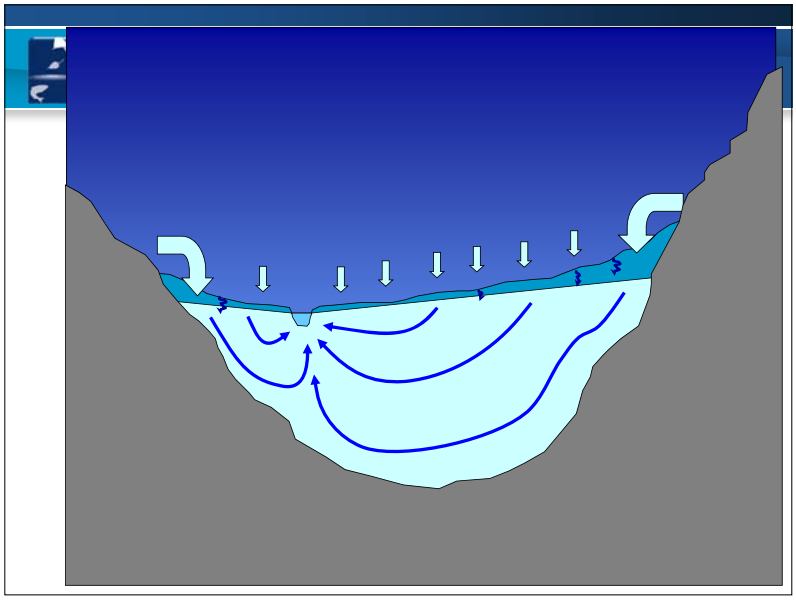


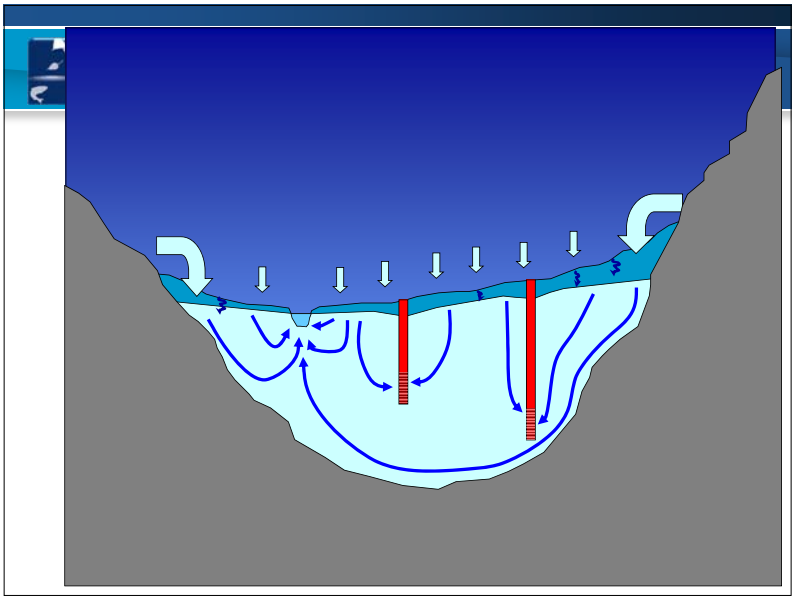


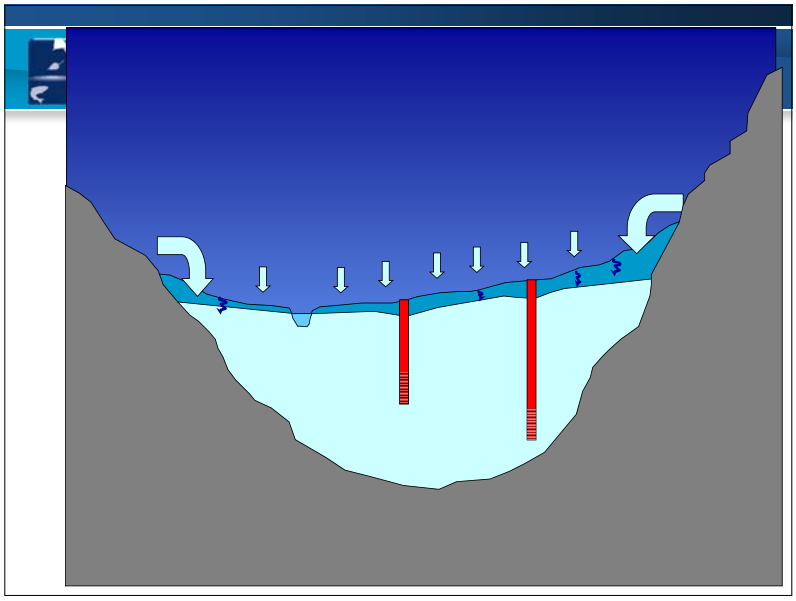


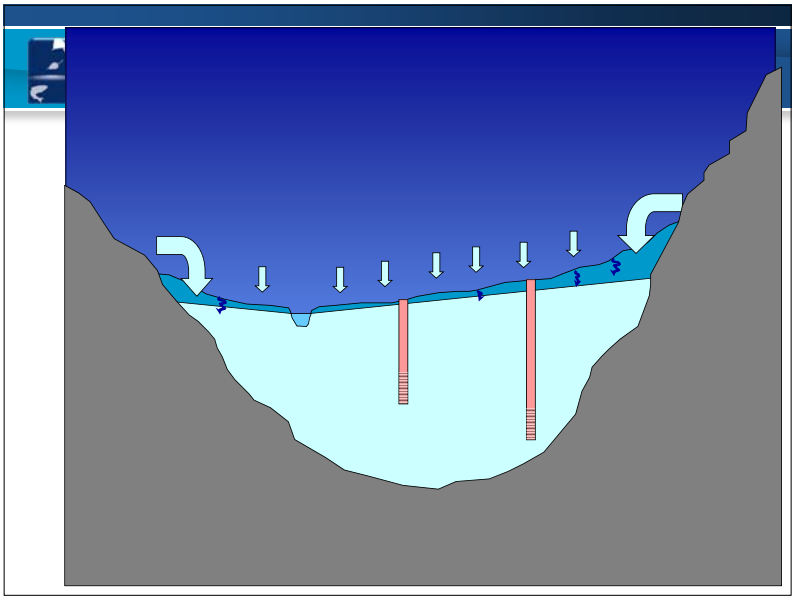

Groundwater Contribution to Streamflow: Baseflow
Baseflow (% of Streamflow)
Ground Water Regions (Heath, 1984)
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
No Data
Sethi et al., J. Hydrology, 2008
Baseflow [mm]

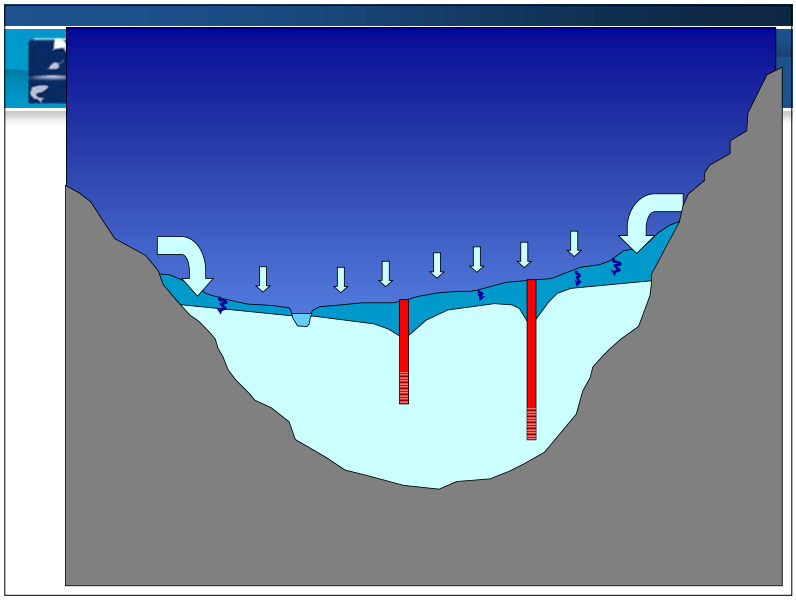


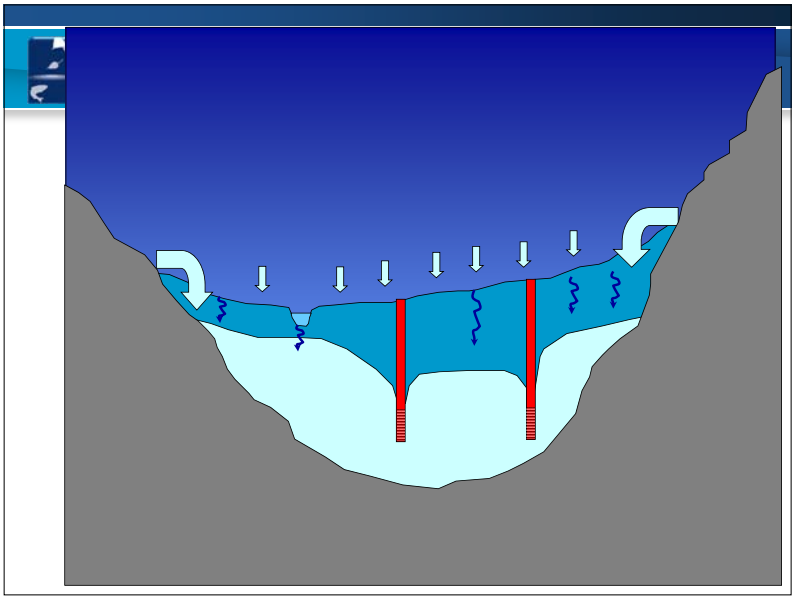


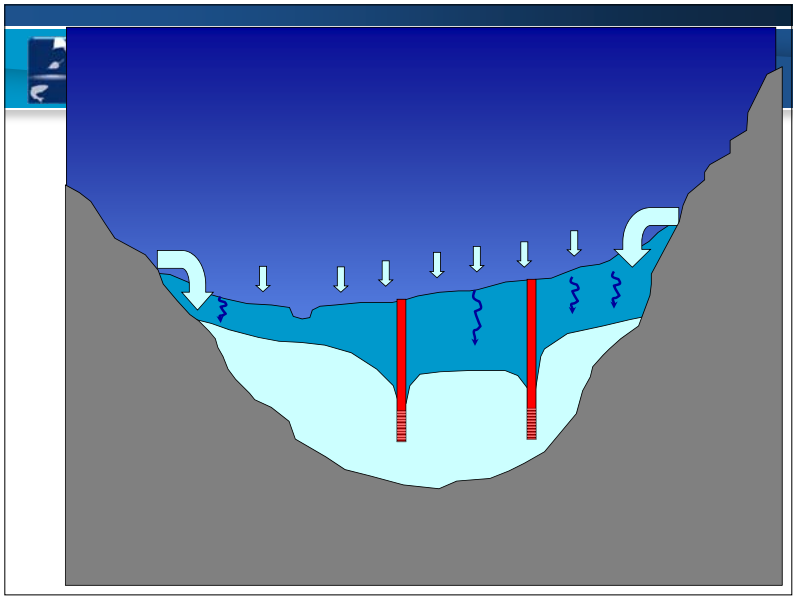




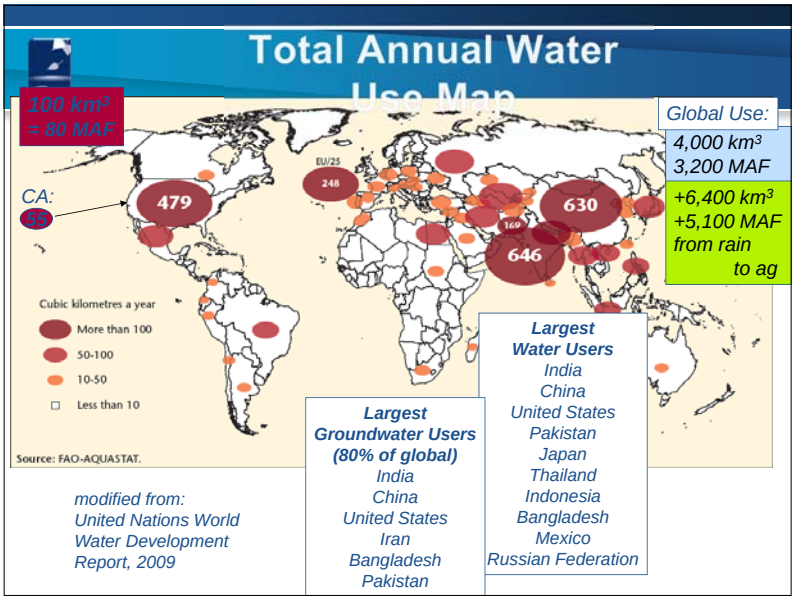








Total Annual Water Use Map



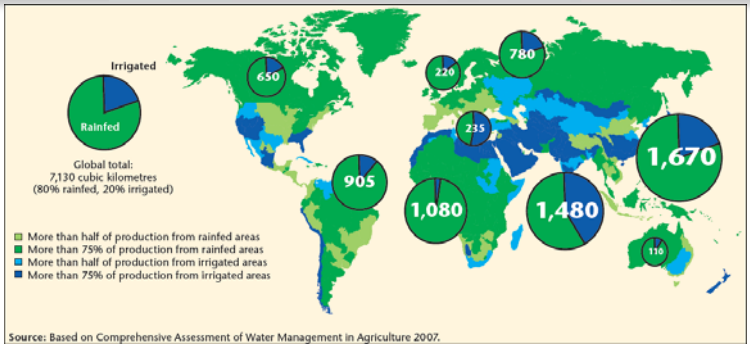
Global Use:
4,000 km³
3,200 MAF
+6,400 km³
+5,100 MAF
from rain to ag

Largest Groundwater Users (80% of global)
India
China
United States
Iran
Bangladesh
Pakistan

Largest Water Users
India
China
United States
Pakistan
Japan
Thailand
Indonesia
Bangladesh
Mexico
Russian Federation

modified from:
United Nations World Water Development Report, 2009

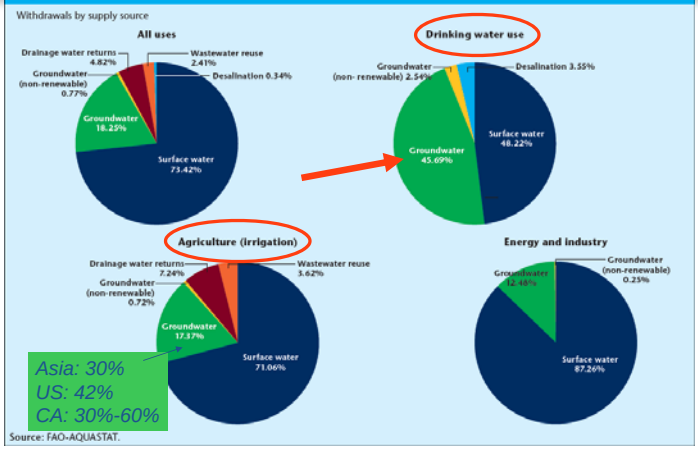
Annual "Green" vs. "Blue" Water Use in Agriculture



from: United Nations World Water Development Report, 2009

Rainfed agriculture = 80% of cultivated land, 60% of crop production
Irrigated agriculture = 70% of applied water use, 90% of consumptive use
20% of cultivated land, 40% of crop production

Groundwater Connection to Food: USE OF GROUNDWATER



modified from: United Nations World Water Development Report, 2009

Global Water Use and Groundwater Use Fraction

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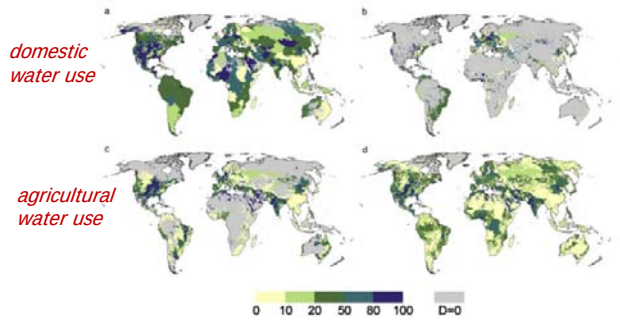
Table 1
Global water use during the period 1998–2002. Total water withdrawals and consumptive water use were computed by the five sectoral water use models of WGHM (Section 2.1). The new groundwater fractions were derived as described in Section 2.2, Appendix A and Siebert et al. (2010).

Water use sector	Withdrawals *WU* [km³/year]	Groundwater fraction of *WU* [%]	Consumptive use *CU* [km³/year]	Groundwater fraction of *CU* [%]
Irrigation	3185	42	1231	43
Thermal power	534	0	13	0
Domestic	330	36	53	37
Manufacturing	264	27	110	24
Livestock	27	0	27	0
All sectors	4340	35	1436	40

percent of water use from groundwater:



domestic water use

manufacturing water use

agricultural water use

total water use

Annual Water Use – California, USA, World

	Public Water Supply			Domestic Water			Irrigation Water			Total (incl. Industrial)		
	GW	SW	Total	GW	SW	Total	GW	SW	Total	GW	SW	Total
	In MILLION ACRE-FEET PER YEAR											
California	3.14	3.73	6.9	0.29	0.03	0.3	13.10	21.10	34	17.04	26.01	43
United States	17.90	30.60	49	3.96	0.07	4.0	63.80	89.70	153	93.40	293.70	387
World			300			<===			2095			3000
	In CUBIC KILOMETERS PER YEAR											
California	3.89	4.62	8.5	0.36	0.04	0.4	16.22	26.12	42	21.10	32.20	53
United States	22.16	37.89	60	4.90	0.08	5.0	78.99	111.06	189	115.64	363.64	479
World			371			<===			2594			3714

California and USA: USGS Circular 1268 (for year 2000); http://pubs.usgs.gov/circ/2004/circ1268/
World: Pacific Institute 2008-2009 World Water Report, Table 2-1

Annual Water Use – California and U.S. 2010

MAF/YR	CA	US	CA-sw	US-sw	CA-gw	US-gw	CA-%gw	US-%gw
groundwater	13.8	85.1						
surface water	21.1	257.6						
public	7.1	47.0	4.4	33.0	3.1	17.6	42%	35%
domestic	0.2	4.0	0.0	0.1	0.2	4.0	81%	98%
irrigation	25.9	128.8	18.0	82.8	9.7	55.4	35%	40%
livestock	0.2	2.2	0.1	1.0	0.1	1.3	41%	57%
aquaculture	1.1	10.5	1.0	9.5	0.2	2.0	16%	17%
industrial	0.4	16.8	-	15.1	0.4	3.2	100%	18%
mining	0.0	2.6	0.0	1.5	0.0	1.3	63%	46%
thermoelectric power	0.1	131.1	0.0	145.6	0.0	0.7	48%	0%
total	35.0	343.1	23.6	288.6	13.8	85.5	37%	23%

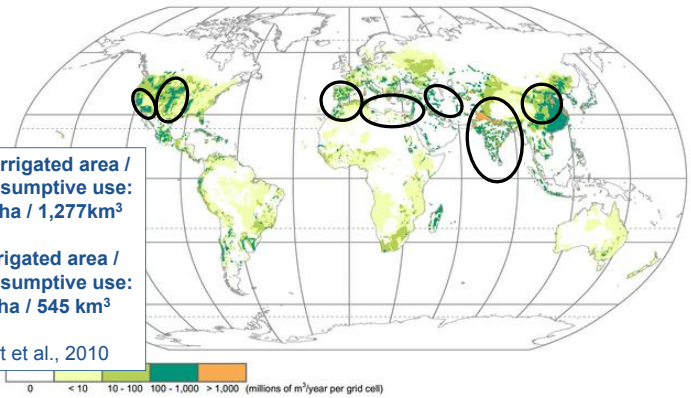
urban-industrial	8	70	4	50	4	26	46%	34%
agriculture	27	142	19	93	10	59	34%	39%
thermoelectric	0	131	0	146	0	1	48%	0%
total	35	343	24	289	14	86	37%	23%

ag / (ag+urban-industry)	78%	67%	81%	65%	73%	69%		

USGS Circular 1405, 2014

Groundwater for Irrigation

(G1) Irrigation Water Withdrawals, year 2000



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

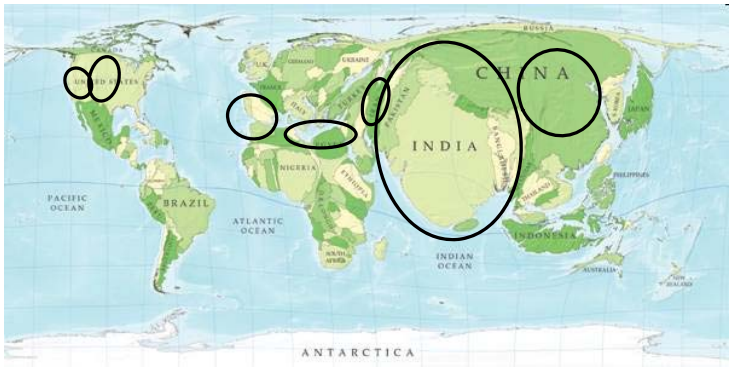
GW irrigated area / consumptive use: 112 Mha / 545 km³

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



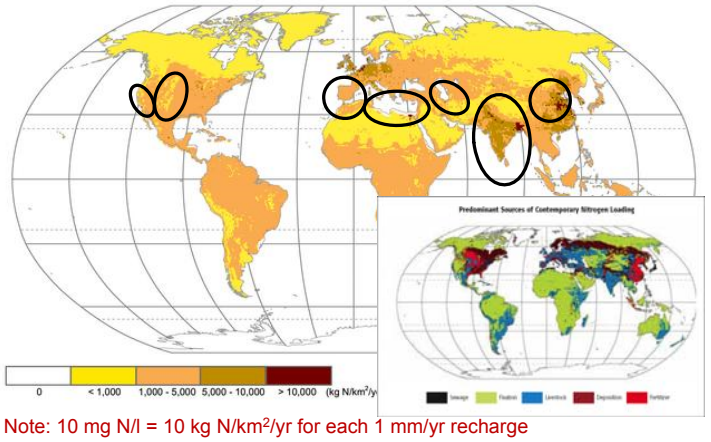
Modified with world population map from: Nature **439**, 800 (16 February 2006) | doi:10.1038/439800a

Groundwater Quality

- Groundwater Supply
- **Groundwater Quality**
- Regulations and Monitoring
- Dairy and groundwater impacts

Global Groundwater Nitrate

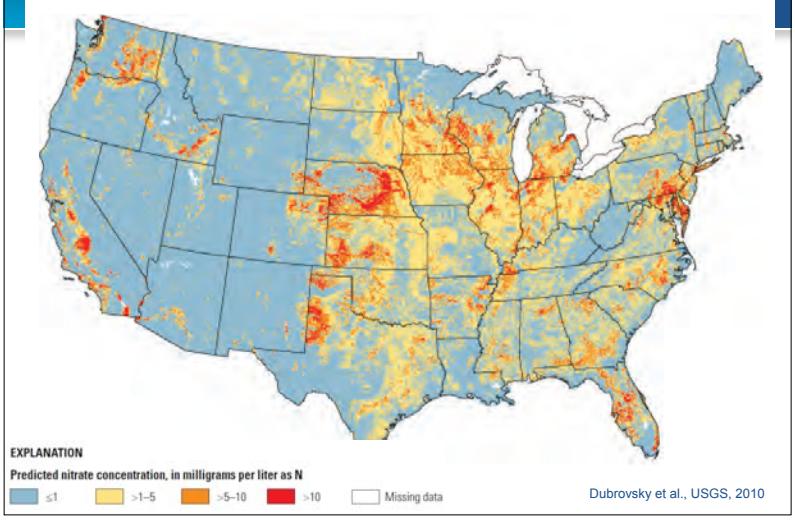
(I1) Mobilizable Nitrogen Loads



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

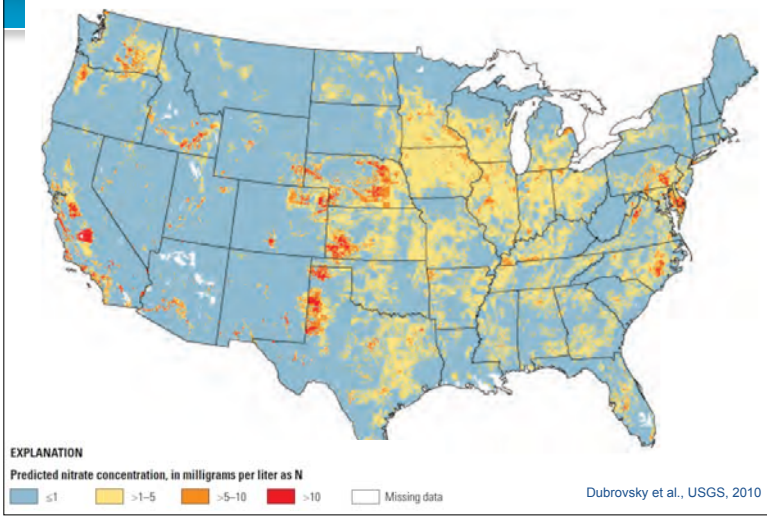
UN World Water Development Report II, 2006

Model for shallow groundwater

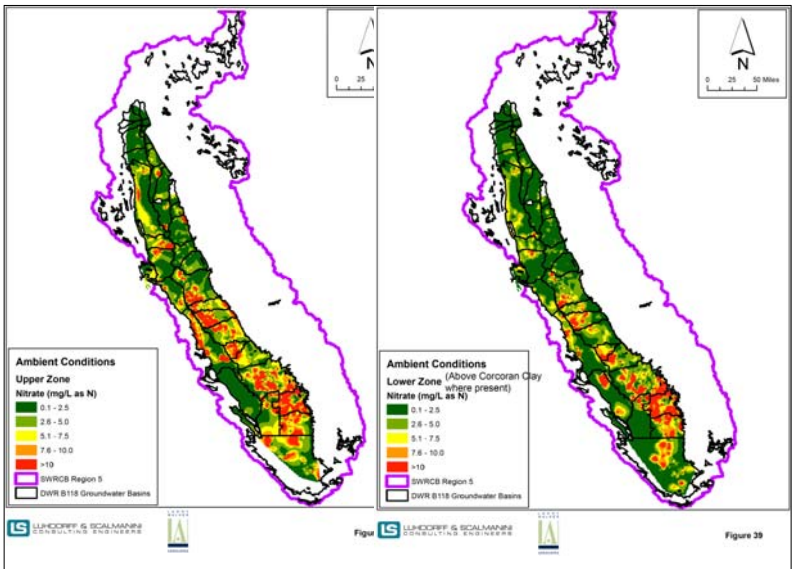


Dubrovsky et al., USGS, 2010

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

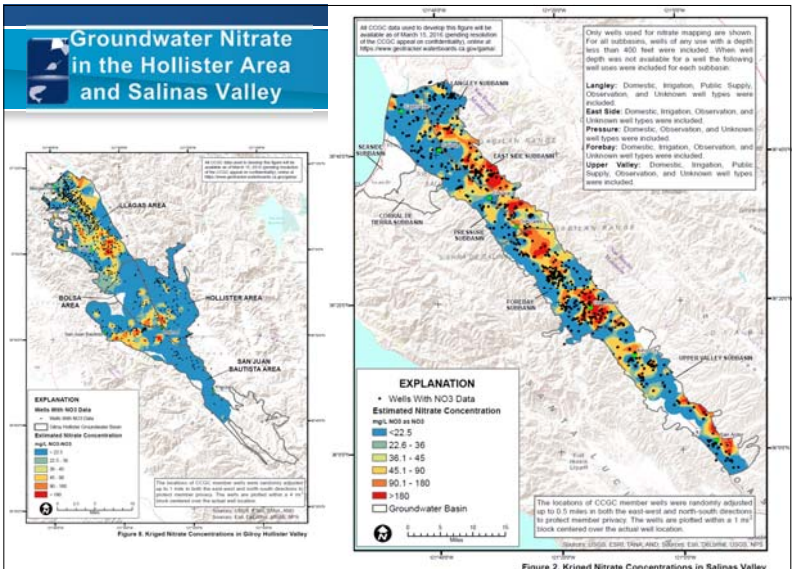


Dubrovsky et al., USGS, 2010



CVSALTS, High Resolution Ambient Water Quality Mapping, Draft, May 2016

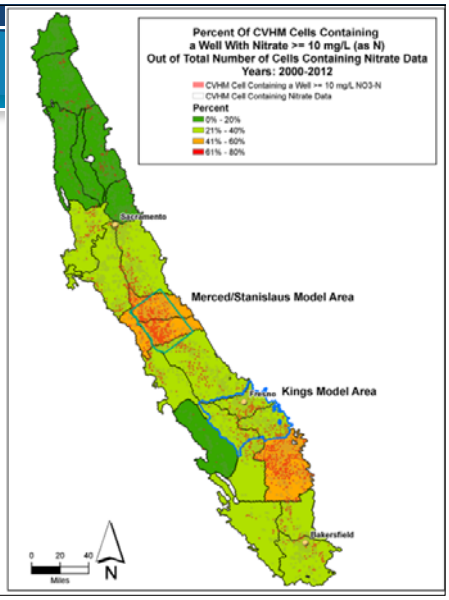
Groundwater Nitrate in the Hollister Area and Salinas Valley



Central Coast Cooperative Groundwater Coalition Report, June 2015; Central Coast RWB Website

Nitrate: Impacted regions within the Central Valley

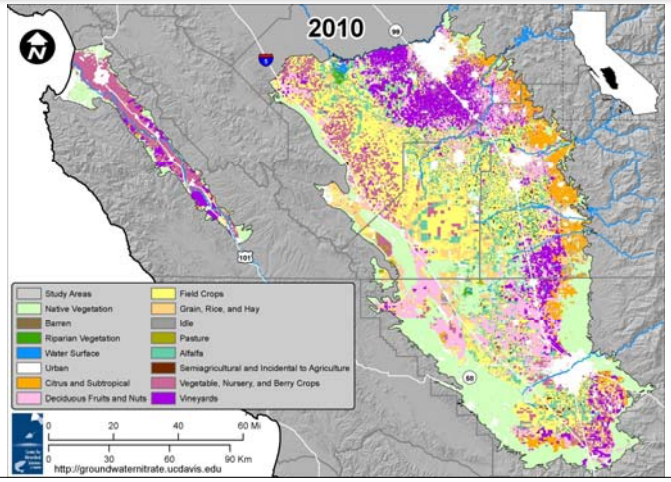
red dots: wells above MCL for nitrate



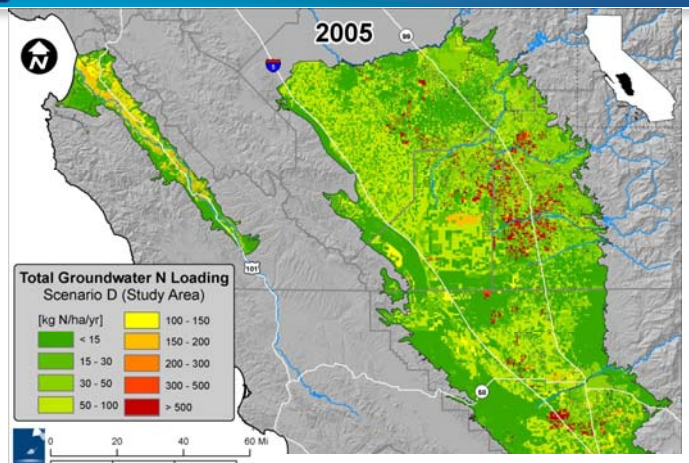
CVSALTS, Tasks 7 and 8 – Salt and Nitrate Analysis for the Central Valley Floor Final Report, December 2013

Figure 7-14

Nitrate Contamination Study Area

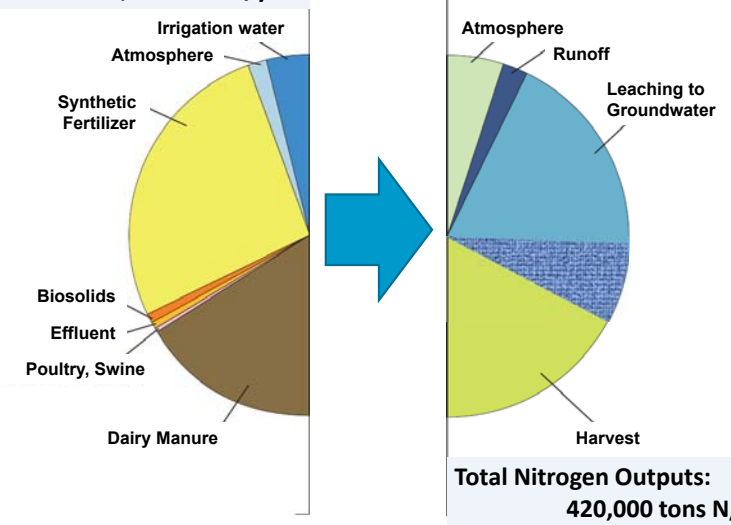


Estimated Groundwater Nitrate Loading



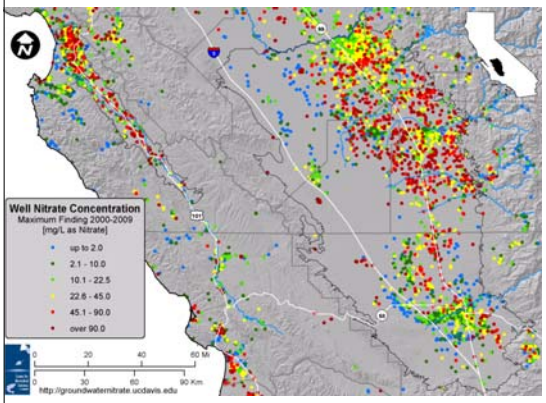
Assume: All Manure Remains On-Dairy

Total Nitrogen Inputs: 420,000 tons N/yr



Total Nitrogen Outputs: 420,000 tons N/yr

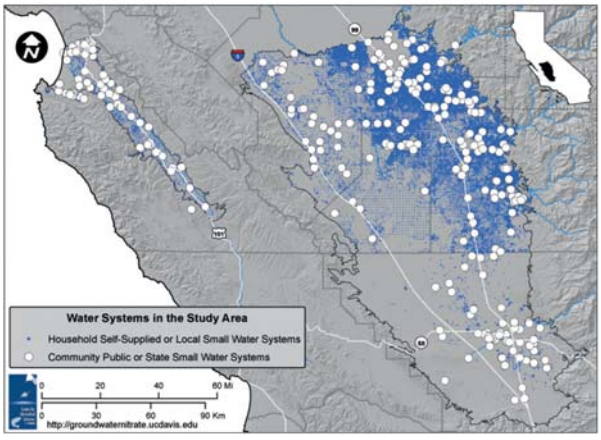
Nitrate Contamination Will Persist



- 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)

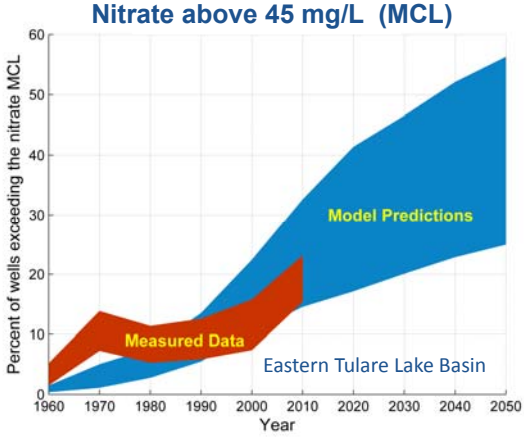
All Water Systems



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.

Future Groundwater Nitrate at Continued Current Nitrate Loading

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



Regulations and Monitoring

- Groundwater Supply
- Groundwater Quality
- **GW Quality: Regulations and Monitoring**
- Dairy and groundwater impacts

Regulating Water Pollution Sources

Point Sources of Pollution

1970s - now
Clean Water Act:
NPDES Permits

1980s - now
Superfund, TSCA, RCRA, FIFRA

Surface Water Quality

Ground Water Quality

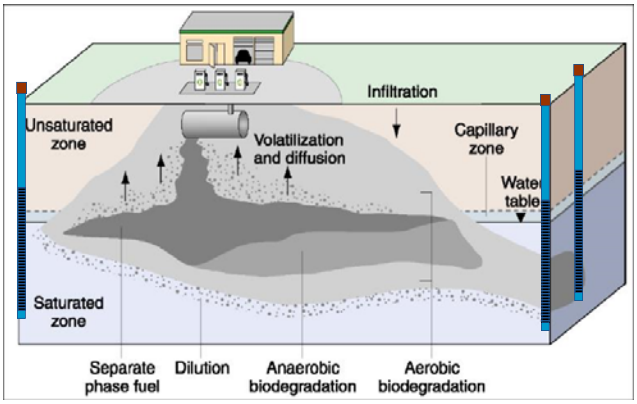
1980s – now
CA pesticide contamination prevention act

2000s - now
Clean Water Act:
TMDL

2010s - future
CA Porter-Cologne:
Dairy Order
ILRP/Ag Orders
CV-SALTS

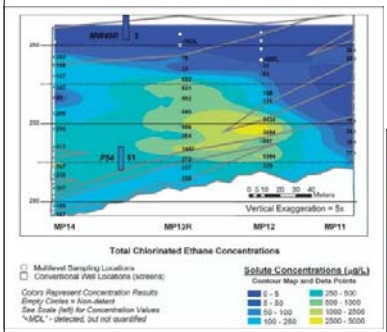
Nonpoint Sources of Pollution

Regulatory Approaches to Groundwater Protection and Monitoring

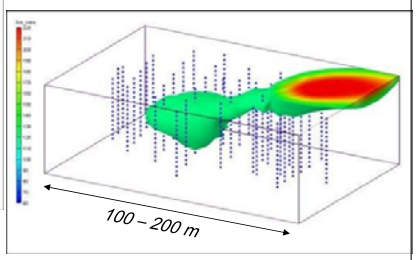


Modified from: EOS, Transactions, AGU 2001

Regulatory Approaches to Groundwater Monitoring



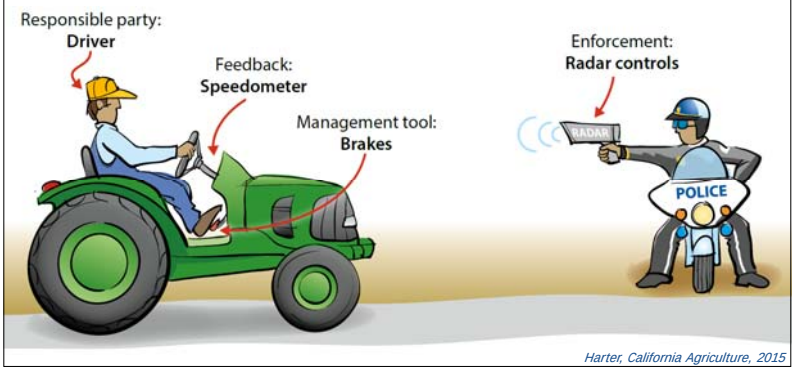
from: Parker, Beth L., Cherry, John A. & Swanson, Benjamin J., 2006. A Multilevel System for High-Resolution Monitoring in Rotasonic Boreholes. Ground Water Monitoring & Remediation 26 (4), 57-73. doi: 10.1111/j.1745-6592.2006.00107



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

The Basics of Management Policy & Regulation

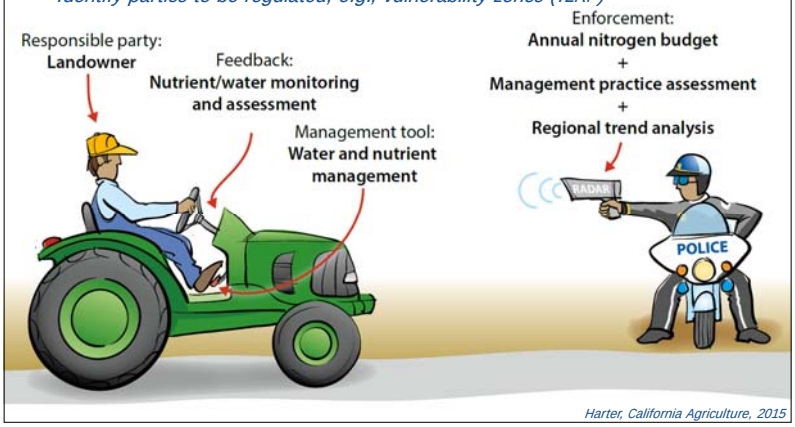
- *Identify impacts (human health, environment, economy) and risk drivers*
- *Identify & prioritize parties to be regulated (universal v structured/categories)*



Harter, California Agriculture, 2015

Application to Nonpoint Source Pollution

- *Identify risks: e.g., Groundwater Assessment Reports (ILRP)*
- *Identify parties to be regulated, e.g., vulnerability zones (ILRP)*



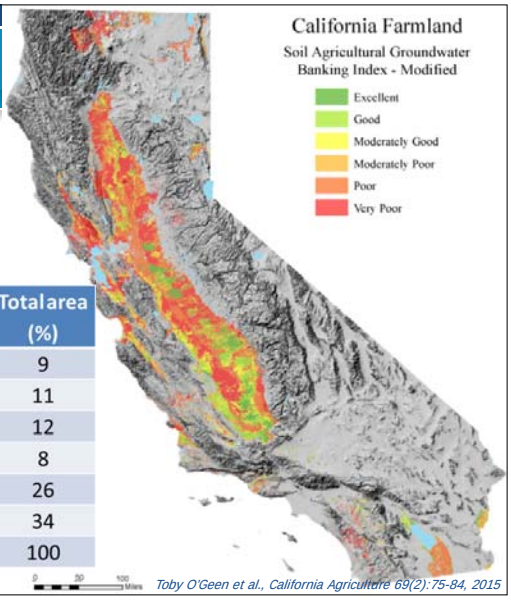
Harter, California Agriculture, 2015

Vision for Regulating Nonpoint Sources of Groundwater

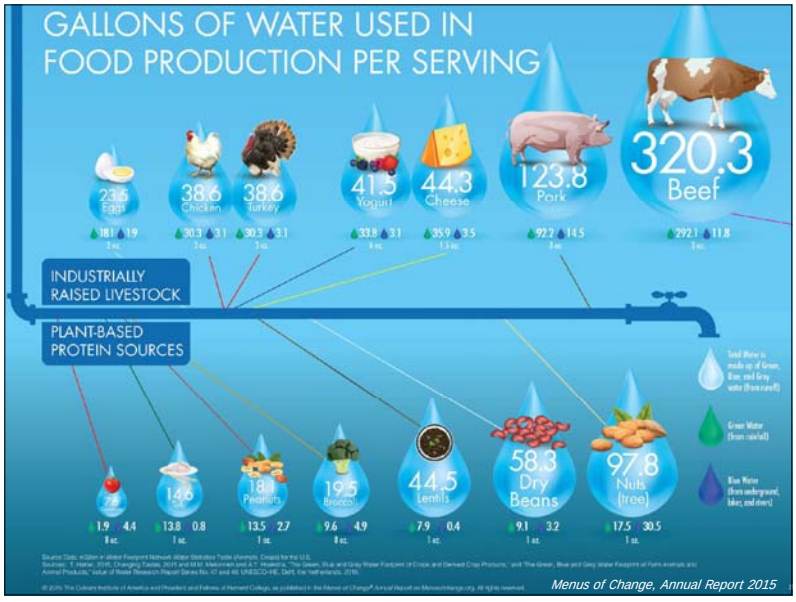
- **SCIENCE**
  - NPS source control
  - NPS pollution soil/groundwater fate, transport
  - NPS pollution assessment, monitoring
- **REGULATORY FRAMEWORK**
  - Enforcement: Paradigm shift in monitoring approaches
- **AGRICULTURE (largest NPS!)**
  - Socio-cultural change needed to work within new regulatory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

SAGBI Accounting for Deep Tillage

Suitability Group	Area (Acres)	Total area (%)
Excellent	1,525,296	9
Good	1,928,650	11
Mod. Good	2,184,882	12
Mod. Poor	1,379,282	8
Poor	4,609,128	26
Very Poor	5,993,345	34
Total	17,620,582	100



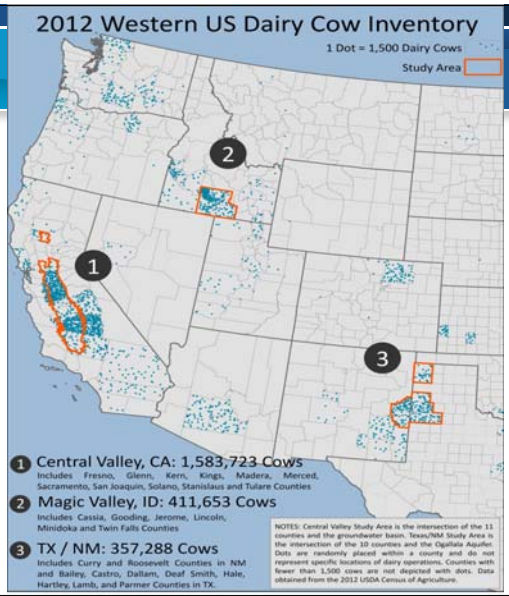
Toby O'Geen et al., California Agriculture 69(2):75-84, 2015



Menus of Change, Annual Report 2015

Dairy and Groundwater Quality

- Groundwater Supply
- Groundwater Quality
- Regulations and Monitoring
- **Dairy and groundwater impacts**



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

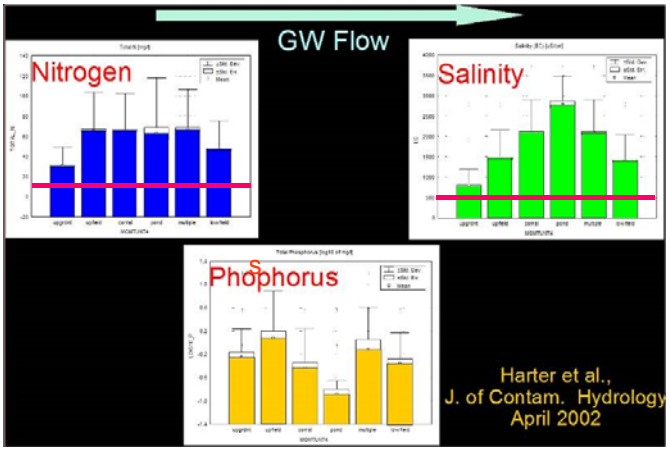
Irrigation Water Source	Salt Input, kg ha^{-1}		Annual Salt Loading kg ha^{-1}
	Winter Forage	Summer Corn	
East Side Sources	86	310	404
Wastewater + East Side	1356	2284	3615
West Side Sources	828	2983	3794
Wastewater + West Side	2000	4792	6452

130 – 220 µS/cm

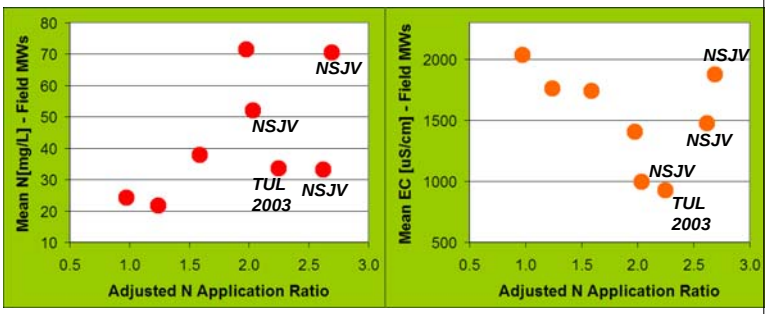
1,200 – 1,900 µS/cm

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).

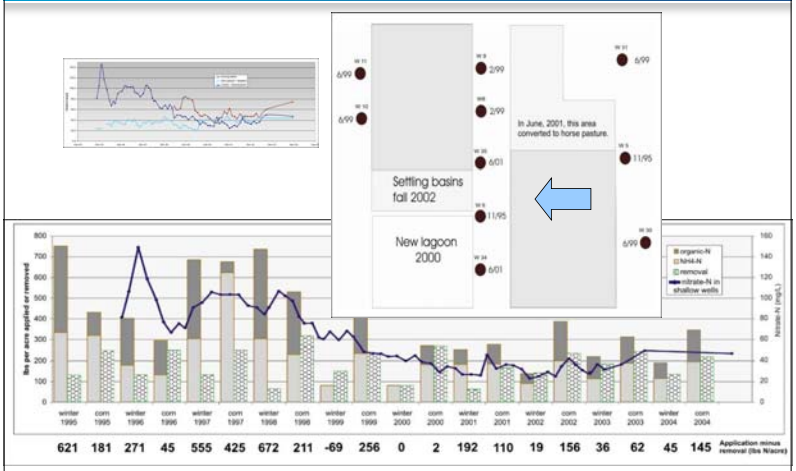
Pollutants by Dairy Management Unit



Manure Application Drives Field N



Testing Field BMPs: Case Studies



Campbell and Harter et al., GRA, 2006