Water Quality for Dairy Cattle; The 1% That May be Holding Back Your Production Goals

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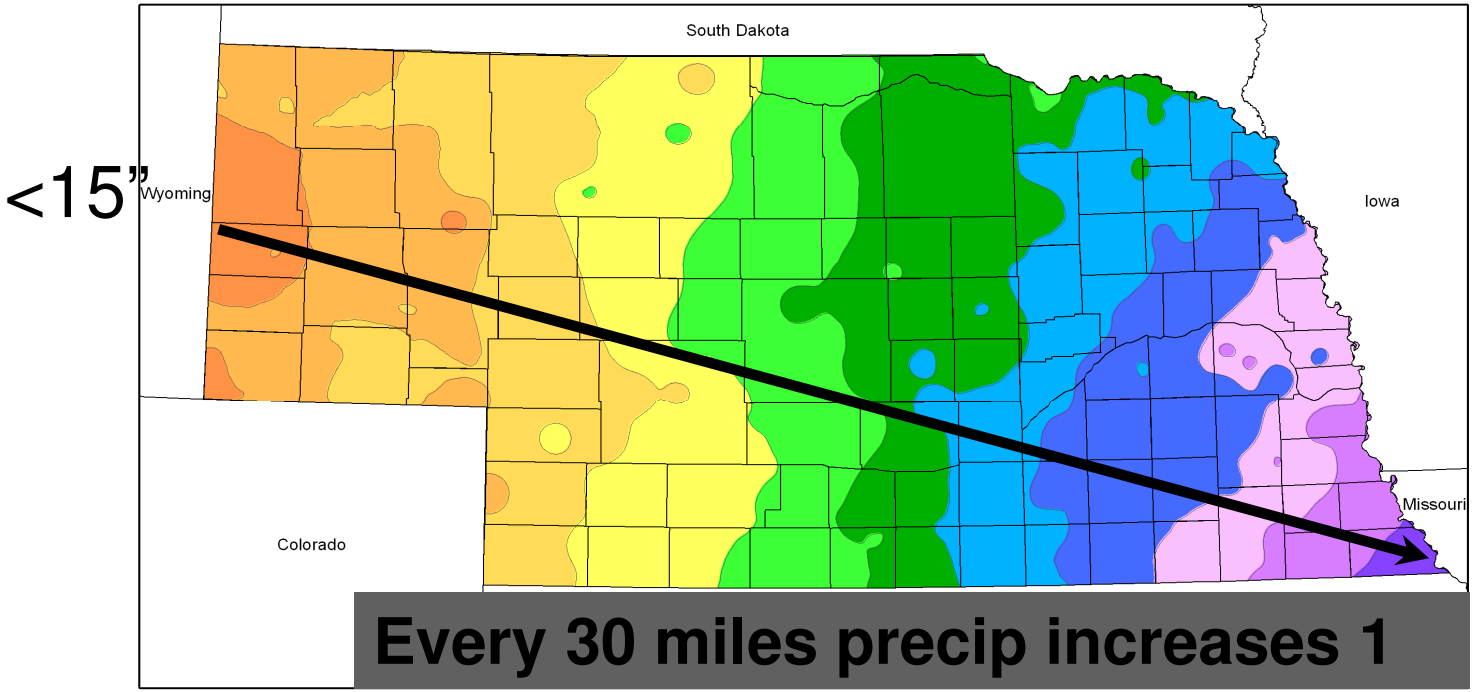
Department Of Animal Science,
2016 Nebraska Dairy Convention,
Columbus, NE
February 18, 2016

Average Annual Precipitation, 1971-2000
Nebraska



<15”

>34”

Every 30 miles precip increases 1 inch

0 25 50 75 100
Miles

Precipitation (inches)

Less than 16	20-22	26-28	32-34
16-18	22-24	28-30	More than 34
18-20	24-26	30-32	

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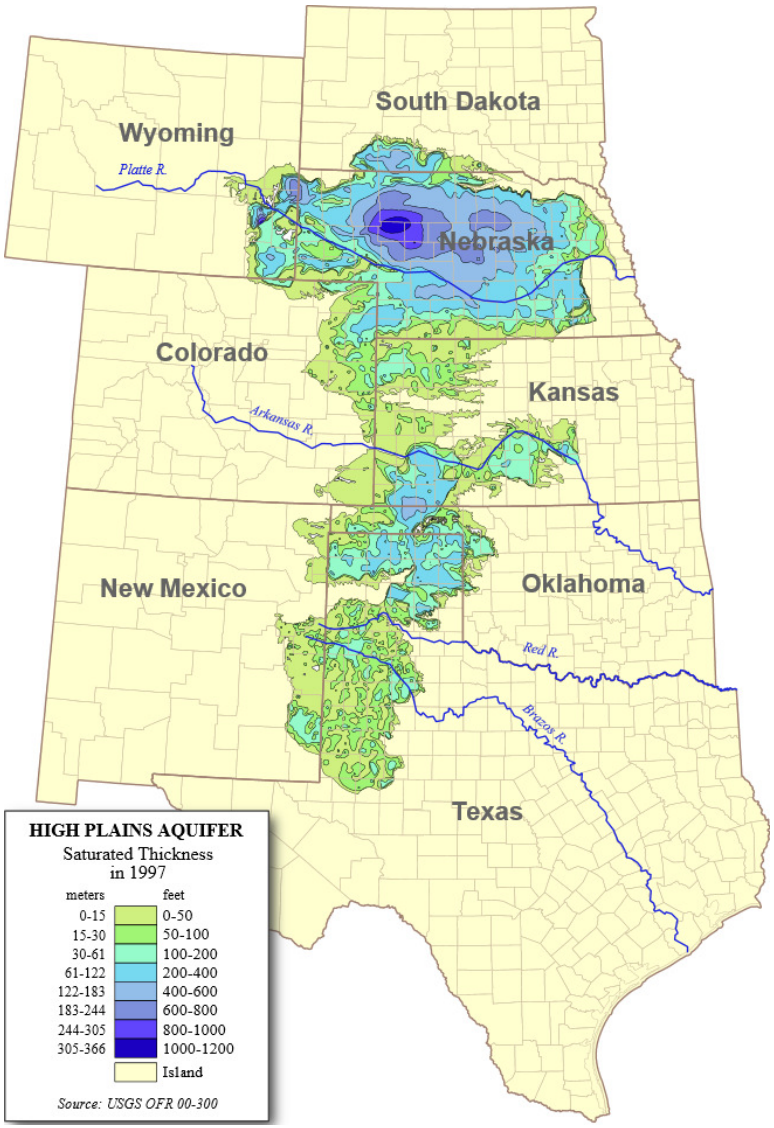
Map copyright (c) 2006 by the PRISM Group and
Oregon Climate Service, Oregon State University.



Saturated Thickness of the High Plains Aquifer:

- shallow water table aquifer located beneath the Great Plains.
- underlies an area of approximately 112 million acres in 8 states.
- 27 % of the irrigated land in the US overlies the aquifer.
- 30 % of the US ground water used for irrigation.

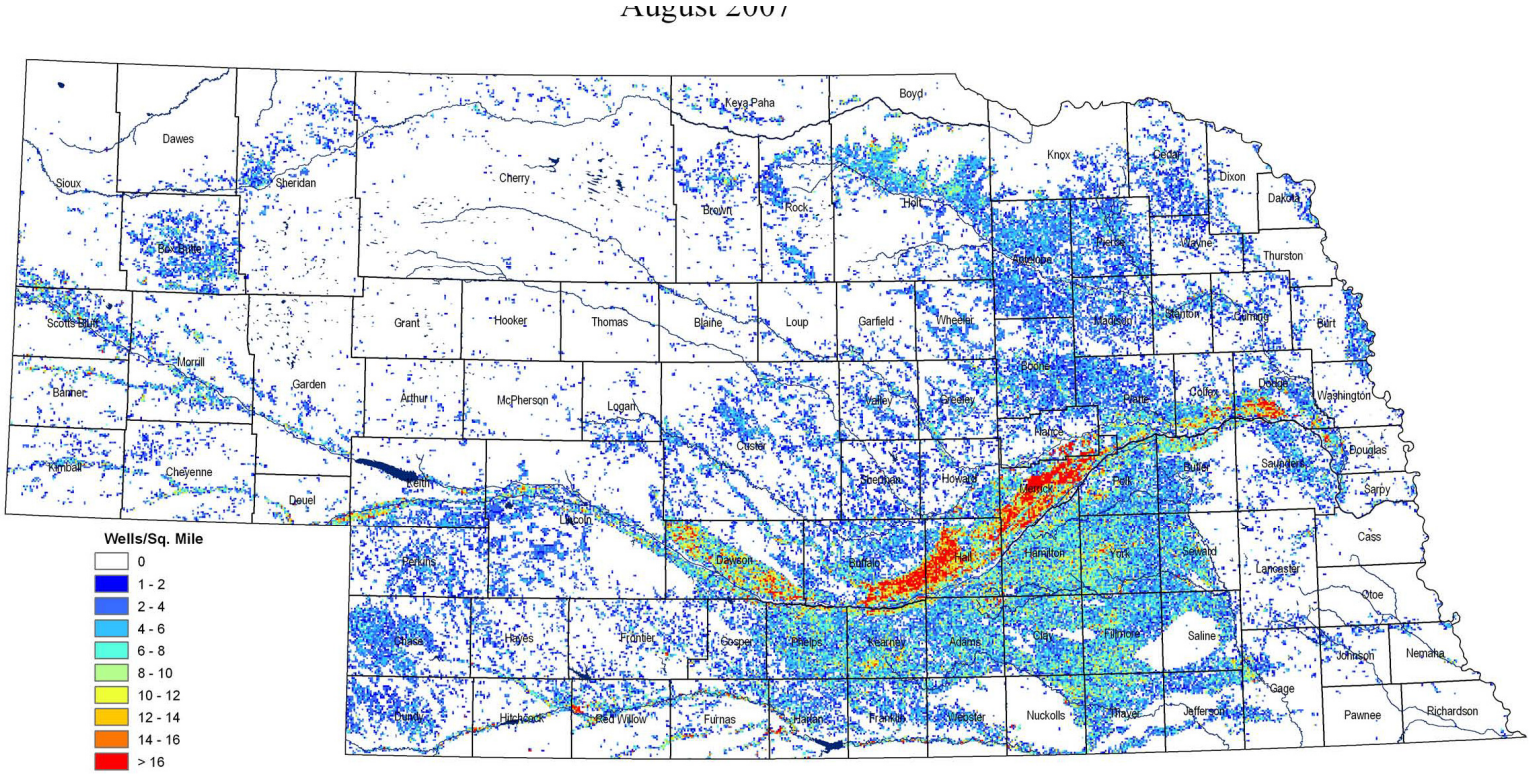
TABLE 2

HYDROGEOLOGIC PROPERTIES OF THE MAJOR ROCK UNITS IN NEBRASKA

			Age	Unit	Lithology	Hydrogeologic properties
CENOZOIC	QUAT.	Holocene	10 ka	Multiple stratigraphic units	Clay, silt, loess, glacial till, sand and gravel	Principal groundwater reservoir, is generally equivalent to High Plains Aquifer; Ogallala Group is absent in parts of eastern and northwestern Nebraska. Arikaree Group is present primarily in west.
		Pleistocene	1.8 Ma			
	TERTIARY	Pliocene	5 Ma			
		Miocene		Ogallala Group	Sand, sandstone, siltstone and some gravel	
			24 Ma	Arikaree Group	Sandstone and siltstone	
		Oligocene		White River Gr. / Brule Fm.	Siltstone, sandstone and clay in lower part	Secondary aquifer in western Nebraska; water may be highly mineralized.
		U. Eocene	34 Ma			
			65 Ma		*UNCONFORMITY*	
MESOZOIC	CRETACEOUS	UPPER CRET.		Lance and Fox Hills Fms.	Sandstone and siltstone	Generally not an aquifer; yields water to a few wells in western Nebraska.
				Pierre Shale Formation	Shale, some sandstone in west	Generally a confining unit; sandstones in west yield highly mineralized water to a few industrialized wells.
				Niobrara Fm.	Shaly chalk and limestone	Secondary aquifer where fractured and at shallow depths, primarily in east.
				Carlile Shale Formation	Shale; in some areas, contains sandstones in upper part	Generally not an aquifer; sandstones yield water to a few wells in northeast.
				Greenhorn and Graneros Fms.	Limestone and shale	Generally not an aquifer; yields water to a few wells in east.
		LOWER CRET.	98 Ma	Dakota Fm.	Sandstone and shale	Secondary aquifer; primarily in east; water may be highly mineralized.

Note: From Flowerday et al, 1998.

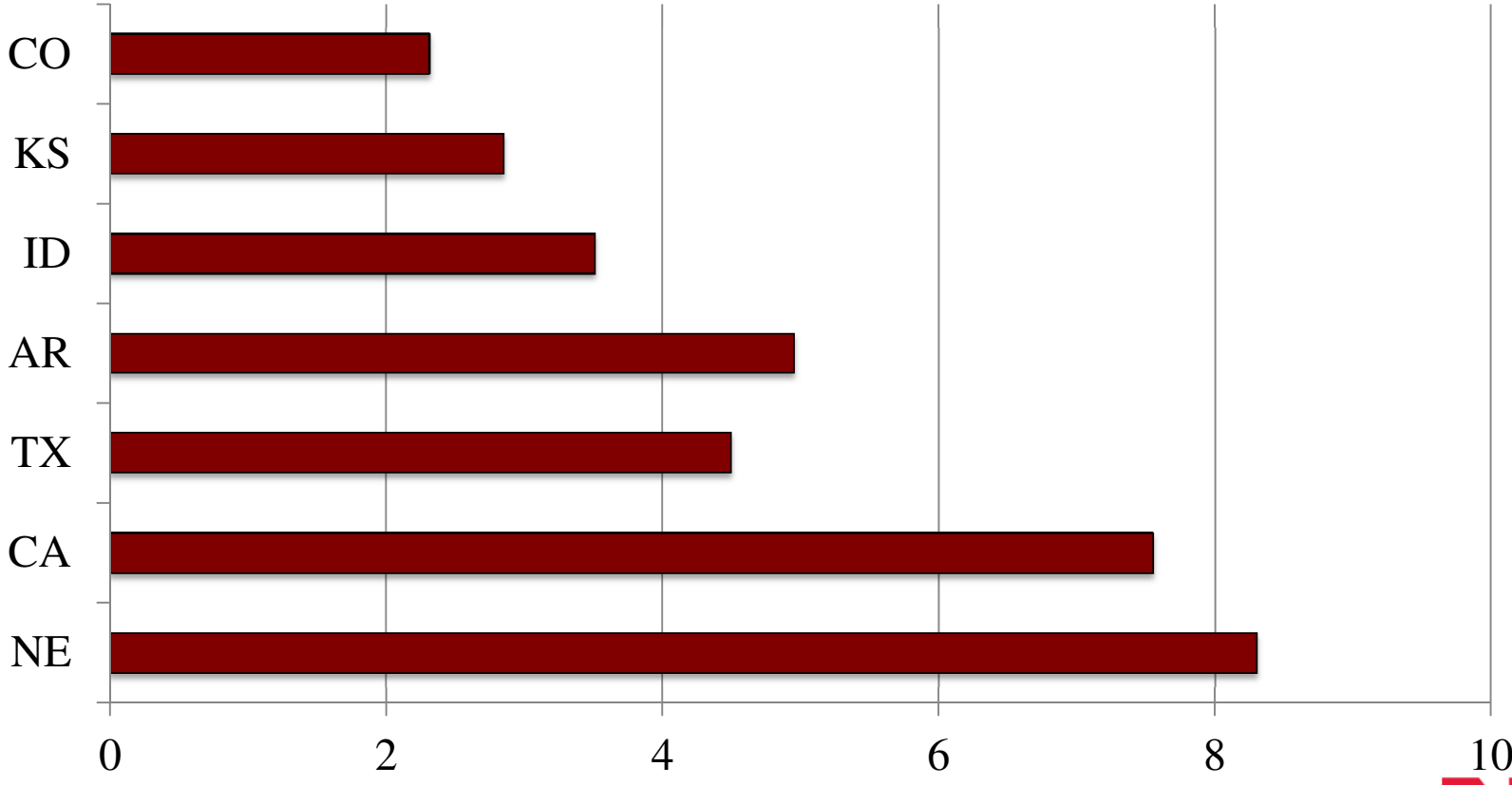
Density of Registered Irrigation Wells (2007)



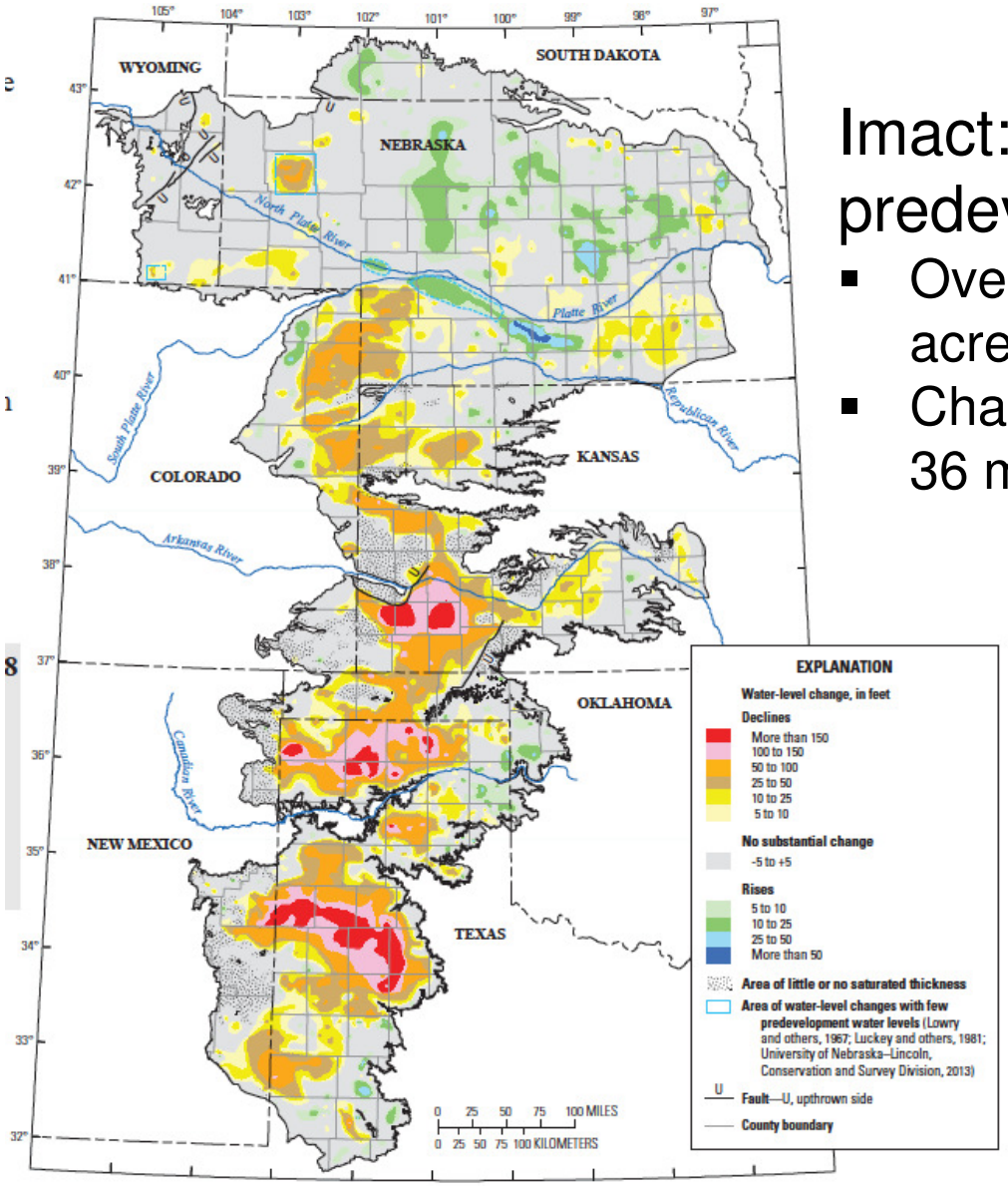
	Water Use	Active
●	Irrigation	96,148
●	Domestic	28,406
●	Livestock	18,793
●	Monitoring (groundwater quality)	16,897
●	Public Water Supply	3,036
●	Commercial/Industrial	1,715
●	Other	12,974
	TOTAL	177,969

Approximately 100, 000 registered wells

Top 5 states in total irrigation, acres (million acres)



USDA, 2012

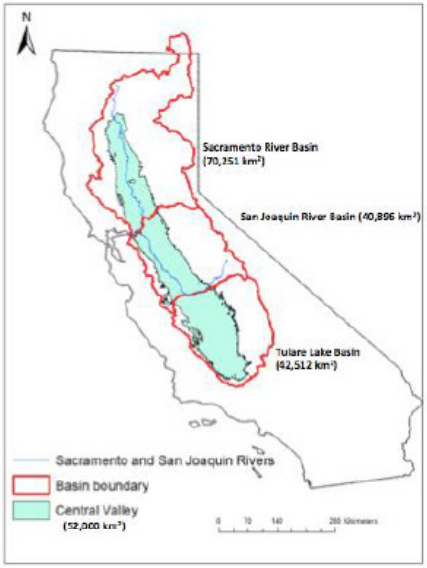


Water-level changes in the High Plains aquifer, predevelopment to 2013

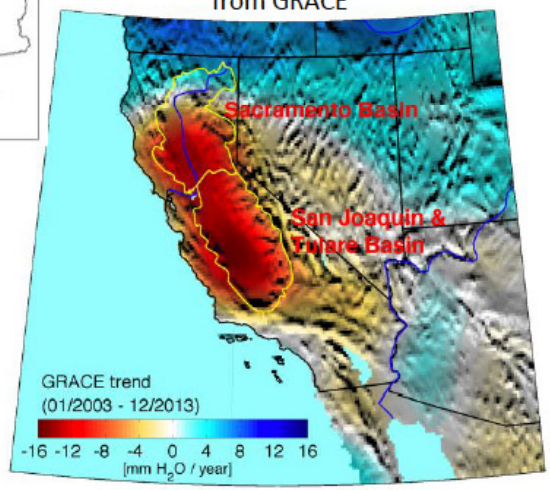
Imact: Water-level changes, predevelopment to 2013:

- Overall decline of 267 million acre-feet
- Change between 2011-13 was 36 million acre-feet

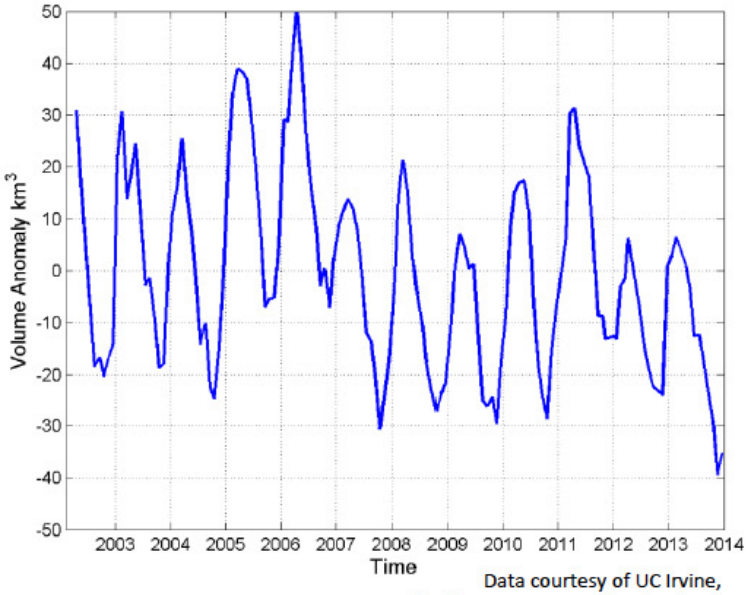
Total Water Storage Changes in the Sacramento-San Joaquin River Basins from the NASA GRACE Satellite Mission for March 2002- December 2013



Trend in total water storage from GRACE



Monthly changes in total water storage from GRACE



Data courtesy of UC Irvine, JPL/California Institute of Technology, National Center for Atmospheric Research, University of Texas, NASA

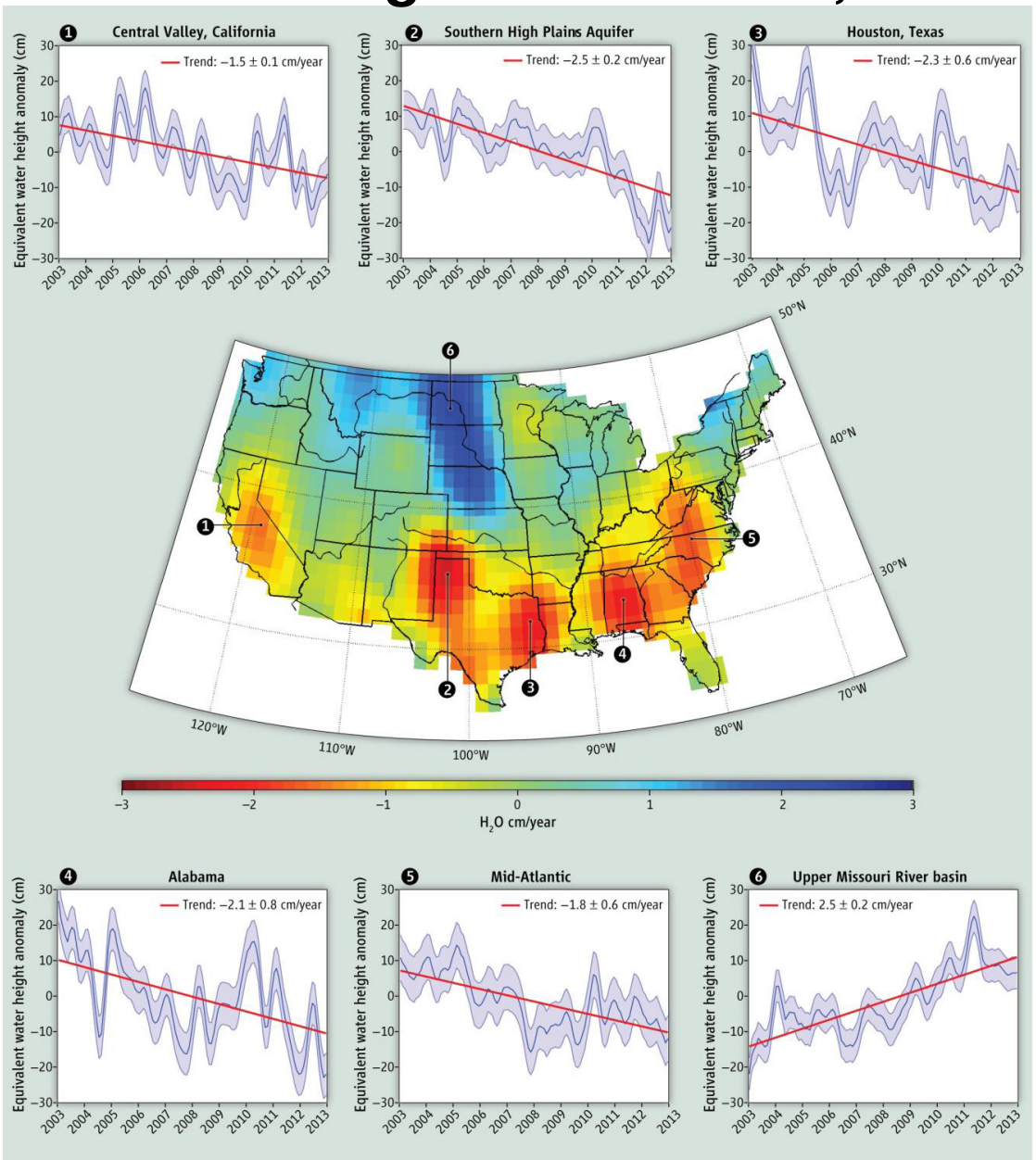
- Monthly changes in all of the snow, river and reservoir storage, soil water and groundwater combined.
- Lowest point since March 2002 is December 2013
- Decline over last 2 years of 25 km^3
- Longer term drought going back to 2006 or longer?

(Jay Famiglietti, 2015)

Famiglietti, 2015 LA Times Op-Ed

- Since 2011 CA has lost 12 million acre-feet of water
  - 2/3 of this is ground water
  - CA's 30 million people use 10 million acre-feet of water for domestic and municipal uses

Trends in Freshwater Storage from GRACE, 2003-2012

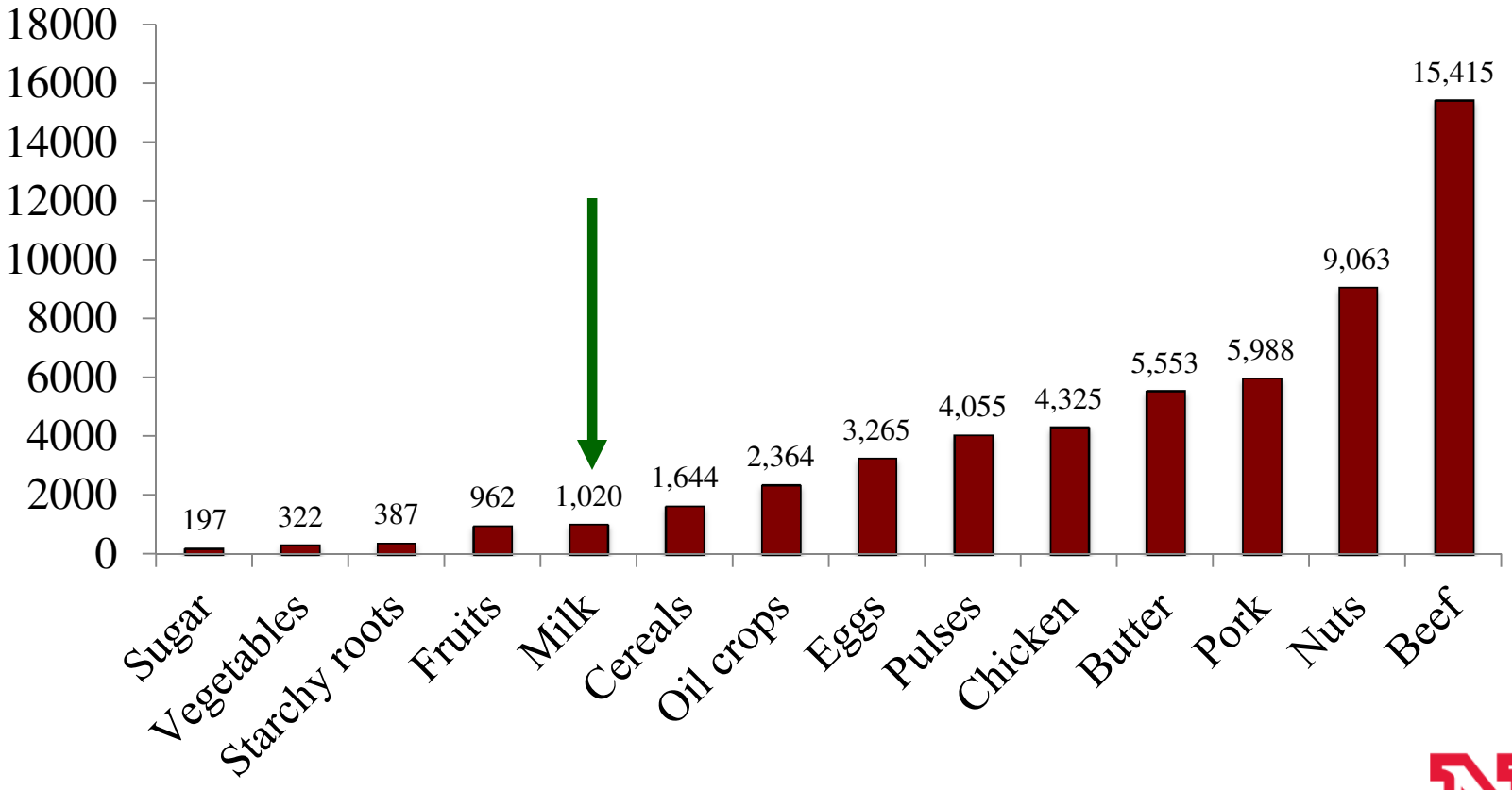


Famiglietti and Rodell, 2013

Famiglietti's messages

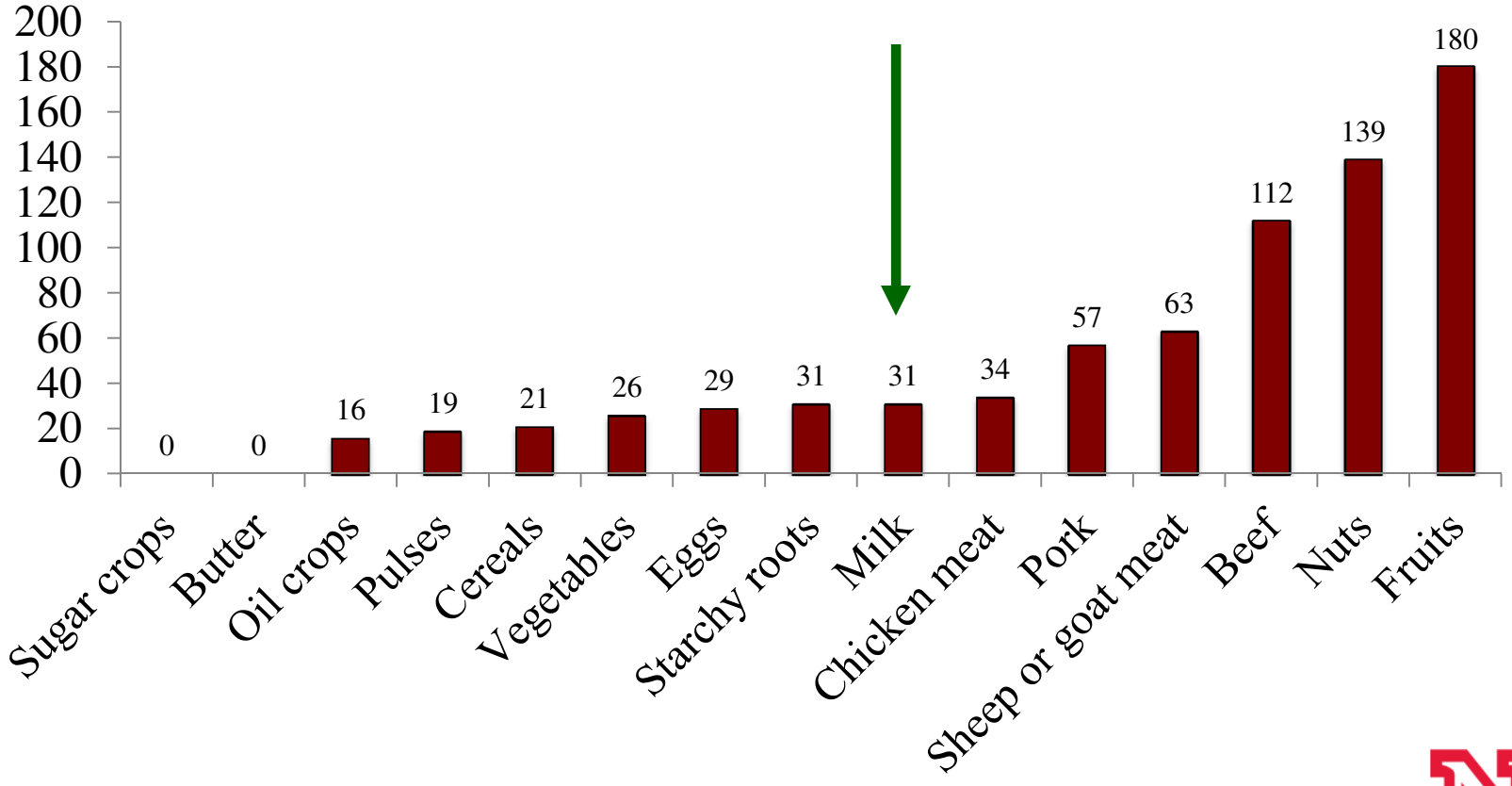
1. The *water cycle and water availability are changing*. Water availability will become progressively more strained, while increasing extremes like flooding and drought threaten both animal exposure and supply chains.
2. Everybody loves food so don't feel like you are a target. We need to *change the conversation* from urban vs. ag; farmer vs fish; growth vs environment, to "how can we produce the best/most using the least amount of water."
3. Clearly animal agriculture uses water and generated considerable waste disposal problems. No need to shy away from that because we need to eat and grow food. Rather take ownership, clearly articulate the issues, and become industry leaders and stewards; "***how can we raise the best product while having the smallest environmental impact***."

Global water footprint of food production, L/kg of product



Hoekstra, 2012

Global water footprint of food production, L/g protein

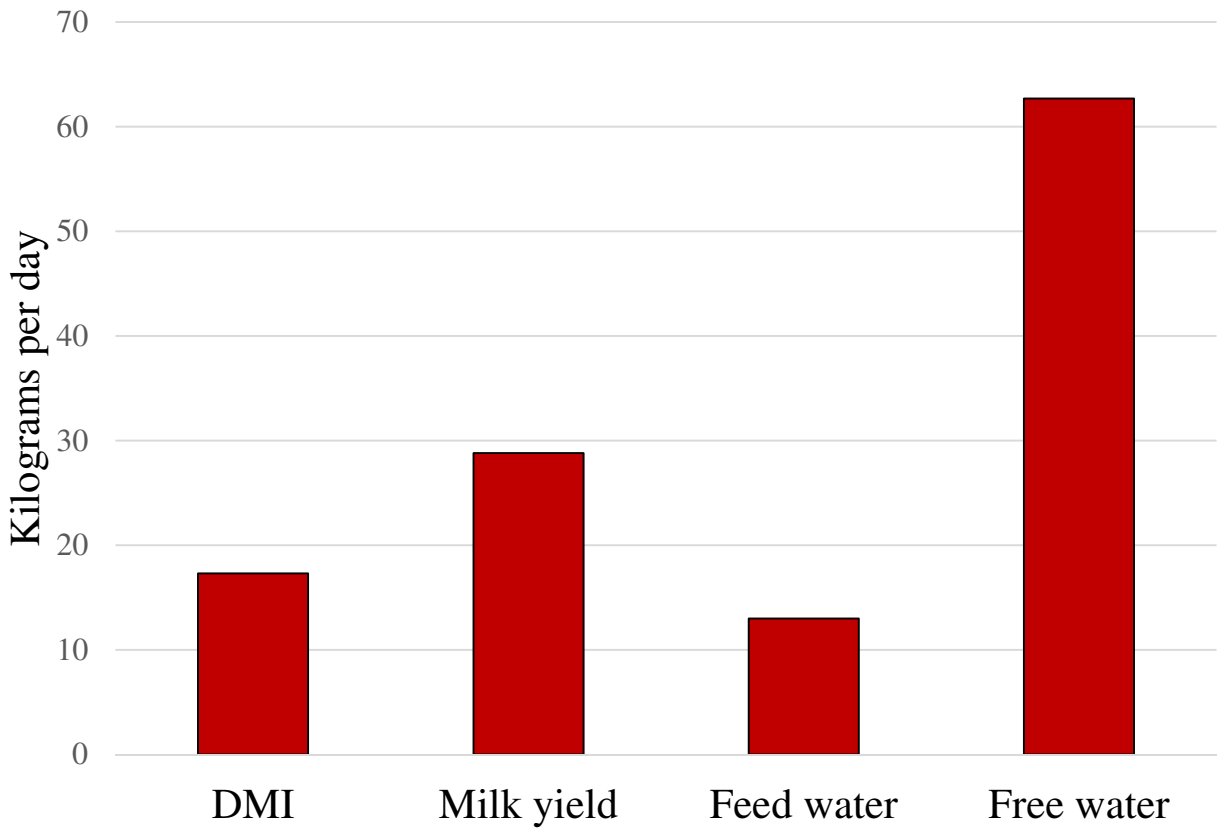


Hoekstra, 2012

% of water used for drinking

- For all livestock, drinking water accounts for 1.1 % of water needed
- It has been estimated that 1,020 kg of water are needed to produce 1 kg of milk
- Cows consume about 100 L of water each day or about 10 % of the total amount of water needed.
- Dairy farms use about 190 L of groundwater each day

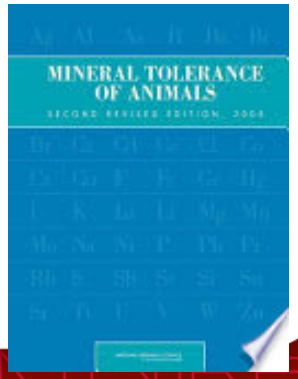
Water Intake and Dairy Cows



Khelil-Arfa et al., 2012

Water Quality

- Has been major analytical advancements
- Still information between intake and effects on animal is limited
- Differences in sensitivity across animals, poorly understood
- Good information of impacts of *livestock on water quality*, less on impacts of *water quality on livestock*



Good water

- Clear and colorless
- Low total solids
- No disease organisms, pesticides
- No undesirable flavor or odor
- No objectionable gases

Very Good Quality Water

	Agriculture Waters
Agriculture Waters	
pH	7.30
Electrical Conductivity	276 µS/cm at 25 C
Calcium	33.8 mg/L
Magnesium	6.38 mg/L
Sodium	1.94 mg/L
Potassium	16 mg/L
Sulfate (SO4)	1 mg/L
Nitrate and Nitrite - N	0.65 mg/L
Chloride	3.0 mg/L
Iron	0.59 mg/L
Manganese	0.165 mg/L
Total Dissolved Solids	177 mg/L
Hardness	110 mg/L as CaCO3
Comments:	

Slide courtesy of D.A. Christensen, U of S

Water testing…

- Forage tests, an indication of quality
- Water testing: pass or fail
- Why test:
  - Human safety
  - Animal safety
  - Animal production
  - Establishes a baseline

Water can be an important contributor of nutrients

	Finishing Steer	Lactating Cow
Water intake, L/day	60	90
Sodium Chloride		
% of Req., Ave. Water	35	19
Max Water	4,700	2,600
Calcium		
% of Req., Ave. Water	16	7
Max Water	49	28
Magnesium		
% of Req., Ave. Water	10	9
Max Water	91	88
Sulfur		
% of Req., Ave. Water	29	20
Max Water	719	507
Iron		
% of Req., Ave. Water	0	0
Max Water	29	21
Zinc		
% of Req., Ave. Water	2	1
Max Water	51	12

Sources of water quality guidelines

- EPA (U.S. Environmental Protection Agency). 2004. Drinking Water Contaminate List. Available at http://www.epa.gov/safewater.
- NRC, National Research Council
  - 1974. Nutrients and Toxic Substances in Water for Livestock and Poultry. Washington D.C.: National Academy Press.
  - 2001. Nutrient Requirements of Dairy Cattle, Seventh Edition. Washington D.C.: National Academy Press.
  - 2005. Mineral tolerance of animals, Second Edition. Washington D.C.: National Academy Press.
- Canadian Council of Ministers of the Environment (CCME). 2005. Canadian water quality guidelines for the protection of agricultural water uses.
- ANZECC, Australian and New Zealand Environment and Conservation Council. (2000)

Total Dissolved Solids (TDS), Salinity

- TDS is a measure of inorganic constituents but may include some organic compounds
  - Does not identify individual components
- The term “salinity” may be used synonyms with TDS
- Nature of TDS is influence by local geology

Makeup of TDS

- About 10 elements make up 99% of TDS: Hydrogen, sodium, potassium, magnesium, calcium, silicon, chlorine, oxygen, sulfur, carbon
- major ions and ionic compounds include: carbonate, bicarbonate, chloride, fluoride, sulfate, phosphate, nitrate, calcium, magnesium, sodium and potassium
- TDS alone is not enough to understand water quality, more or a "*pre-indicator*"

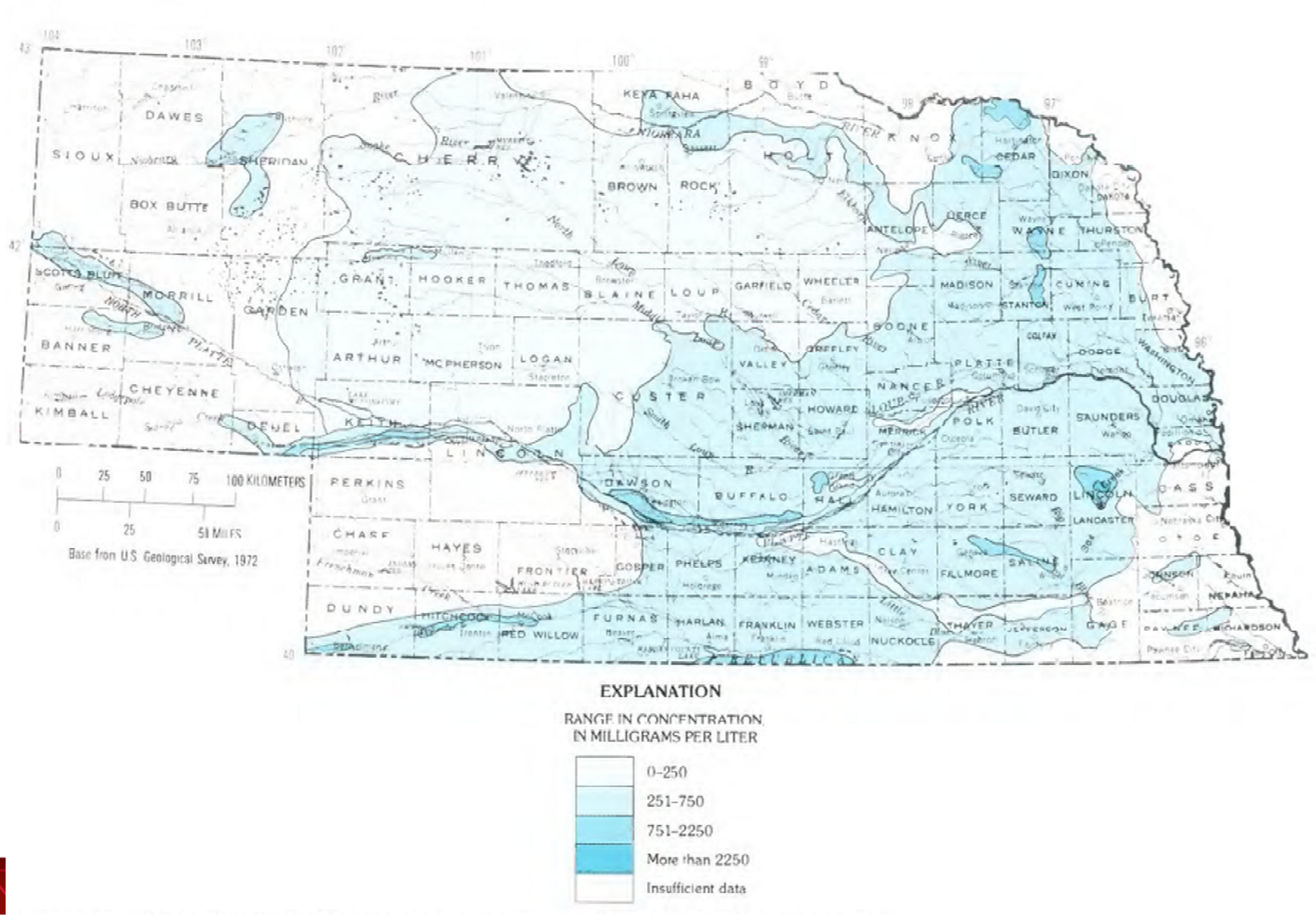
TDS Table 1 in handouts.

Table 1. Guidelines for Total Dissolved Solids (TDS) in water for dairy cattle consumption. In general TDS alone is not adequate to characterize drinking water of cattle and it is further suggested that specific salt components and bacteriological measures are also needed (adapted from Dairy NRC 2001).

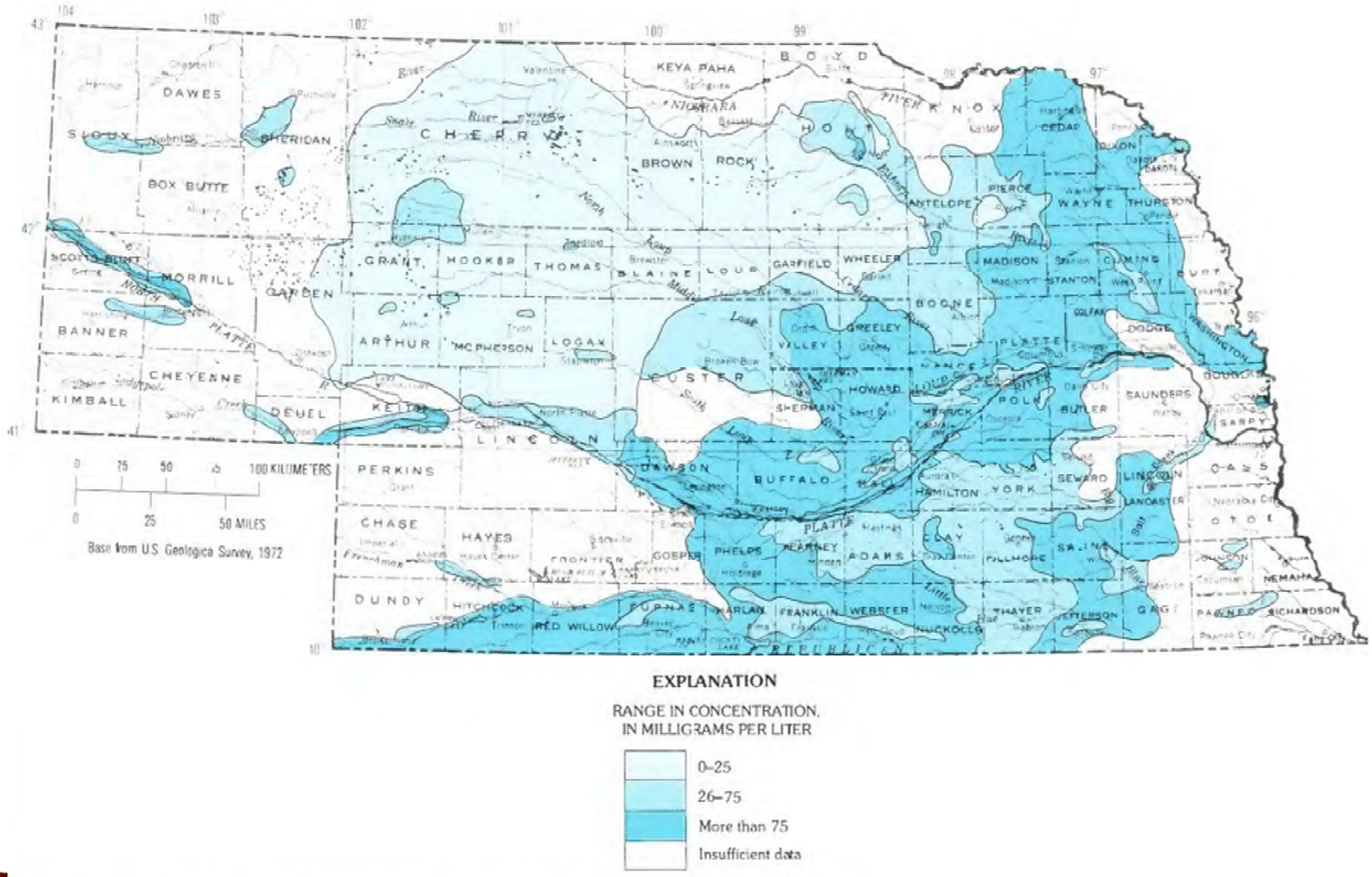
TDS (mg/L)	Comments
< 1000	Safe and should pose no health problems.
1,000- 2,999	Generally safe but may cause a mild temporary diarrhea in animals not accustomed to the water.
3,000 – 4,999	Water may be refused when first offered to animals or cause temporary diarrhea. Animal performance may be less than optimum because water intake is not maximized.
5,000 – 6,999	Avoid these waters for pregnant or lactating animals. May be offered with reasonable safety to animals where maximum performance is not required.
> 7000	These waters should not be fed to cattle. Health problems and/or poor production will result.

[1]Source NRC (1974)

Total Dissolved Solids (TDS)



Calcium, contributes to hardness



Hardness

- Estimate of “dissolved minerals” in water
- Total cationic effects of calcium and magnesium
  - May also include zinc, iron, strontium, aluminum, manganese
- Generally believed it *does not* affect FWI,
  - may affect accumulation of scale and negatively affect water delivery systems and cleaning efficiency of milking equipment (Elmpslemany et al., 2009)

Table 2 in handouts.

Table 2. Categories for water hardness (adapted from Dairy NRC 2001).

Category	**Hardness, mg/L**
Soft	0 - 60
Moderately Hard	61 – 120
Hard	121 – 180
Very Hard	> 180

[a] 1 grain/gal = 17.1 mg/L
[b] NRC, 1980

Ionic constituents of water

- Speciation: form of any given element in water
  - Hydrated ion, molecule, complex with additional ion or molecule
- Fresh water usually contains hydroxyl and carbonate complexes
- Reactivity and toxicity of minerals is dependent upon form
  - Mineral concentration is usually not enough

Sulfate

- Origin is usually sulfate bearing minerals (Gymsum) in soil and rocks but may come from household or industrial contamination.
- Negatively affects intake of water
- Common forms calcium, iron, magnesium, manganese, and sodium salts.
- Reduces availability of Ca, Zn, Fe, Mn, Mo and *may tie up Cu* (thiomolybdates)

Sulfate: recommendations

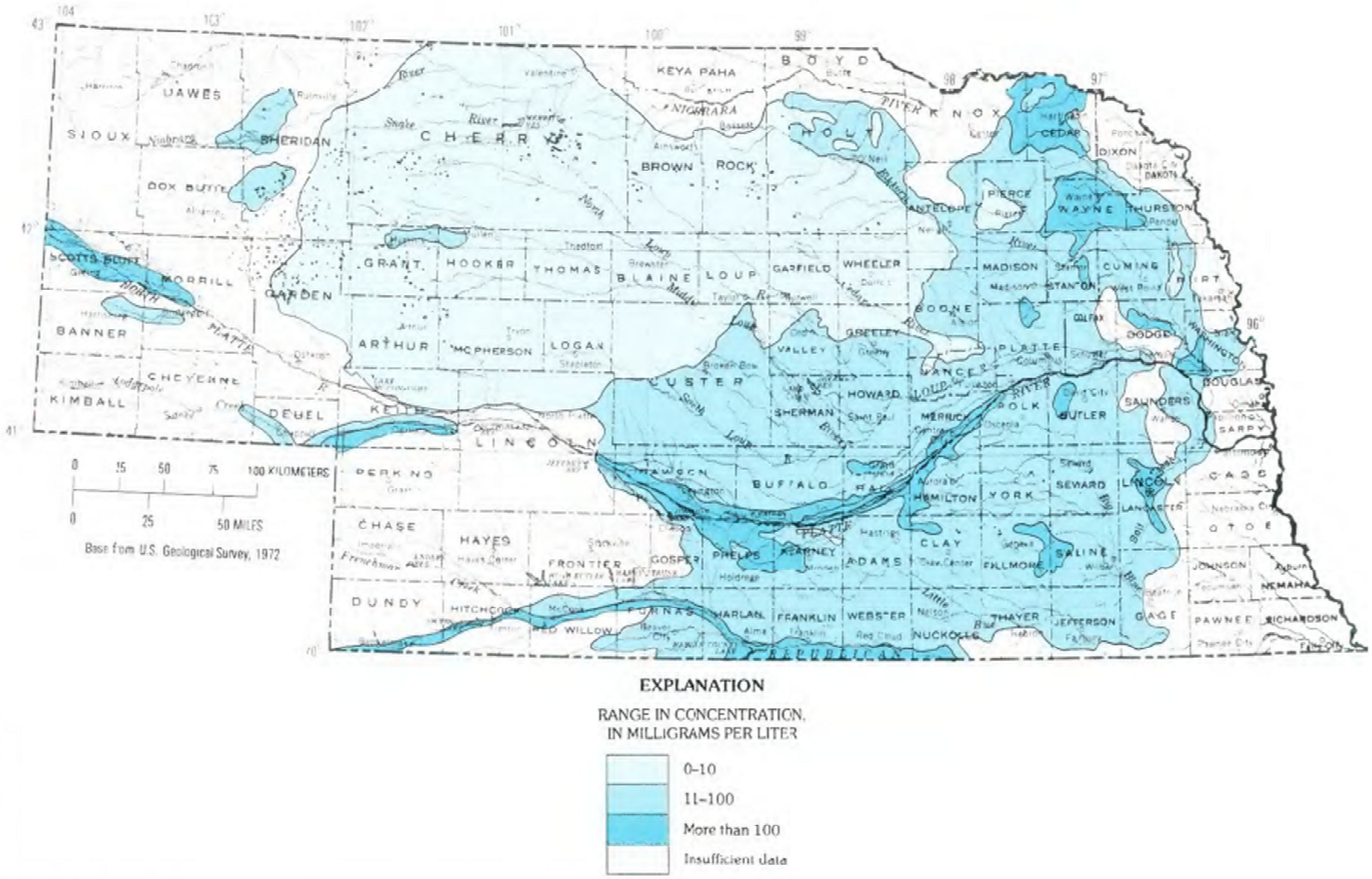
- When over 500 mg/L check for specific salt or sulfate
- High concentrations of sulfate (SO_4^{2-}) ions in drinking water may negatively affect both feed and water intake
  - Not exceed 500 mg/L and 1, 000 mg/L for calves and adult cows
  - Beef cattle on a high grain diet should be < 600 mg/L
  - If high provide additional trace minerals especially copper (chelate form?)

Sulfate, caution 250-500 mg/L

Beede (2006)

- If > 1000 mg/L careful evaluation should be conducted
- > 1200 mg/L may affect milk yield, Retained placentas and DA's
- sulfate + chloride > 500 mg/L may be problematic for fresh cows

Sulfate, caution 250-500 mg/L



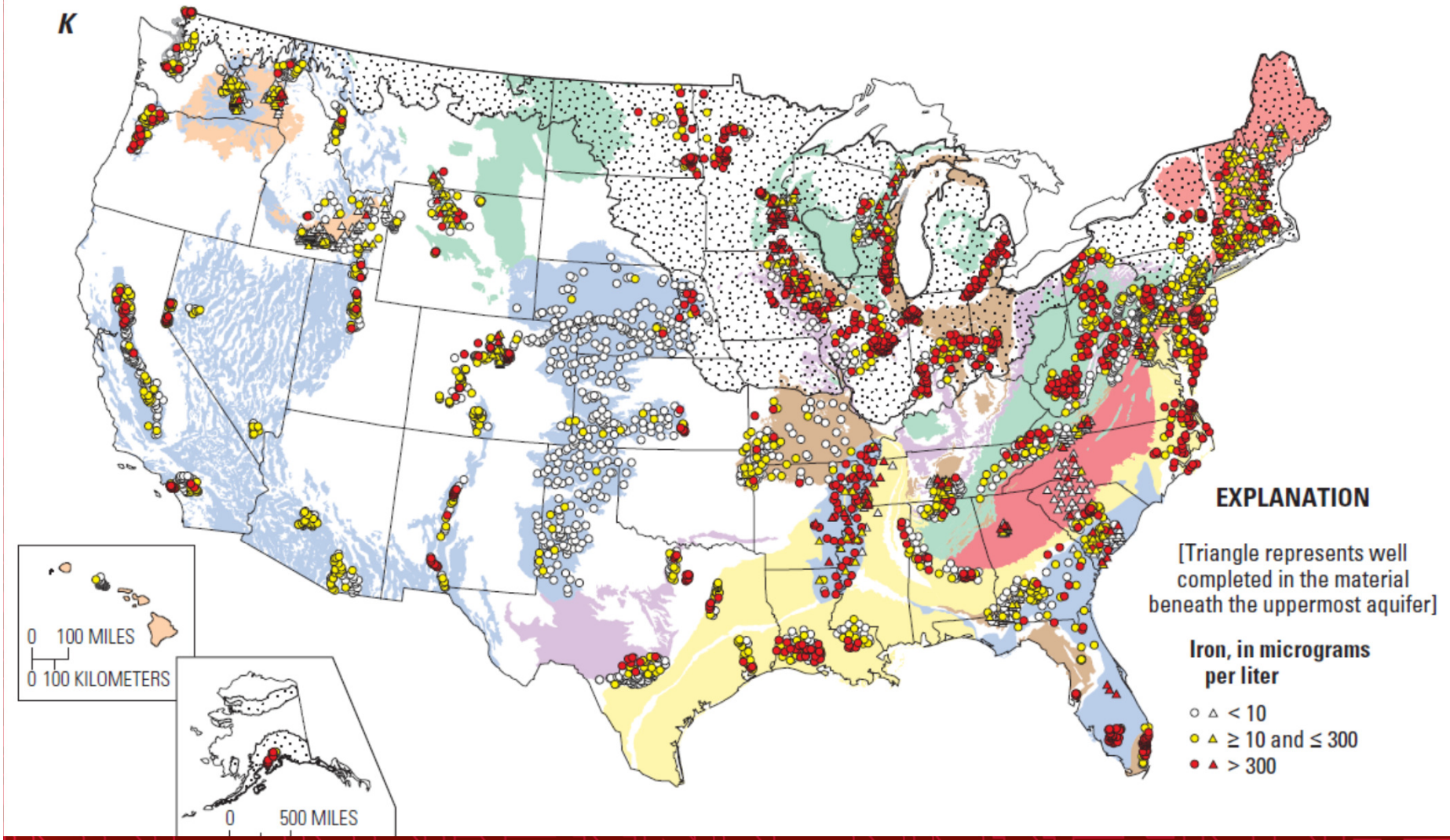
Iron

- easy to recognize, as the water appears rusty in color, contains sediment, and possesses a metallic taste
- may interact with Co, Cu, Mn, Se, and Zn, thus causing nutritional deficiencies in these essential nutrients
- consumption of high amounts of iron (250 – 1200 mg/L) from ferris carbonate is known to reduce the absorption of copper in mature cattle (Spears et al., 2003)

Iron

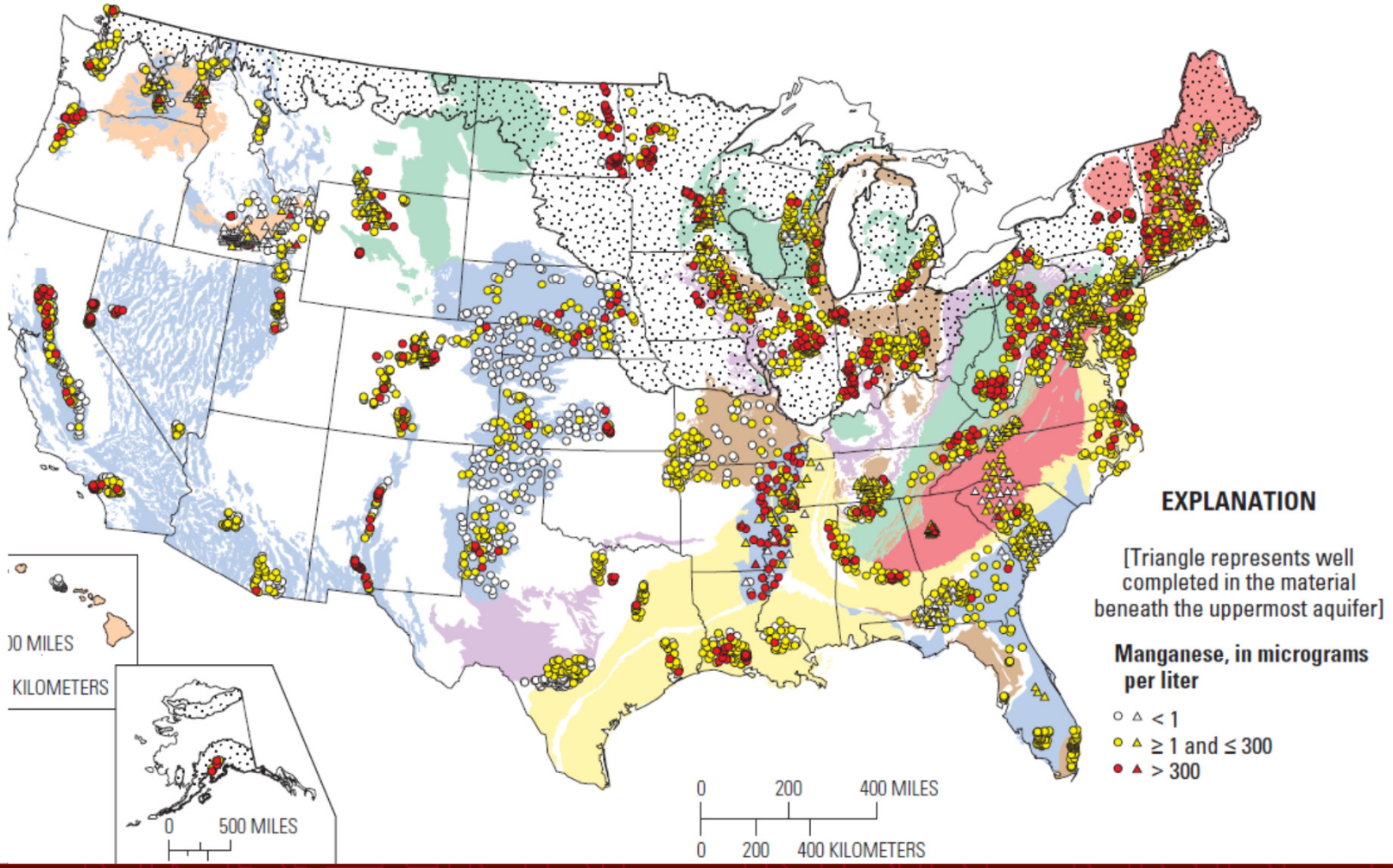
- High amounts of Fe^{+2} may result in high iron in blood
- May impair absorption of copper and zinc
- May result in oxidative stress
  - Warning on periparturient cows (compromised immune system)
  - Keep ration iron < 750 ppm, increase Vitamin E past 500 IU/d
- Caution level 0.30 mg/L

Iron, caution 0.3 mg/L



Manganese, caution 0.05 mg/L

Greatest impact is on taste and consumption



Arsenic

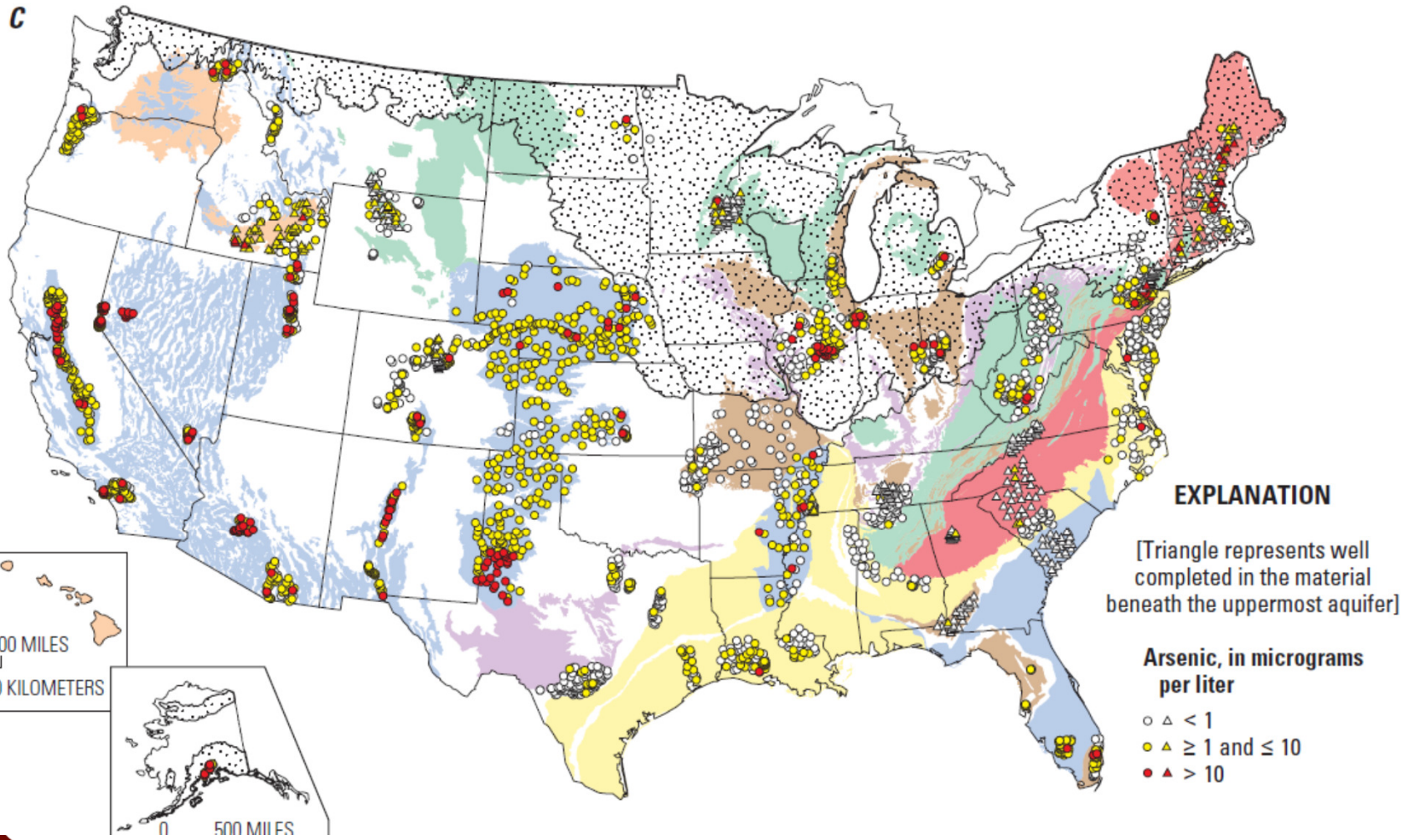
- Occurs naturally in soil and minerals and may enter the air, water, and land from wind-blown dust and may enter water from runoff and leaching.
- Arsenic cannot be destroyed in the environment.
- Arsenic is a known human carcinogen, shown to cause vascular disease, other chronic health issues

Arsenic

- Methods for removing arsenic from water include adsorptive media, reverse osmosis, distillation, and anion exchange.
- Problems expected at > 0.20 mg/L
- Appears to be excreted in urine (Liukkonen, 2007)

Well water As (ppb)	Urine As (ppb) Average of 5 cows	Stnd Dev.
< 10	16	4
46	54	20
76	74	36
113	137	38

Arsenic


C
0 100 MILES
0 100 KILOMETERS
0 500 MILES
EXPLANATION
[Triangle represents well completed in the material beneath the uppermost aquifer]
Arsenic, in micrograms per liter
< 1
≥ 1 and ≤ 10
> 10

Great Plains Research 16 (Fall 2006):137-48
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ARSENIC IN GROUNDWATER AND RURAL PUBLIC WATER SUPPLIES IN NEBRASKA, U.S.A.

David C. Gosselin, Lynne M. Klawer, R.M. Joeckel, F. Edwin Harvey, Angela R. Reade, and **Kevin McVey**

Region	Region name	Average (µg/L)	Range (µg/L)	Number of samples	Percentage of samples >10 µg/L
1	Sandhills	7.0	<1.0-18.0	75	25
2	Platte River Valley	5.4	<1.0-59.0	210	7
3	Missouri River Lowland	4.8	1.0-13.0	8	25
4	South-Central Plains	3.3	<1.0-11.0	85	5
5	Southwestern Tableland	11.4	5.0-39.0	9	33
6	Northern Panhandle Tableland	5.1	<1.0-11.0	28	7
7	Southern Panhandle Tableland	7.3	2.0-18.0	31	19
8	East-Central Dissected Plains	6.3	1.0-17.0	20	20
9	Republican River Valley	8.7	3.0-14.0	12	42
10	Northeast Nebraska Glacial Drift	1.7	<1.0-5.0	19	0
11	Southeast Nebraska Glacial Drift	2.7	<1.0-12.0	31	3
12	North-Central Tableland	3.5	1.0-7.0	6	0
13	Hat Creek-White River Drainage	No USGS Samples			

Nitrate

- Nitrate (NO_3^-) presence in the drinking water may be a result of industrial pollution, heavy fertilization of fields or may be associated with shallow wells
- In the case of acute toxicosis, nitrite may be absorbed into the bloodstream, which triggers oxidation of the ferrus iron in haemoglobin to form methemoglobin. This reaction reduces the oxygen carrying capacity of blood and may cause asphyxiation

Nitrate

- In dairy cows, nitrate concentrations up to 180 mg/L in drinking water did not increase the concentration of nitrate in milk (Kammerer et al. 1992).
- More recently, in a survey of 128 Iowa dairy farms, an elevation in the nitrate concentration of drinking water was correlated with increasing calving intervals (Ensley, 2000).

Table 4 in handouts.

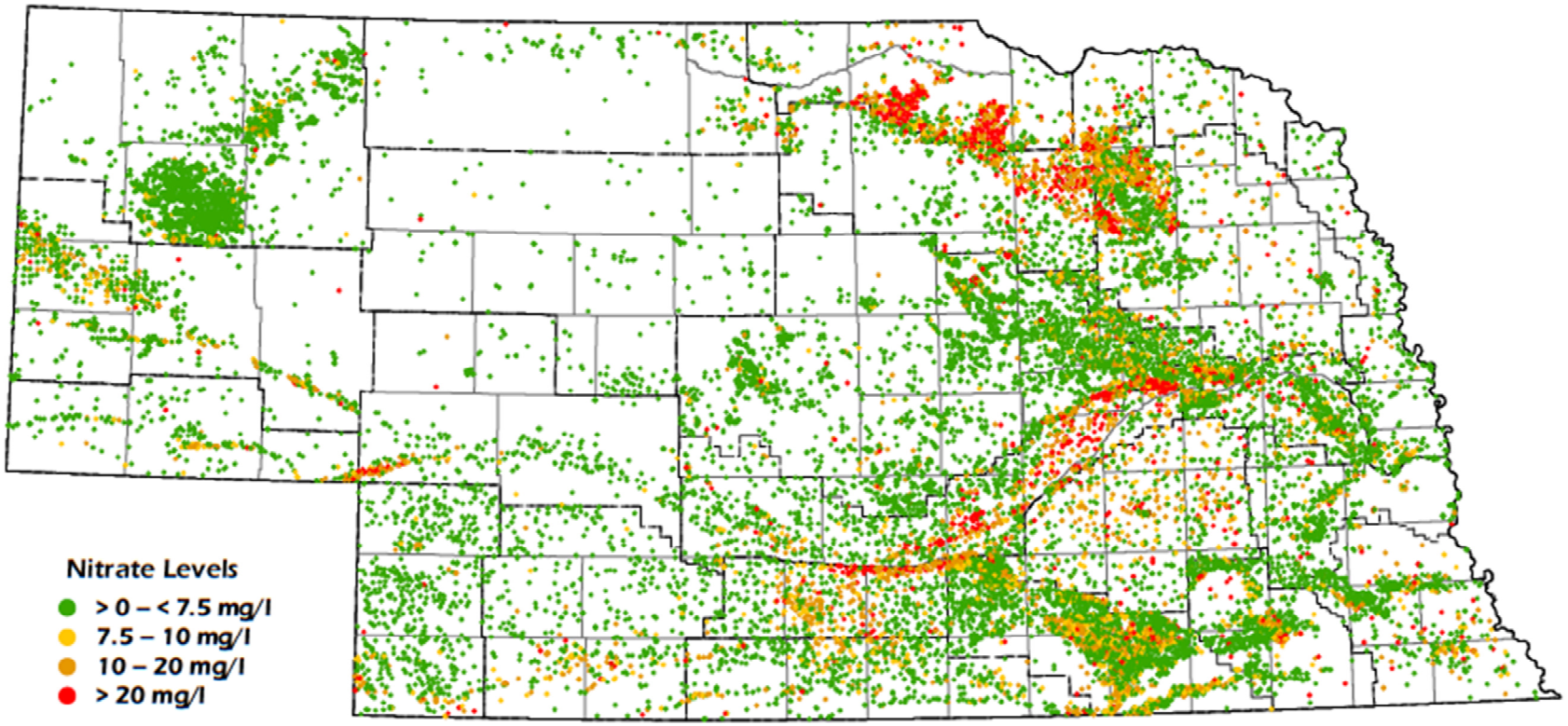
Table 4. Basic guidelines[1] for nitrate (NO_3^-) and nitrate nitrogen (NO_3-N) in drinking water[2] for dairy cattle (adapted from Dairy NRC 2001)

Nitrate (NO_3^-)	Nitrate Nitrogen (NO_3-N)	Guidelines
0 – 44	0 – 10	Safe for consumption by cattle
45 – 132	10 -20	Generally safe when offered with balanced diets with low nitrate feeds
133 – 220	20 – 40	May be harmful if consumed for long periods of time
221 -660	40 – 100	Cattle at risk and possible death
> 660	>100	Unsafe-possible death; do not use as water source

[1] NRC, 1974

[2] nitrate nitrogen (NO_3-N) × 4.43 = nitrate (NO_3^-)

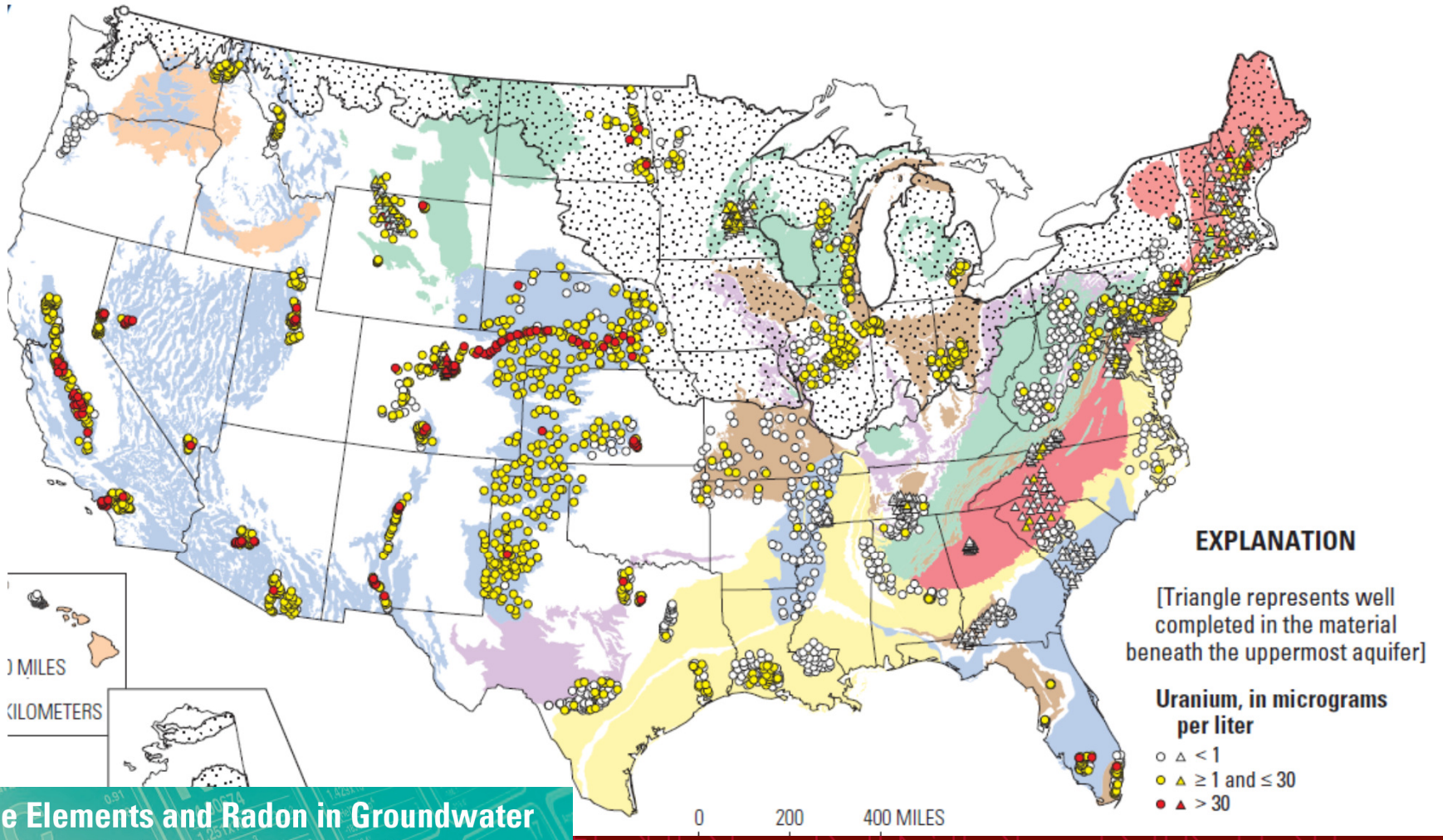
Nitrate, caution 20 mg/L NO3-N



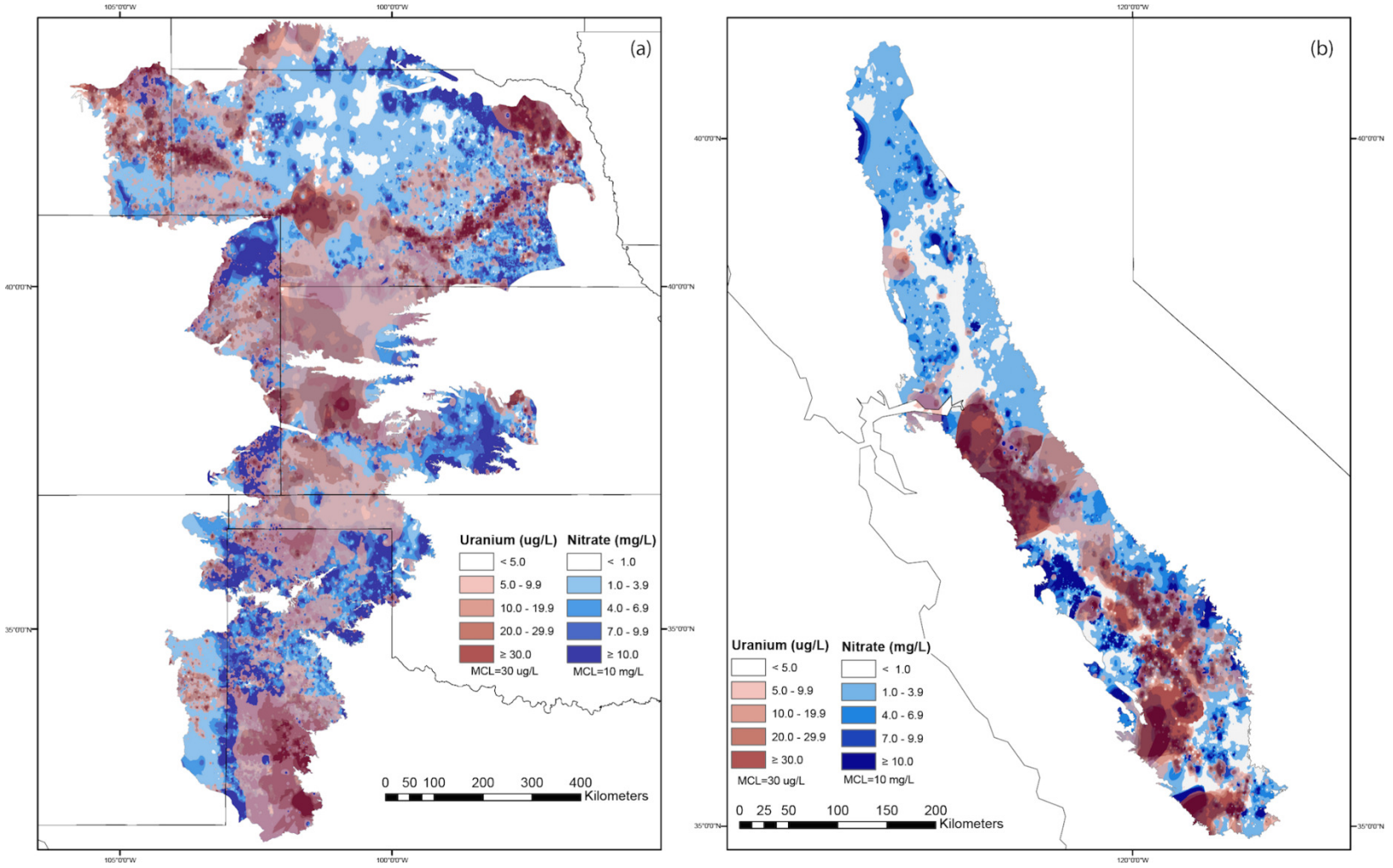
Uranium

- Most drinking water sources have very low levels of uranium if shallow wells.
- Most uranium is naturally occurring, although contamination of drinking water sources from human-made nuclear materials can also occur.
- Nitrates, carbonates, iron, increasing pH, increasing water velocity all contribute to increased biological activity in the aquifer
- MCL 30 ug/L

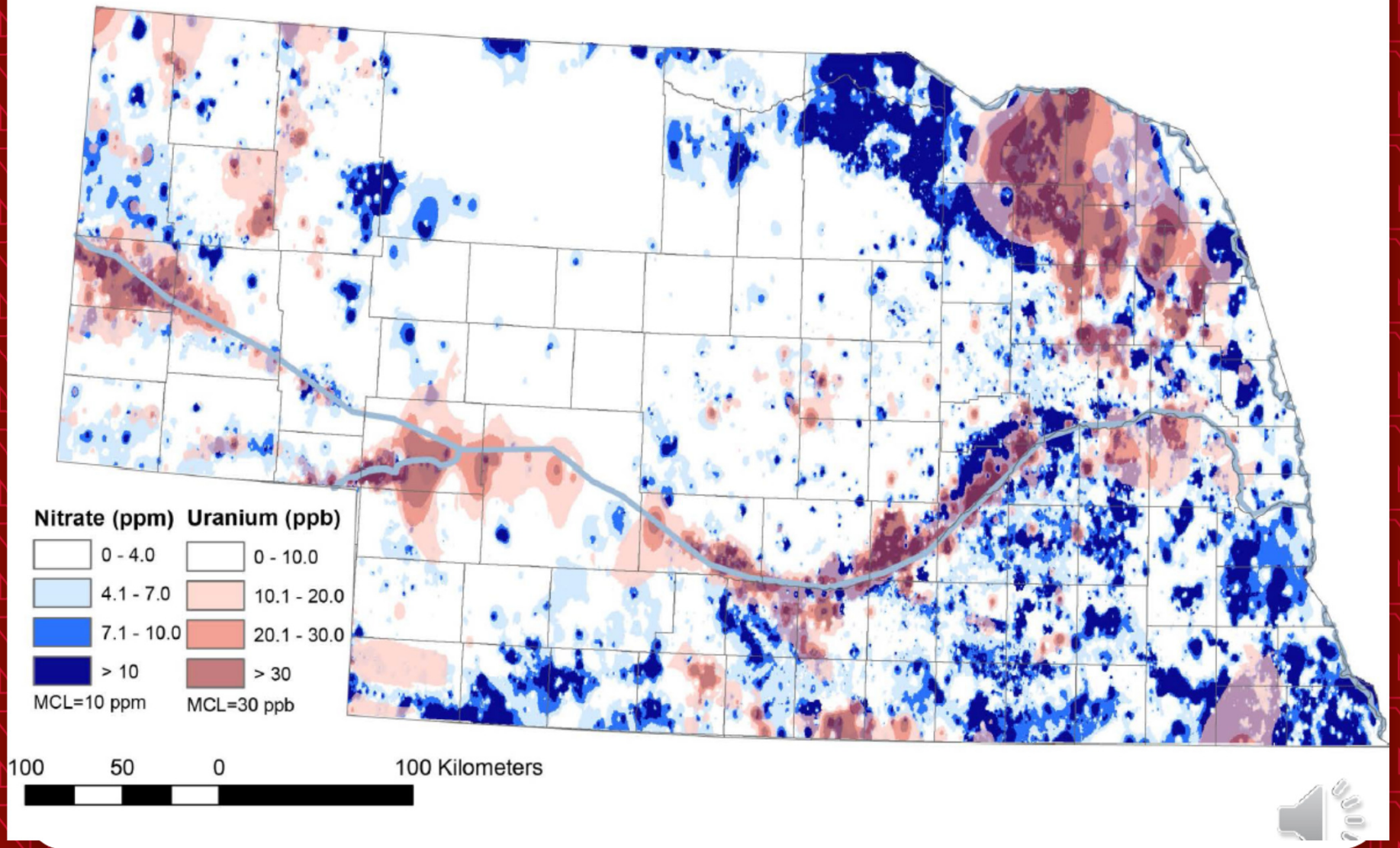
Uranium



Trace Elements and Radon in Groundwater Across the United States, 1992–2003


(a)
105°0'0"W
100°0'0"W
40°0'0"N
35°0'0"N
Uranium (ug/L)
< 5.0
5.0 - 9.9
10.0 - 19.9
20.0 - 29.9
≥ 30.0
MCL=30 ug/L
Nitrate (mg/L)
< 1.0
1.0 - 3.9
4.0 - 6.9
7.0 - 9.9
≥ 10.0
MCL=10 mg/L
0 50 100 200 300 400
Kilometers
(b)
120°0'0"W
40°0'0"N
35°0'0"N
Uranium (ug/L)
< 5.0
5.0 - 9.9
10.0 - 19.9
20.0 - 29.9
≥ 30.0
MCL=30 ug/L
Nitrate (mg/L)
< 1.0
1.0 - 3.9
4.0 - 6.9
7.0 - 9.9
≥ 10.0
MCL=10 mg/L
0 25 50 100 150 200
Kilometers

Nitrate and Uranium in Nebraska Groundwater



Microbiological considerations

- Common bacteria known to be found in contaminated water include enteric bacteria *Escherichia coli* and *Salmonella*, *Campylobacter jejuni*, *C coli*, *Yersinia enterocolitica*, *Y pseudotuberculosis*, *Leptospira*, *Burkholderia pseudomallei*, *Clostridium botulinum*, *Mycobacteria* (pulmonary disease), *Pseudomonas Cyanobacteria*, *Cryptosporidum*, and *Giardia* (ANZECC, 2000).

Microbiological considerations

- Water is frequently tested for the presence of thermotolerant (fecal) coliforms; however, test provides no indication of the presence of microbial pathogens (ANZECC, 2000).
- In a study of involving feedlot cattle, Sanderson et al (2005) observed no relationship between water coliform count and fecal prevalence of *E. coli* O157, would not support the water coliform counts as a measure of E. coli O157 exposure

Microbiological considerations

- median threshold for thermotolerant (fecal) coliforms for livestock has been recommended to be 100 thermotolerant (fecal) coliforms/100 mL (ANZECC, 2000).

Biofilm formation

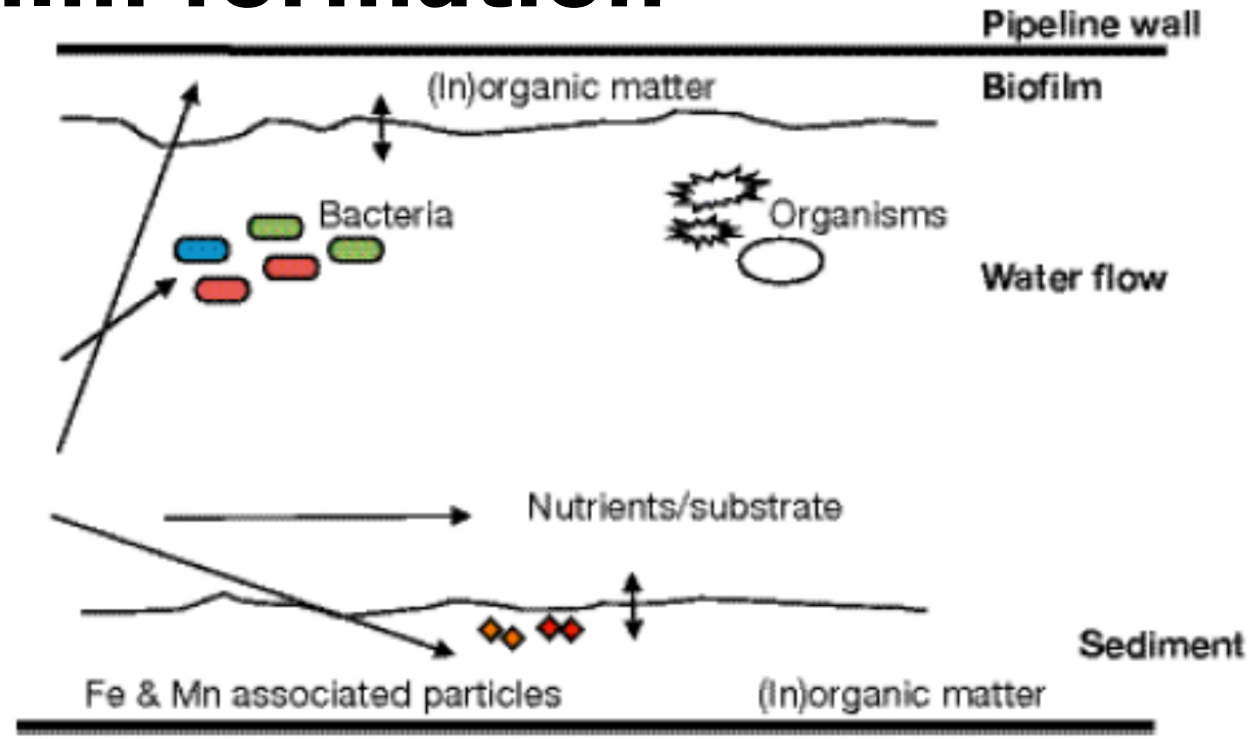


Fig. 1. Schematic view of the dynamic components in a water pipeline, with the formation of biofilm and sediment (after van de Kooij, 104).

(Van Eenige et al., 2013)

Fig. 2. Sediment in a deep, open water trough for cattle

(Van Eenige et al., 2013)

Fig. 3. a & b. Sedimentation and biofilm in water distribution pipelines on a dairy farm.

(Van Eenige et al., 2013)

Fig. 5. A common rectangular open water trough for cattle.

(Van Eenige et al., 2013)

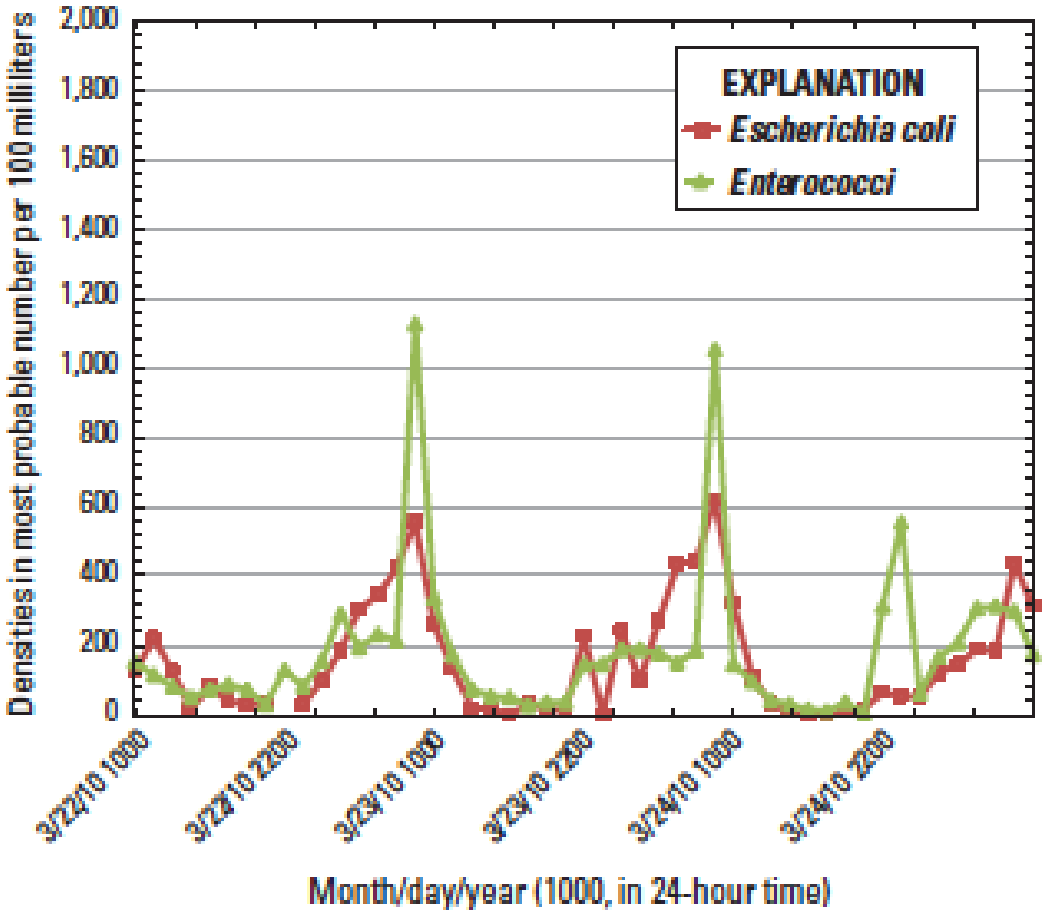


Figure 2. *Escherichia coli* and *Enterococci* densities (in most probable number per 100 milliliters) during March 22–25, 2010, near Grand Island, Nebraska (Vogel and others, 2013).

Be aware

- Understand where your water is coming from, depth, pump setting, screen
- Know is there are naturally occurring contaminated or water quality issues
- Ask questions
- Sample your well

Social Dimensions of Private Well Testing: Why Don't People Test their Water?

- When people who hadn't tested their water were asked, *"Why haven't you tested water from your well?"* the top ten reasons they gave were ...

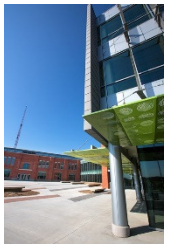
1. We've been drinking it for years – 53%
2. Didn't know what to test for – 41%
3. Don't know how to test – 35%
4. It's probably fine – 25%
5. Didn't know I should test it – 17%
6. Testing costs too much– 17%
7. I'll Wait for others to find problems – 12%
8. Dealing with problem would be to costly - 12%
9. Missed the testing program – 8%
10. I don't want to know – 8%

Liukkone, 2007

Conclusions

- Water will continue to challenge the global dairy industry.
- Availability and quality related to many factors.
- Other related areas, not covered here
  - Water treatment
  - Water access

Resources Available



- Nebraska Water Center

  http://unlcms.unl.edu/ianr/water-for-food/nebraska-water-center/

- Check out UNL's NebGuides on water treatment methods, contaminants, etc

- UNL Water Sciences Laboratory

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