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Table 1. Sodium toxicity studies reviewed in the UW report.

UW Report Ref. No.	Reference	Chemical Form Admin-istered	NOAEL Na intake, ppm	NOAEL Equiv. NaCl intake, ppm	LOAEL Na intake, ppm	LOAEL Equiv. NaCl intake, ppm	Endpoint	Study Duration	Duration classifi-cation	Receptor	Statistically Id'd N/LOAEL?	Notes
560	Amaral et al. 1985	NaCl			23,602	60,000	DMI, WI, digestion patterns	28 days	subchronic	cattle	Y	
544	Baird 1969	unknown	unknown	unknown	unknown	unknown	blindness, convulsions	<24 hrs	acute	dogs	N	vet clinical report; uncontrolled experiment
556	Barr et al. 2004	NaCl			3,421	8,696	acidosis, seizure, hyperthermia, related effects	<1 day	acute	dogs	N	vet clinical report; uncontrolled experiment
582	Berg and Bowland 1960	NaCl			2,026	5,150	WI	unknown	unknown (assume chronic)	pigs	N	
569	Boyd et al. 1966	NaCl			3,035	7,714	LC-50	100 days	chronic	rats	N	
551/559	Croom et al. 1983, Croom et al. 1985 (exp 1)	NaCl			27,536	70,000	growth, feed eff (weight gain + carcass weight)	126 days	chronic	cattle	Y	7% did not affect gains, only carcass weight.
554	Fountaine et al. 1975	NaCl			420,000	1,067,712	death	<1 day	acute	pigs	N	vet clinical report; uncontrolled experiment
573	Gudmundson and Meagher 1961	unknown	unknown	unknown	unknown	unknown	convulsions, death	unknown	unknown (assume acute)	pigs	N	vet clinical report; uncontrolled experiment
564	Hamilton and Webster 1987	NaCl			19,668	50,000	growth, DMI, diarrhea	lifetime	chronic	lambs	Y	
532	Harvey et al. 1986 (Trial 1)	NaCl	18,445	46,891			growth, feed eff	84 days	chronic	cattle	Y	roughage diet
532	Harvey et al. 1986 (Trial 1)	NaCl	21,291	54,127			growth, feed eff	84 days	chronic	cattle	Y	corn silage diet
565	Heller 1932	NaCl			5,900	15,000	behavior, WI	30 days	subchronic	pigs	N	
557	Heller 1933 (exp. 1)	NaCl			4,917	12,500	growth, death	10 weeks	chronic	rats	N	Specific threshold not reported by Raisbeck.
205	Hibbs and Thilsted 1983	unknown			4,370	11,109	PEM, death	< 24 hrs per dose	acute	cattle	N	well water contam. With multiple constituents, organo-S chief among them; vet clinical report, no controls.
555	Hughes and Sokolowski 1978	NaCl			39,336	100,000	death	< 24 hrs	acute	dogs	N	vet clinical report, uncontrolled experiment
547	Jaster et al. 1978	NaCl			4,958	12,604	milk production, WI, diarrhea	28 days	subchronic	cattle	Y	stat significance marginal (0.05<p<0.08)
548	Khanna et al. 1997	NaCl	unknown	unknown	unknown	unknown	death	<1 day	acute	dogs	N	vet clinical report, uncontrolled experiment
572	Lames 1968	unknown	unknown	unknown	unknown	unknown	death	unknown	acute	pigs	N	vet clinical report; uncontrolled experiment
571	Medway and Kare 1959 (exp 1)	NaCl			52,868	134,400	death	<1 day	acute	pigs	N	
581	Meyer and Weir 1954	NaCl	35,796	91,000			reproductive and wool production	253 days	chronic	sheep	Y	
561	Nestor et al. 1988 (NaCl exp.)	NaCl			53,498	136,000	udder edema	52 days	chronic	cattle	Y	
551	Ohman 1939	NaCl			6,726	17,099	body condition, death	<96 hrs	acute	cattle	N	vet clinical report; uncontrolled experiment
575-580	Peirce 1959, 1960, 1962, 1963, 1966, 1972	NaCl	5,114	13,000	5,114	13,000	growth, DMI, WI	15 months	chronic	sheep	N	WI affected but not growth, DMI
546	Perice 1957	NaCl			5,900	15,000	DMI, BW, WI	460 days	chronic	sheep	N	
562	Potter and McIntosh 1974	NaCl			5,114	13,000	neonatal distress, death	80 days	chronic	sheep	N	
580	Potter et al. 1972	NaCl	5,114	13,000			WI	<24 hrs	acute	sheep	Y	Sheep already accustomed to drinking 1.3% NaCl for 6-12 months.
553	Pretzer 2000	NaCl			4,720	12,000	diarrhea	<96 hrs	acute	gilts	N	vet clinical report, uncontrolled experiment
570	Rossi et al. 1998	NaCl			11,801	30,000	DMI, WI	30 days	subchronic	goats	Y	
538	Sandals 1978	NaCl			19,668	50,000	CNS disruption	<24 hrs	acute	cattle	N	vet clinical report, uncontrolled experiment
566-568	Saprirstein et al. 1950, Koletsky 1959, Koletsky 1958	NaCl			3,934	10,000	hypertension	6 months+	chronic	rats	Y	
552	Sautter et al. 1957	NaCl	unknown	unknown	unknown	unknown	death	6 days	acute	pigs	N	vet clinical report, uncontrolled experiment
540	Tomas et al. 1973	NaCl	5,114	13,000			mineral balance		chronic	sheep	N	
543	Trueman and Clague 1978	NaCl			229,888	584,416	death, blindness, disorientation	1 day after dehydrating the animal	acute	cattle	N	vet clinical report, uncontrolled experiment
558	Weeth and Haverland 1961	NaCl			4,720	12,000	DMI, WI, diarrhea	30 days	subchronic	cattle	Y	
574	Weeth and Hunter 1971	NaCl	1,617	4,110			growth, WI, related effects	30 days	subchronic	cattle	Y	
550	Weeth and Lesperance 1965	NaCl			5,900	15,000	DMI, WI, renal function	<24 hrs	acute	cattle	N	
539	Weeth et al. 1968 (exp. 1)	NaCl	2,557	6,500			WI, diuresis, related effects	30 days	subchronic	cattle	Y	
542	Wilson 1966	NaCl	19,668	50,000	39,336	100,000	DMI	21 days	subchronic	sheep	Y	
563	Wilson 1967 (exp. 1)	NaCl	7,867	20,000	7,867	20,000	DMI	3-5 days	subchronic	sheep	N	no control group, DMI affected at 3 days but recovered by 5 days.

Notes:
DMI = dry matter intake
WI = water intake
If not otherwise reported, assumed a 273 lb cow feeding at a rate of 6.8 kg/day for cattle studies
NOAEL and LOAEL concentrations represent reported daily exposure rates

Table 2. Sodium toxicity studies specific to livestock that are not referenced in the UW report.

Reference	Chemical Form Administered	Receptor	Endpoints	Study Duration	Duration classifi-cation	NOAEL NaCl (ppm)	LOAEL NaCl (ppm)
Bahman et al. (1993)	brackish water well, total TDS measured.	dairy cows	milk production, growth	196 days	chronic	3574	not identified
Ballantyne (1957)	NaCl	growing & adult cattle	mortality	not reported	subchronic	861	not identified
Ballantyne (1957)	NaSO4	growing & adult cattle	mortality	not reported	subchronic	1721	not identified
Challis et al. (1987)	well water (NaCl measured)	dairy cows	milk production	unknown	subchronic	448	4387
Embry et al. (1959)	NaCl	growing cattle	food/water intake, growth	112 days	chronic	7000	10000
Frens (1946)	NaCl	dairy cows	milk production		chronic	10000	not identified
Heller (1933)	NaCl	dairy cows and steers	milk production, reproduction, weight gain	21 weeks	chronic	17500	not identified
Lassiter and Cook (1963)	NaHCO3	growing cattle (yearlings)	food/water intake, digestibility	21 days	chronic	5000	not identified
Patterson et al. (2003)	NaCl	growing cattle	food/water intake, weight gain	3 months	chronic	not identified	not identified
Ramsey (1924)	NaCl	cattle	water intake, weight gain, survival	3 mo - 2 yrs	chronic	17,190	not identified
Ray (1989)	CaCl, NaSO4, NaHCO3, NaCl (all added together).	growing cattle	food/water intake, efficiency of growth	112 days	chronic	1300	6000
Solomon et al. (1995)[1]	natural water sources	dairy cows	milk production, water intake	4 months	chronic	35	867
Spafford (1941)	NaCl	cattle	water intake, survival	unknown	subchronic	14250	18500
Weeth and Haverland (1961) (exp 1)	NaCl	growing cattle	food/water intake, growth	30 days	subchronic	100	10000
Weeth and Haverland (1961) (exp 2)	NaCl	growing cattle	food/water intake, growth	30 days	subchronic	15000	17500
Weeth et al. (1960)	NaCl	growing cattle	food/water intake, growth	30 days	subchronic	10100	20100

Notes:

Sodium dose calculated only from water intake; additional sulfate intake from food not factored in.

1 Cows were sodium deficient during study.

All references have statistically identified a NOAEL and/or a LOAEL.

NOAEL and LOAEL concentrations represent reported daily exposure rates.

Table 3. Fluoride literature data pertaining to growth and reproductive effects in livestock from chronic exposure.

Reference	Receptor	NOAEL (mg/kg in diet)	LOAEL (mg/kg in diet)	Effect Noted
Shupe et al. (1963a,b), Shupe et al. (1964)	Dairy cows	27	49	Decreased milk production
Schmidt and Rand (1952) [1]	Cattle	1 mg per kg BW	n/a	
Suttie et al. (1972), Suttie et al. (1957a,b)	Dairy cows	35		
Suttie et al. (1961)	Dairy cows		128	dental fluorosis
Shupe and Olson (1969) [2]	Dairy cows	30	n/a	
	Beef cows	40	n/a	
	Sheep	50	n/a	
	Horses	60	n/a	
Phillips et al. (1960)	Cattle	30 to 50	n/a	various[3]
Harris et al. (1963)	Lambs	200		
Suttie et al. (1985)	Deer	25		

Notes:
BW = body weight.
n/a = not applicable.
ND = not determinable
[1]Schmidt and Rand (1952) provided a review of studies and recommended a "safe" forage concentration for cattle.
[2]Shupe and Olson (1969) recommended ranges of fluorine tolerances in domestic animals for breeding/lactating animals.
3 The Phillips et al. (1960) citation is a literature review. Safe daily intake level for fluorine from a soluble source was cited between 30 and 50 ppm. Phillips et al. (1960) also reported that other animal species were able to tolerate much higher levels of fluorine in the diet.

Table 4. Sulfate toxicity studies reviewed in the UW report.

UW Report Ref. No.	Reference	Chemical Form Administered	S intake, total (%)	Endpoint	NOAEL SO4 equiv. intake, total (ppm)	LOAEL SO4 equiv. intake, total (ppm)	Study Duration	Duration classifi-cation	Receptor	Statistically Id'd N/LOAEL?	Notes
594	Albert et al. 1956	elemental S	0.4 / 0.55	growth	11,985	16,479	56 days	chronic	lambs	N	Not a clean study- study objective included N and S effects together, specifially measuring effects of urea N supplements.
594	Albert et al. 1956	methionine	0.05	growth		1,498	56 days	chronic	lambs	N	Not a clean study- study objective included N and S effects together, specifially measuring effects of urea N supplements.
594	Albert et al. 1956	Na2SO4	0.40	growth	11,903	16,366*	56 days	chronic	lambs	N	Not a clean study- study objective included N and S effects together, specifially measuring effects of urea N supplements; *authors claim that 2.42 should not be a LOAEL, should result in max gains.
631	Beke and Hironaka 1991	SO4	0.47	PEM		13,935	< 96 hrs	acute	cattle	N	vet clinical report; uncontrolled experiment
591	Bouchard and Conrad 1974	unknown	0.35	DMI		10,487	unknown	acute	dairy cow	Y	
625	Bulgin et al. 1996	elemental S	unknown	PEM, death		unknown	< 1 day	acute	sheep	N	vet clinical report; uncontrolled experiment
585	Digesti and Weeth (1976)	Na2SO4	0.26	growth, DMI, WI	7,691		90 days	chronic	growing cattle	Y	
602	Gooneratne et al. 1989	S	0.04	Cu and B1 intake		1,328	3 weeks	subchronic	calf	Y	
627	Hamlen et al. 1993	Na2SO4	0.16	PEM		4,869	3 days	acute	cattle and calves	N	vet clinical report; uncontrolled experiment
630	Haries 1987	SO4	0.17	PEM		5,203	<96 hrs	acute	steers	N	vet clinical report; uncontrolled experiment
619	Harper et al. 1997	SO4	0.03	DMI		1,000	unknown	chronic	cattle	Y	
619	Harper et al. 1997	SO4	0.07	DMI		2,000	unknown	chronic	cattle	Y	
634	Haydock 2003	SO4	0.77	PEM		23,175	unknown	acute	cattle	N	vet clinical report; uncontrolled experiment
620	Johnson et al. 1968	Na2SO4	0.50	growth, DMI, feed eff.		15,014	67 days	chronic	lambs	Y/N**	Non-peer reviewed data (abstract only) **no stats for weight gain, only feed eff. and DMI.
621	Khan et al. 1987	CaSO4	0.75	growth	22,471		85 days	chronic	beef calves	Y	
597/Not Re	Loneragan et al. 1997 /Loneragan et al. 2005	SO4	0.24	blood thiamine, ruminal gas cap H2S		7,154	113 days	chronic	yearling steer	Y	1 case of PEM noted but incidence frequency close to norm at .11% vs .07%
614	Loneragan et al. 2001	SO4	0.20	DMI		6,013	112 days	chronic	cattle	Y	
633	McAllister et al. 1997	SO4	0.67	blood thiamine levels due to PEM		20,074	3 weeks	subchronic	beef cow	N	vet clinical report; uncontrolled experiment
632	Niles et al. 2002	SO4	0.18	PEM		5,540	<96 hrs	acute	beef calves	N	vet clinical report; uncontrolled experiment
632	Niles et al. 2002	SO4	0.23	PEM		7,010	<96 hrs	acute	beef calves	N	vet clinical report; uncontrolled experiment
589	NRC 2005	S	0.50	PEM, Max tolerable dose to prevent	14,981		chronic	chronic	cattle	N	Recommended max for range cattle
589	NRC 2005	S	0.30	PEM, Max tolerable dose to prevent	8,989		chronic	chronic	cattle	N	Recommended max for feedlotted cattle
639	Olkowski et al. 1991	SO4	0.03	blood thiamine levels		1,000	varies	unknown	beef cattle	Y	not a controlled study; metadata analysis.
618	Patterson et al. 2002	SO4	0.29	growth, DMI, WI		8,780	84 days	chronic	steers	Y	PEM noted
626	Patterson et al. 2003	SO4	0.32	PEM, death		9,658	3 months	chronic	growing steers	Y	
624	Pendium et al. 1976	elemental S	0.30	growth, DMI, feed eff.	8,989		140 days	chronic	steers	N	Not a clean study- study objective included N and S effects together, specifially measuring effects of non-natural protein N supplements.
623	Qi et al. 1993	CaSO4	0.28	growth, DMI	8,389		8 weeks	chronic	goats	N	Interaction between N (added at 2.28%) and S.
628	Raisbeck 1982	gypsum, KSO4 or MgSO4	0.67	PEM		20,000	varies	acute	cattle	Y	vet clinical report; uncontrolled experiment
622	Rumsey 1978 (Trial 1)	sublimed S	0.56	growth, DMI	16,779		28 weeks	chronic	steers	Y	Not a clean study- cattle implanted with DES. Purpose of study was to gauge implant performance on varying levels of S, not a tox study on S.
622	Rumsey 1978 (Trial 1)	sublimed S	1.12	growth, DMI		33,557	10 weeks	chronic	steers	N	Not a clean study- cattle implanted with DES. Purpose of study was to gauge implant performance on varying levels of S, not a tox study on S.
615	Sadler et al. 1983 (Trial 1)	MgKSO4	0.24	growth, PEM		7,200	14 days	subchronic	steers	not stated	different than trial 1, producing the effects. Differences not elaborated on.
615	Sadler et al. 1983 (Trial 2)	MgKSO4	0.24	growth, PEM	7,200 (growth)	7,200 (PEM)	56 days	chronic	steers	not stated	Non-peer reviewed data (abstract only)
606	Smart et al. 1986	S	0.21 / 0.4	growth, Cu and Zn uptake	6,285	11,913	2 years	chronic	cattle and calves	Y	
640	Wagner et al. 1997	S	0.14	growth, DMI, WI	not identified	not identified	84 days	chronic	steers	N	Non-peer reviewed data (abstract only); trend analysis conducted only; no NOAEL, LOAEL id'd.
629	Ward and Patterson 2004	SO4	0.13	PEM		3,780	84 days	chronic	steers	Y	
617	Weeth and Caps 1972	SO4	0.28	DMI		8,314	30 days	subchronic	heifers	Y	

Table 5. Produced water quality in some Wyoming area basins.

	-Groundwater dataset--	----------Surface water dataset----------			
Data	Powder River Basin, groundwater data	Bighorn Basin, at outfall	Platte River Basin, at and below discharge area	Powder River Basin, at discharge area	Powder River Basin, outfall data
% samples > 2 fluoride	1%	66%	25%	96%	3%
% > samples 1000 sodium	1%	8%	5%	87%	0%
% samples > 1000 sulfate	2%	55%	45%	30%	<1%
% samples > 500 TDS	n/a	88%	50%	100%	100%
Average of fluoride	1.0	2.6	1.5	2.7	1
Average of sodium	312	516	323	1115	442
Average of sulfate	61	1278	1305	1094	8
Average of TDS	n/a	2640	2917	4338	1545
Max of fluoride	4.1	4.1	3.8	3.41	4
Max of sodium	1470	1620	1700	1400	910
Max of sulfate	3870	3270	8500	1680	1790
Max of TDS	n/a	7320	5430	7320	4980
Min of fluoride	0.1	0.9	0.3	1.96	0
Min of sodium	11	27	35	895	137
Min of sulfate	1	58.6	130	368	0
Min of TDS	n/a	310	351	2810	674
# Samples - Fluoride	11332	17	14	23	260
# Samples - Sodium	21705	86	14	23	2106
# Samples -Sulfate	2284	136	19	13	627
# Samples - TDS	n/a	122	11	23	87

Notes:
All results in mg/L
n/a = not applicable. Data not available for this constituent.
Data sources: CBMA; Cottonwood, Salt and Poison Spider UAAs; WY NPDES data for select areas in Powder River and Bighorn basins; additional monitoring data courtesy of Marathon oil, Fidelity.
Data collected "at discharge area" in the Powder River basin reflects a mixture of natural background and produced water. Water was collected in vicinity of discharges.
Yellow-highlighted boxes are > 10%
Orange-highlighted boxes are > or = 25%

Table 6. Natural background water quality at some areas in Wyoming.

	Groundwater dataset			Surface water dataset		
Data	State-wide USGS groundwater (mostly background)	Powder River Basin background groundwater stock use	Powder River Basin background groundwater non-stock	Bighorn Basin, Background	Platte River Basin, Background	Powder River Basin, Background
% samples > 2 fluoride	16%	5%	4%	25%	100%	42%
% > samples 1000 sodium	7%	1%	1%	0%		65%
% samples > 1000 sulfate	15%	32%	24%	25%	100%	45%
% samples > 500 TDS	n/a	n/a	n/a	50%	100%	100%
Average of fluoride	2.3	0.8	0.8	1.5	2.9	0.6
Average of sodium	627	276	239	257		1195
Average of sulfate	554	881	691	508	1708	2792
Average of TDS	n/a	n/a	n/a	1235	3157	5449
Max of fluoride	130	30.2	9.3	4.12	3.88	2.2
Max of sodium	75700	1980	2510	692		6000
Max of sulfate	68000	7250	18300	1180	1746	12000
Max of TDS	n/a	n/a	n/a	2310	3430	25100
Min of fluoride	0	0.1	0.1	0.39	2.3	0.22
Min of sodium	0.3	2	2	51		73
Min of sulfate	0	1	1	109	1633	252
Min of TDS	n/a	n/a	n/a	260	2990	590
# Samples - Fluoride	3526	2422	1115	4	3	69
# Samples - Sodium	3547	2816	1285	4	0	69
# Samples -Sulfate	3993	2026	814	4	3	43
# Samples - TDS	n/a	n/a	n/a	4	3	69

Notes:
All results in mg/L
n/a = not applicable. Data not available for this constituent.

Data sources: CBMA; Cottonwood, Salt and Poison Spider UAAs; WY NPDES data for select areas in Powder River and Bighorn basins; additional monitoring data courtesy of Marathon oil, Fidelity.
Data collected "at discharge area" in the Powder River basin reflects a mixture of natural background and produced water. Water was collected in vicinity of discharges.
Yellow-highlighted boxes are > 10%
Orange-highlighted boxes are > or = 25%

Figure 1. General Risk Management Evaluation Process

Date: 9/12/2007

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- Anecdotal Information
- Report
- Public input

- Evaluate anecdotal info
- Toxicological literature collection
- Identify:
  - background water quality (surface / stock wells)
  - water source availability
  - forage type & quality
  - production per species
  - impact on production from breed & genetics
  - impacts on production from climate, drought, predation
  - supplemental feed type & amount
- Collect data on actual impacts due to each constituent
- Public input

- Rigorous protocol followed
- Consideration of background
- Determine appropriate toxicological endpoints (define "measurable decrease")
- Determine statistical relevance of toxicity data
- Calculate probability of risk
- Public input

- Identify risk management alternatives
- Evaluate alternatives considering balancing criteria W.S. §35-11-302(a)(vi):
  - character & degree of injury to or interference with the health & well being of people, livestock, wildlife, plants
  - social & economic value of oil & gas production
  - priority of location in the area involved
  - technical practicability of reducing or eliminating produced water discharges
  - economic reasonableness of reducing or eliminating produced water discharges
  - effect upon the environment of reducing or eliminating produced water discharges
- Evaluate a no action alternative
- Public input

- Describe selected alternative
- Explain
  - Scientific & technical basis
  - Evaluation of balancing criteria

Figure 2. Example of the Risk Management Evaluation Process Applied to the Agricultural Use Ruling Proposal

Environmental, Inc. • Environmental, Inc.

Date: 9/12/2007

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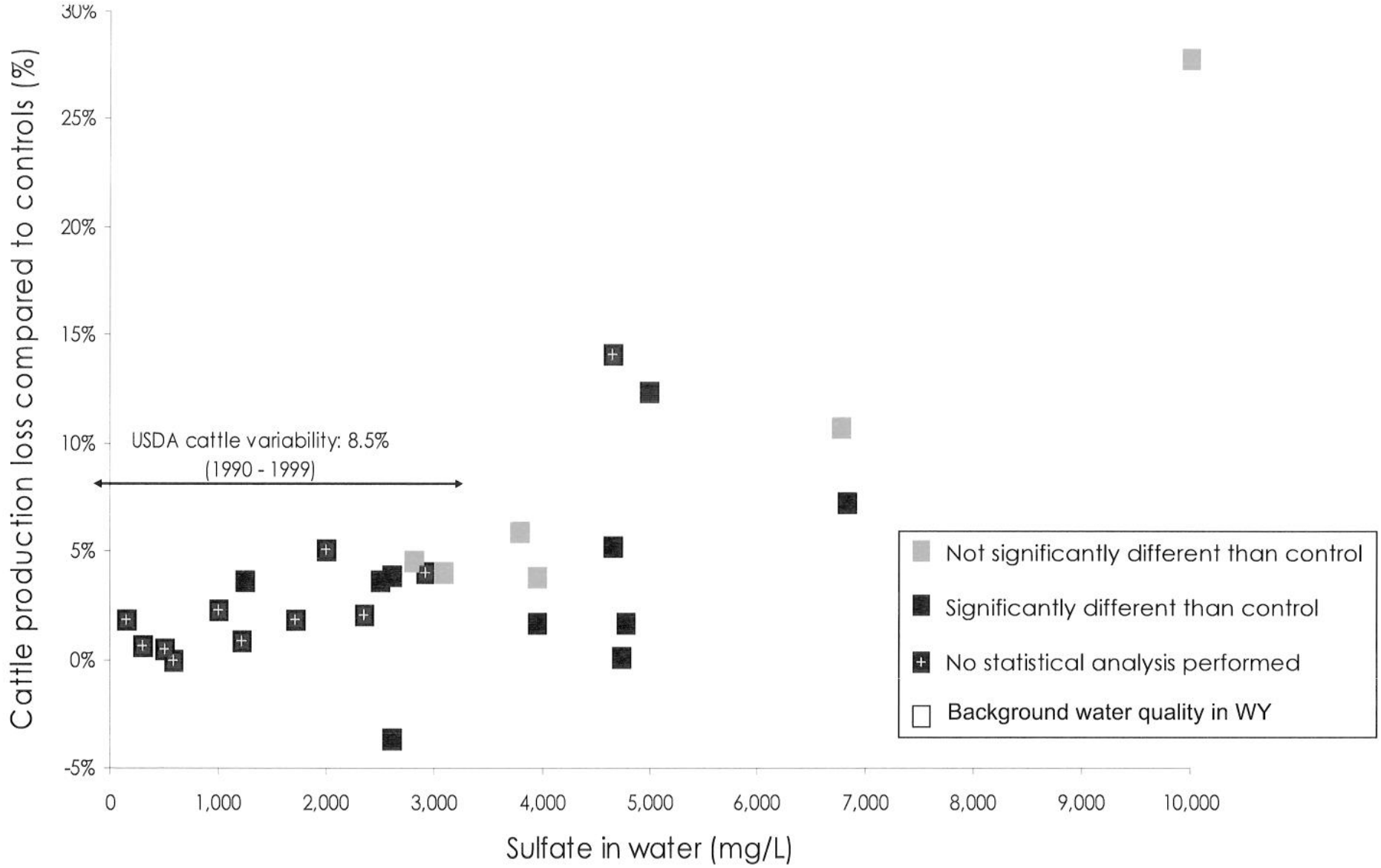

Figure 3. Metadata showing relationship between sulfate in water to loss of cattle production in test groups compared to controls.

Date: 9/12/2007

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