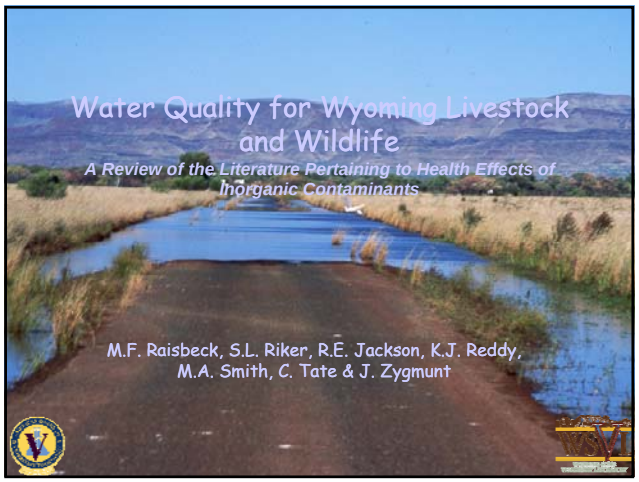


Water's Role in Physiology & Health

- *The* most essential nutrient in terrestrial animals
  - Loss of 10-20% body water is fatal
  - Most large mammals cannot survive more than 2-3 days without water
- Universal solvent
  - Uptake, transport and distribution of nutrients throughout the body
  - Transport and elimination of metabolic wastes, "toxins", etc.

Water's Role in Physiology & Health

- Heating & cooling
  - Heat transfer throughout body
  - Buffering temperature swings
  - Evaporative cooling
- Highly polar, non-ionic molecule
  - Basis of physico-chemical environment that permits most biochemical reactions
- Sources
  - Metabolism
  - Feedstuffs
  - *Drinking water*

Water Quality

- *" The physical, chemical and biological characteristics of water in relationship to a set of standards."*
  - -Ideal quality = "pure" H_2O
    - •All solutes subtract from "quality"
- •*Measurement* is based upon a variety of *chemical* tests which do not directly correlate with physiology or animal health

Effects on Animal Health

- Decreased Production ($$$)
  - Death
  - Health
  - Reproduction
  - Gain
  - Efficiency
- Secondary problems for human consumers (residues)

Factors that Affect Toxicity

- Water consumption
  - Ambient temperature, diet, lactation, etc.
- Species
- Ancillary dietary factors
  - Most waterborne toxicants are additive with the same element in dry feedstuffs
  - Antagonists/synergists
- Age, sex
- Individual variation

Historical

- *NRC '72*
- *CCREM '87*
- *ANZEC 2000*
- *Extension websites*

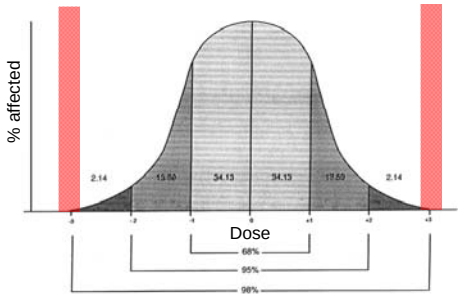
Objective

- A thorough review of the biomedical literature re: water quality for the classes of livestock and economically important wildlife species common in Wyoming.

The "Team"

- Raisbeck *Toxicology*
- Reddy *Water Chemistry*
- Smith *Range Science*
- Tate *Wildlife Medicine & Ecology*
- Zygmunt *WYDEQ*
- Riker *BS ANVS*
- Jackson *PhD Water Chemistry*

Risk Assessment



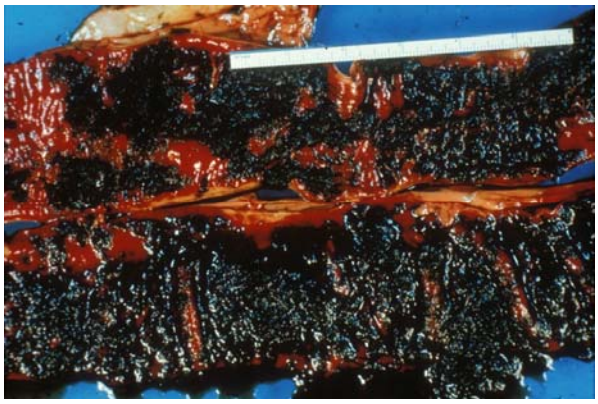
"Safety" Factors

- Uncertainty factor (UF) – *A judgmental factor used to compensate for the uncertainties inherent in experimental data*
  - 10X – 2 or more *controlled, chronic* experiments in the same species and supported by data in other species
  - 100X – 2 or more *controlled, chronic* experiments in a different species
  - 1000X – anecdotal (field) data only
  - Add 10X when limit is based upon LOAEL rather than NOAEL

From NAS, CCME, EPA

Arsenic

- Sources
  - Industrial, agricultural, mining, drugs
  - Natural
- Two oxidation states (As^{III} and As^{V})
  - Both occur naturally in water
  - As^{III} considered more toxic than As^{V}



Human

- "Blackfoot" disease
- Cardiovascular disease
- Diabetes mellitus
- Spontaneous abortion
- Cancer
- Potable water action limit dropped from 50 to 10 ppb – EPA, 2006

Wilson, 2001

Residues

www.extension.umn.edu

- "If dairy cows drink water containing high levels of arsenic, will milk be contaminated?"
- Dairy cattle, fed naturally contaminated water (<140 ppb As)
  - Urine concentration corresponded with water concentration
  - No detectable As in milk, cheese, nor edible tissues except (possibly) kidney

Arsenic

- Threshold toxic dose in domestic ruminants = 1-2 mg/kg BW
  - agrees with NRC recommendation of 30-50 ppm *dietary* As as Max Tolerated dose
  - EU recommendation = 2 ppm dietary As – couldn't find any justification
- No good quantitative data in horses, but other, non-rodent species seemed to be quantitatively similar to cattle
- Limited data in wildlife suggest similar to cattle
- Assuming negligible forage concentrations and a NOAEL of 0.5 mg/kg, 1 ppm should protect under "worst" case conditions

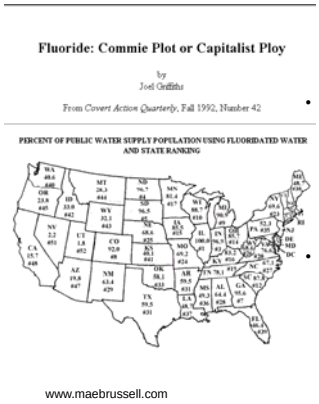
Barium

- Sources
  - Predominately natural
  - Drilling muds
- Forms
  - Barite ($BaSO_4$) – insoluble below pH 9.3
  - Witherite ($BaCO_3$) – intermediate sol.
  - $BaCl_2$ – most soluble, most toxic

Barium

- Acute toxic effects due to passive K^+ channel blockade in myocardium by Ba^{++} ion
  - Nervous & cardiac malfunctions in lab animals, people
  - Chronic effects *seem* to be related to repeated, subclinical, acute insults
- Limited data in ruminants suggests similar acute toxic mechanism(s)
- Dose data
  - Reagor et al (2005) – 69 mg Ba/kg BW ($BaCO_3$) NOAEL
  - Richards et al (2006) – 2.2 mg/L in water lethal to cattle
  - Ram et al (1999) – 4.6 mg/kg BW ($BaCl_2$) lethal in goats
- Interim recommendation 10 ppm

Fluoride


Fluoride: Commie Plot or Capitalist Ploy

by
Joel Griffiths

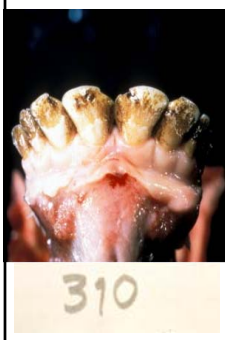
From *Covert Action Quarterly*, Fall 1992, Number 42

PERCENT OF PUBLIC WATER SUPPLY POPULATION USING FLUORIDATED WATER AND STATE RANKING

www.maebrussell.com

- Sources
  - Mining, aluminum smelting, water treatment, phosphate supplements
  - Natural deposits in NW Wyoming – wells, geothermal
- Toxicity
  - Interferes with electrical activity of heart, brain
  - Corrosive (HF)
  - Interferes with calcification of bone, teeth

Clinical Effects



- High dose
  - Gastroenteritis
  - Cardiac arrythmias
  - Kidney damage
  - Neurologic damage
  - Reproductive failure
- Low (realistic, natural) dose
  - Tooth & bone deformities
  - Sensitive life stage = periods of rapid calcification
    - Sporadic exposure more toxic than equivalent dose given continuously

Fluoride

- Most sensitive = dairy heifers
  - Wild ruminants approximately equally sensitive
  - Horses ???
- Dietary and water Fl^- are additive
  - Summary LOAEL from papers reviewed = 1 mg Fl^-/kg BW
- Assuming forage 10 ppm Fl^-, 3.75 ppm Fl^- in water would provide the minimum toxic dose
  - Should be adjusted for forage

Molybdenum

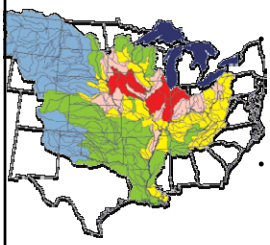
- Sources
  - Industrial, mining
  - "Black shales"
  - Predominately MoO_4^{2-} ion in natural waters
- Toxic Effects
  - Direct effects upon GI tract, muscle, skeleton and nervous system
  - Antimetabolite (Cu)
    - Immune suppression, reproductive failure, poor gain

Kubota, 1975

Molybdenum (summary)

- Most sensitive species = cattle
- Forage & water sources are additive
- Anti-metabolite effects are dependent upon total dietary Cu:Mo ratio (<4 is toxic)
  - If high Mo soils or marginal Cu diets, *any* additional Mo from water is hazardous
  - Assuming "normal" (7 ppm) Cu forages (or good supplementation) & < 1 ppm Mo from dry matter, water containing more than 375 ppb Mo would exceed toxic ratio.

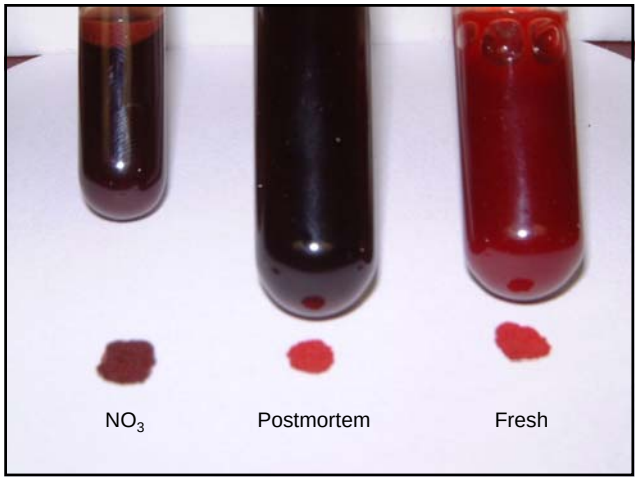
Nitrate & Nitrite



ks.water.usgs.gov

Two chemical forms - NO_2 & NO_3
- Natural
- Agriculture

- "Blue baby syndrome"
  - Gastrointestinal conversion of $NO_3 \rightarrow NO_2$
  - NO_2 oxidizes hemoglobin iron from $Fe^{2+} \rightarrow Fe^{3+}$



Clinical Effects

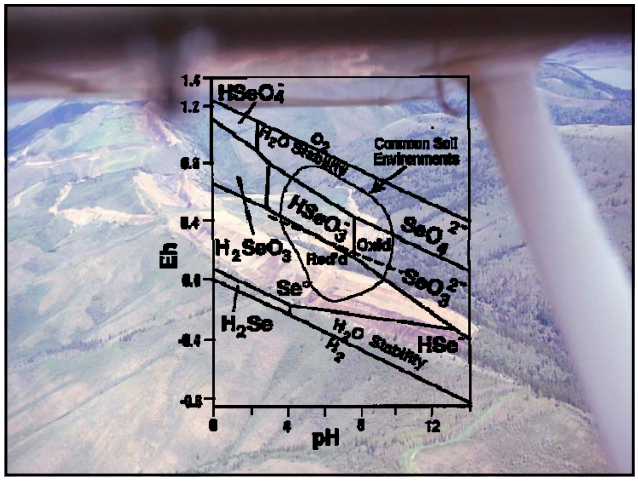
- Acute death
- Abortion
- "subclinical effects"
  - Vitamin A
  - Thyroid function
- "Safe" concentration
  - Feed + water < 200 mg/kg BW in well-managed, nutritionally adequate, animals
  - *Assuming neglible feed NO_3*, water < 500 ppm NO_3 ion

pH

- Human standards (6.5 – 8.5) established for esthetics (taste) and to protect plumbing from corrosion
- Theoretically
  - "Excessively" acid water can leach toxic metals (esp. Pb) from household plumbing
  - Claimed - Extremes of pH could alter blood pH
- Swine & rodent confinement facilities routinely acidify water to pH 3 to improve health
- Feeding "strong acids" (equivalent to pH 3 in drinking water) results in improved calcium metabolism in preparturient dairy cows
  - Feedlot cattle on acidogenic diets ???

Selenium

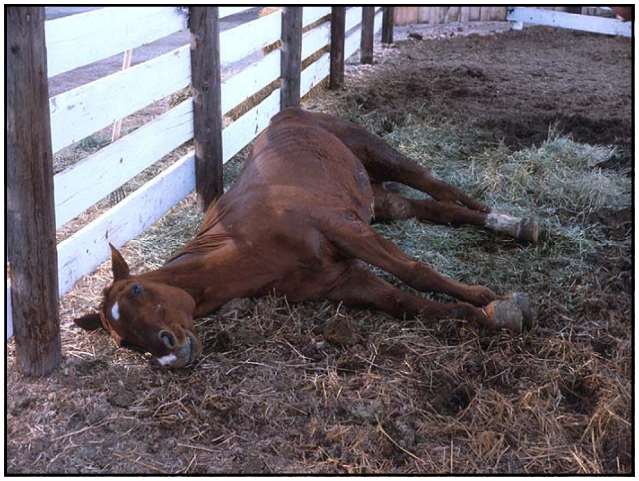
- Essential trace element, highly toxic metalloid
  - $SeO_3^=$, $SeO_4^=$ are most common in water
  - "organic" forms in forages
- Acute vs. chronic poisoning
  - Acute poisoning usually involves "artificial" sources such as feed supplements
  - Chronic poisoning usually involves "natural" sources
    - forage, water



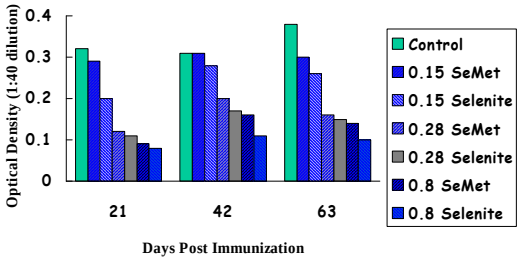
Acute Selenosis

- *Usually* iatrogenic, but may also be water-borne
- Syndromes
  - Sudden death
  - Heart, liver, kidney damage
  - Anemia

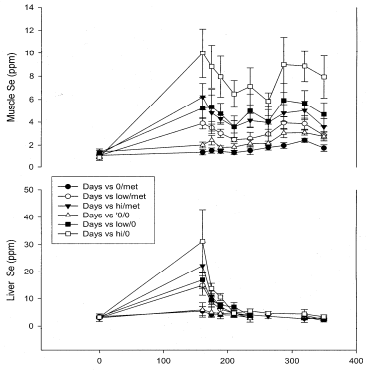
Chronic Selenosis



Primary Antibody Response to OVA in Steers



•Residues



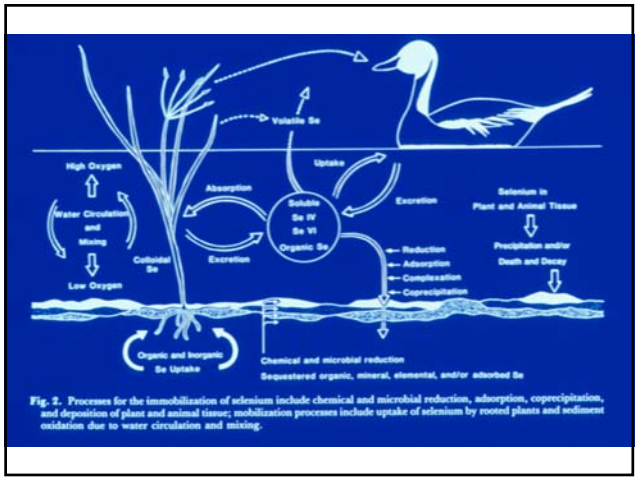
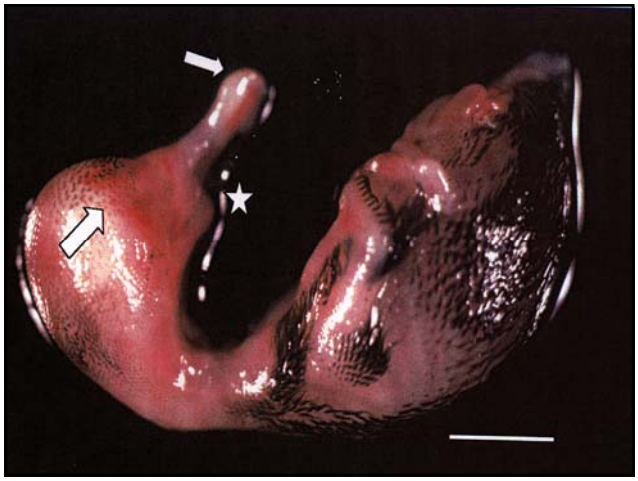
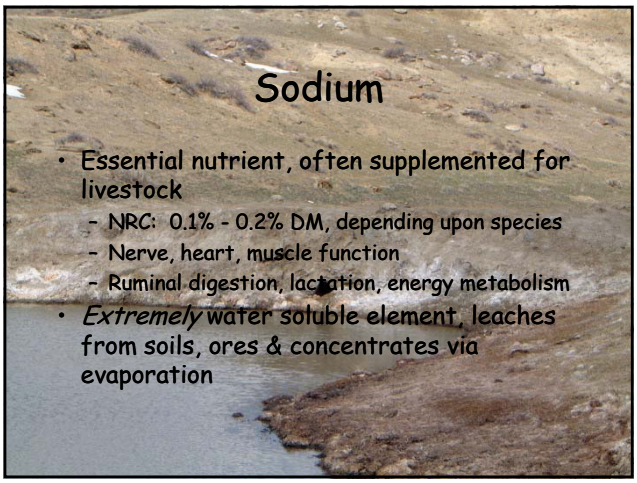


Fig. 2. Processes for the immobilization of selenium include chemical and microbial reduction, adsorption, coprecipitation, and deposition of plant and animal tissue; mobilization processes include uptake of selenium by rooted plants and sediment oxidation due to water circulation and mixing.



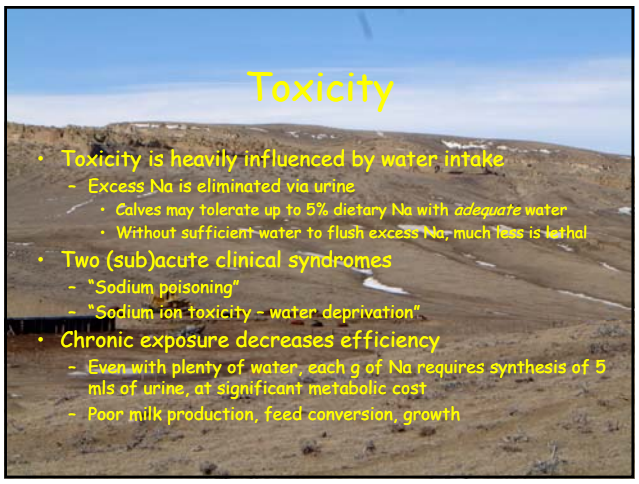
Selenium

- Sensitivity: horse > cattle > sheep
  - Cattle > wild ruminants > sheep
- Chronic LOAEL (horses) 50-100 μg/kg BW/day
- Water Se additive with forage
  - Assume forage = 1 ppm
  - 250 ppb Se @ 10% BW => toxic dose
  - 125 ppb Se @ 20% BW => toxic dose
- Recommend < 100 ppb



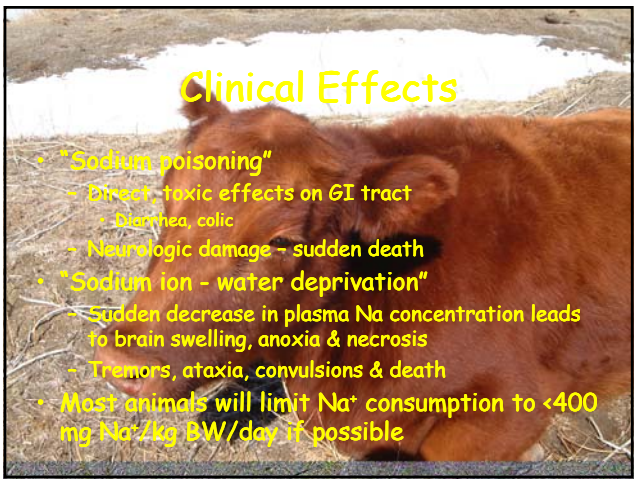
Sodium

- Essential nutrient, often supplemented for livestock
  - NRC: 0.1% - 0.2% DM, depending upon species
  - Nerve, heart, muscle function
  - Ruminal digestion, lactation, energy metabolism
- *Extremely* water soluble element, leaches from soils, ores & concentrates via evaporation



Toxicity

- Toxicity is heavily influenced by water intake
  - Excess Na is eliminated via urine
    - Calves may tolerate up to 5% dietary Na with *adequate* water
    - Without sufficient water to flush excess Na, much less is lethal
- Two (sub)acute clinical syndromes
  - "Sodium poisoning"
  - "Sodium ion toxicity – water deprivation".
- Chronic exposure decreases efficiency
  - Even with plenty of water, each g of Na requires synthesis of 5 mls of urine, at significant metabolic cost
  - Poor milk production, feed conversion, growth

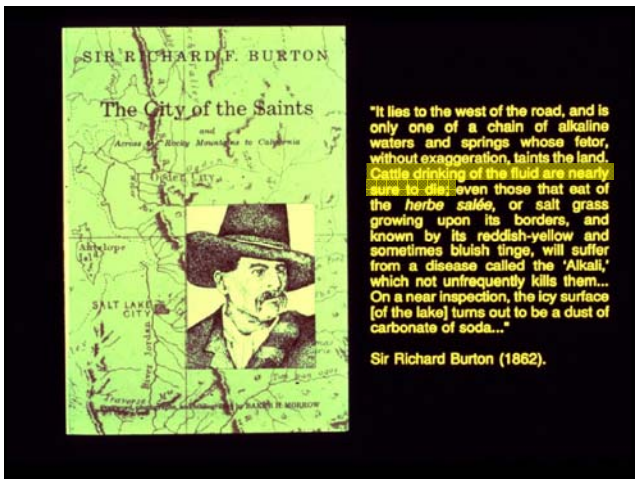


Clinical Effects

- "Sodium poisoning"
  - Direct toxic effects on GI tract
    - Diarrhea, colic
  - Neurologic damage – sudden death
- "Sodium ion - water deprivation"
  - Sudden decrease in plasma Na concentration leads to brain swelling, anoxia & necrosis
  - Tremors, ataxia, convulsions & death
- Most animals will limit Na^+ consumption to <400 mg Na^+/kg BW/day if possible

Sulfur

- Several chemical forms: S_2^-, S, SO_3^{2+}, SO_4^{2+}
- Mostly natural sources, but exacerbated by human activities – irrigation, mining
- Toxic effects vary with species
  - Ruminant >> monogastric animals
  - $SO_4 \rightarrow H_2S$ by rumen and absorbed
- Toxicity influenced by other dietary/environmental factors
  - Adapation
  - Other macro/micro nutrients (?)
  - Energy



Sulfur

- Sudden death w/o lesions
- Polioencephalomalacia
  - Blindness, staggering, convulsions
- Respiratory
  - Pulmonary edema, anoxia
  - Impaired lung macrophage function
- Nutritional antagonism
  - Impaired immune function, infertility via impaired Cu metabolism
- Economic
  - Decreased gain, efficiency & condition in *controlled* experiments down to 500 ppm sulfate in water.
- "Safe" concentration
  - Lethality – 1800 ppm SO_4
  - Production – 1000 ppm SO_4

Cases

- July, 2005 – Alcova area
  - Bulls turned into pasture with water varying from 1040 – 3000 ppm SO_4. 3/13 died of PEM within 48 hr
  - History of sporadic PEM since brought in new ditch.
  - Ruled out Pb, thiamine, salt, CNS infections
- Oct, 2005 – Monolith Ranch, Laramie
  - 3/300 dead, undetermined # sick with CNS signs typical of PEM
  - Diagnosed as PEM at *post mortem*
  - Ruled out: Pb, salt, thiamine
  - Highest water concentration sampled 1880 ppm SO4
  - Veg 0.2% S
- May, 2004 – Torrington
  - Steer diagnosed with PEM on necropsy
  - Pb negative
  - Water "safe" (i.e. < 3000 ppm) at private lab in Casper
- July, 2000 – Riverton
  - 25/200 cows developed PEM when exposed to 5-6000 ppm.
  - Pb, salt negative. No response to thiamine
- May, 2000
  - Angus bull and heifer developed PEM in drylot. Total exposed "about 20".
  - No Pb. Water SO_4 2900 ppm.

McAllister, 1994

- Sept, 2000 – Rawlins
  - Clinical PEM in cattle
  - No response to thiamine, Pb not analyzed but "no source"
  - SO_4 in pasture water supplies 600 – 2100 ppm
- Sept, 2000 – Chadron, NE
  - 15/180 bison developed signs of PEM
  - No response to thiamine (rules out thiamine deficiency and Pb)
  - Water SO_4 2000 – 2400 ppm
- Aug, 1999 – Sheridan
  - Well failed and cattle forced to drink from S-treated reservoir. 4 dead within 48 hr
  - PEM
- Aug, 1999 – Laramie
  - Rancher inaugurated new well (1800 ppm SO_4) in dry pasture. Killed "5-6" heifers (PEM) within 48 hrs
  - Forage 0.2 – 0.3% S, Pb neg, Salt neg.
- Aug, 1999 – Basin
  - "several" of 200 head died of PEM after turned in
  - Water samples 4000-6000 ppm SO_4
- July, 1998 Rawlins
  - Rotational grazing scheme with separate water sources (1800 and 540 ppm)
  - 7 died of PEM within 1 week of turning into higher SO_4 paddock More sick.
  - Ruled out Pb, salt, thiamine

Total Dissolved Solids (TDS)

- Defined as *all inorganic substances contained in water that can pass through a 2 micron filter*. i.e. sum of cations and anions dissolved in water
- Cheap & easy test
  - Evaporate sample at 180° C in a pre-weighed dish until the weight of the dish no longer changes.
  - Can be estimated fairly accurately from the electrical conductivity of a sample or approximated from measurement of individual ions by simply adding them together
- *Just not very useful in predicting toxicity*
  - Toxicity actually depends upon specific ions present
    - Hg^{2+}, Se^{4+}, As^{3+} >> Na^{+}, SO_4^{2-} > Ca^{2+}, HCO_3^{-}
  - Crude measure of water's suitability as solvent
    - Plasma, seawater > 20,000 ppm
- Palatability (threshold: 500 – 5000 ppm)
- Poor reproduction, gain, milk production (threshold: 2,000 – 13,000 ppm, depending upon source cited)
  - Susceptibility: Sheep < horses < cattle