INTRODUCTION

To evaluate levels at which sulfate may become toxic to aquatic biota, available studies on the toxicity of sulfate were reviewed. Sulfate itself is not a stable compound and is always associated with other elements. For the purposes of this evaluation, only calcium, magnesium, and sodium sulfate compounds were considered since the anions of these compounds have low toxicity.

With respect to the propagation of fish and wildlife, there is no recommended ambient water quality criterion for the protection of aquatic life for sulfate because sulfate is not generally considered a significant ecological concern, except perhaps where it is a dominant component of total dissolved solids (TDS)[1]. However, there are several sources where published ecotoxicological data are available with which to evaluate the effects of sulfate. These include, USEPA's Aquatic Information Retrieval System (AQUIRE), the Hazardous Substances Databank (HSDB), and published scientific literature. The following assumptions were made for tabulation and interpretation of the available data:

- Only freshwater data were considered.
- Endpoints of survival, growth or reproduction were considered.
- Values for unicellular organisms were not considered. As per USEPA guidelines (*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* [USEPA 1985]) tests with single-celled organisms are not considered acute tests even if the duration is 96 hours or less.
- Studies where no endpoint was reported were not considered.

A summary of relevant aquatic toxicity data compiled from the above-mentioned sources is presented in Tables 1 and 2. Toxicity data were identified for aquatic plants, invertebrates, and fish. All results have been converted and expressed as sulfate. In some instances, discrepancies were noted between the values reported in compilation databases such as AQUIRE or HSDB and the original paper. Where these discrepancies were identified, values from the original paper were used.

ACUTE TOXICITY

Most of the toxicity data identified are based on acute toxicity studies reporting LC_{50} concentrations[2]. All of these studies are based on test durations of six days or less. Results indicate a wide range in the potential acute effects of sulfate. To examine relative sensitivities, data were grouped by similar taxonomic group (genus) and a genus mean acute value (GMAV) was calculated as the geometric mean of the reported genus LC_{50}s. The GMAVs were then ranked from highest to lowest, as presented in Table 3. The lowest GMAV, 446 mg/L, is for the mayfly (*Tricorphus* sp.).

[1] That is, when sulfate would contribute significantly to excessive "salinities" (i.e., >1,000 mg/L) in naturally fresh waters.

[2] The LC_{50} is a statistically or graphically estimated concentration that is expected to be lethal to 50% of a group of organisms under specified conditions (ASTM 1995).

Except for striped bass, all of the reported LC_{50} values and GMAVs were above 300 mg/L. LC_{50} values for striped bass fry as reported by Hughes (1975) were 1,352 mg/L (24 hr), 676 mg/L (48 hr), 338 mg/L (72 hr), and 169 mg/L (96 hr). The original study for these reported values (Hughes 1975) could not be located and the test validity and data could not be verified. However, the sulfate LC_{50} concentration essentially halved during each 24-hr exposure interval. This is an unusual coincidence, which places into question the results of the test[3]. LC_{50}s presented for striped bass fingerlings by Hughes (1975) were reported as 2,367 mg/L for all four exposure periods.

Note that one study reported in AQUIRE that contained reported sulfate LC_{50} concentrations less than 300 mg/L was rejected. Specifically, a paper by Surber and Thatcher (1963)[4] indicated acute toxicity to the caddisfly (*Stenonema ares*) at 216 mg/L. However, review of the original paper indicated greater than 50% mortality in controls, as well as no consistency between dose and survival response. Therefore, these data were rejected and are not included in the attached tables.

CHRONIC TOXICITY

Relative few chronic toxicity data for sulfate are available (Table 2). Several studies were identified for Eurasian watermilfoil (a plant), in which no effects were observed at sulfate concentrations ranging from 628 mg/L to as high as 2,272 mg/L. Among fish and invertebrates, the only study identified is by Hancher et al. (1987). This study reported a lowest-observed-effect concentration (LOEC[5]) and no-observed-effect concentration (NOEC[6]) for sulfate using *Ceriodaphnia dubia*, commonly known as the water flea. *Ceriodaphnia* is used as a common toxicity test organism because of its ease of culturing and its sensitivity to a wide range of toxicants. Hancher et al. (1987) reported no effects on survival of *Ceriodaphnia* at 2,009 mg/L. However, the NOEC for reproduction was reported as less than 1,488 mg/L suggesting that an effect was observed at the lowest concentration tested. As a result, there is an absence of chronic toxicity data for fish and invertebrates that can be effectively classified as a no effect concentration. However, there are two additional pieces of information that provide estimates of the chronic effects of sulfate. These are: (1) the chronic toxicity of similar compounds, and (2) the sulfate concentration used in culture water of freshwater organisms. Each is discussed below.

The mode of toxic action for sulfate is most likely related to ionic and osmotic regulation. In this sense, the toxicity of sulfate would be expressed in a fashion similar to "salt" or total dissolved solids. The acute toxicity of sodium sulfate (Na_2SO_4) is compared to that of sodium chloride (NaCl), as presented in the following table (USEPA 1991).

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[3] Without elaboration, after reporting the LC_{50} value the author stated: "Sulfates are not apt to be a problem for striped bass in natural waters." (Hughes 1975).

[4] This was also reported by Environment of Canada in HSDB.

[5] LOEC – lowest observed effect concentration - the lowest concentration measured in which a statistically significant difference is observed as compared to controls.

[6] NOEC – no observed effect concentration – the concentration at which there is no statistically significant difference from controls.

Organism	Acute Toxicity (LC_{50})	
	Na_2SO_4 (mg/L)[7]	NaCl (mg/L)
Fathead Minnow	7,960 to 14,000	3,500 to 7,900
Ceriodaphnia dubia	3,080 to 3,590	2,100 to 2,800

These acute data suggest that the acute toxicity of sodium sulfate is approximately 60 percent that of sodium chloride. The conclusion is that the chronic toxicity of sodium sulfate is less than that of sodium chloride. The chronic toxicity of sodium chloride is as follows (USEPA 1992):

Organism	Chronic Toxicity of NaCl (mg/L)(NOEC)
Fathead Minnow	500 to 2,000
Ceriodaphnia dubia	630 to 1,000

Given that sodium sulfate is approximately 60 percent as toxic as sodium chloride, based on acute toxicities, and the lowest reported chronic toxicity of sodium chloride is 500 mg/L, the corresponding chronic toxicity of sodium sulfate is on the order of 800 mg/L.

Also of direct relevance to chronic effects levels of sulfate are the "recipes" presented by USEPA for culturing organisms for acute and chronic toxicity testing (USEPA 1994). These recipes consist of mixtures of calcium sulfate, manganese sulfate, sodium bicarbonate, and potassium chloride for producing culture waters of varying hardness. The sulfate concentrations in these culture waters range from 45 mg/L in soft water to 361 mg/L in very hard water. Both concentrations of sulfate are lower than the estimated chronic toxicity of 800 mg/L.

SUMMARY

Based on the lowest reported chronic toxicity endpoint (i.e., effectively a LOEC) of <1,488 mg/L, and a culture water sulfate concentration as high as 361 mg/L, it may be inferred that a sulfate concentration that would not result in chronic effects lies between concentrations of 361 mg/L and 1,488 mg/L. Also, given the lowest sulfate GMAV of 446 mg/L for the mayfly and the lower toxicity of sodium sulfate versus sodium chloride, it is concluded that the chronic toxicity concentration for sulfate is very close to the acute toxicity level of 446 mg/L. For the purpose of screening of sulfate concentrations in Midnite Mine drainages, it is assumed the chronic threshold is 400 mg/L (400,000 µg/L). This value is lower than the estimated chronic toxicity of sodium sulfate (800 mg/L) and between 361 and 1,488 mg/L. The acute toxicity threshold is assumed to be 450 mg/L (450,000 µg/L).

[7] Values for these organisms in Table 1 are represented as SO_4. The original Na_2SO_4 values are equivalent to presented numbers.

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TABLE 1
ACUTE TOXICITY OF SULFATE

Chemical Name	Scientific Name	Common Name	Endpoint	Effect	Test Duration (Hour)	Exposure Type	Sulfate Concentration (mg/L)	Source*	References
Sodium sulfate	Polycelis nigra	Planarian	LT50	MOR	48	S	4610.76	AQUIRE	Jones, J.R.E. 1941. A Study of the Relative Toxicity of Anions, with Polycelis nigra As Test Animal. J Exp Biol 18:170-181
Sodium sulfate	Amphipoda	Scud order	LC50	MOR	24	S	1609.55	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Amphipoda	Scud order	LC50	MOR	48	S	750.67	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Amphipoda	Scud order	LC50	MOR	72	S	595.00	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Amphipoda	Scud order	LC50	MOR	96	S	595.00	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Ceriodaphnia dubia	Water flea	LC50	MOR	24	S	2427.86	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Sodium sulfate	Ceriodaphnia dubia	Water flea	LC50	MOR	48	S	2082.96	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Calcium sulfate	Ceriodaphnia dubia	Water flea	LC50	MOR	24	S	1368.85	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Calcium sulfate	Ceriodaphnia dubia	Water flea	LC50	MOR	48	S	1347.68	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Magnesium sulfate	Ceriodaphnia dubia	Water flea	LC50	MOR	24	S	1412.58	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Magnesium sulfate	Ceriodaphnia dubia	Water flea	LC50	MOR	48	S	1412.58	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Sodium sulfate	Daphnia magna	Water flea	LC50	MOR	24	S	4253.83	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Sodium sulfate	Daphnia magna	Water flea	LC50	MOR	48	R	6172.28	AQUIRE	Arambasic, M.B., S. Bjelic, and G. Subakov 1995. Acute Toxicity of Heavy Metals (Copper, Lead, Zinc), Phenol and Sodium on Allium cepa L., Lepidium sativum L. and Daphnia magna St.: Comparative.. Water Res 29(2):497-503
Sodium sulfate	Daphnia magna	Water flea	LC50	MOR	48	S	3097.39	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Sodium sulfate	Daphnia magna	Water flea	LC50	MOR	24	S	5669.97	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Daphnia magna	Water flea (Young)	LC50	MOR	24	S	4598.74	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316

TABLE 2
CHRONIC TOXICITY OF SULFATE

Chemical Name	Scientific Name	Common Name	Endpoint	Effect	Test Duration (Days)	Exposure Type	Sulfate Concentration (mg/L)	Source*	References
Sodium sulfate	Ceriodaphnia dubia	Water flea	LOEC	Survival			2975.65	Hancher et al. 1987	Hancher, C.W, P.A.Taylor, A. Stewart, K.R. Zabelsky, and J.M. Napier. 1987. Development and Operational Performance of the Central Pollution Control Facility II/S-3Liquid Treatment Facility. Oak Ridge Y-12 Plant Publication Number ORNL Y/DZ-257
Sodium sulfate	Ceriodaphnia dubia	Water flea	LOEC	.eproduction			1501.35	Hancher et al. 1987	Hancher, C.W, P.A.Taylor, A. Stewart, K.R. Zabelsky, and J.M. Napier. 1987. Development and Operational Performance of the Central Pollution Control Facility II/S-3Liquid Treatment Facility. Oak Ridge Y-12 Plant Publication Number ORNL Y/DZ-257
Sodium sulfate	Ceriodaphnia dubia	Water flea	NOEC	Survival			2008.57	Hancher et al. 1987	Hancher, C.W, P.A.Taylor, A. Stewart, K.R. Zabelsky, and J.M. Napier. 1987. Development and Operational Performance of the Central Pollution Control Facility II/S-3Liquid Treatment Facility. Oak Ridge Y-12 Plant Publication Number ORNL Y/DZ-257
Sodium sulfate	Ceriodaphnia dubia	Water flea	NOEC	.eproduction			1487.83	Hancher et al. 1987	Hancher, C.W, P.A.Taylor, A. Stewart, K.R. Zabelsky, and J.M. Napier. 1987. Development and Operational Performance of the Central Pollution Control Facility II/S-3Liquid Treatment Facility. Oak Ridge Y-12 Plant Publication Number ORNL Y/DZ-257
Sodium sulfate	Myriophyllum spicatum	Eurasian watermilfoil	EC50	GRO	32	S	1580.48	AQUIRE	Stanley, R.A. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch Environ Contam Toxicol 2(4):331-341
Sodium sulfate	Myriophyllum spicatum	Eurasian watermilfoil	EC50	GRO	32	S	627.59	AQUIRE	Stanley, R.A. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch Environ Contam Toxicol 2(4):331-341
Sodium sulfate	Myriophyllum spicatum	Eurasian watermilfoil	EC50	GRO	32	S	2272.32	AQUIRE	Stanley, R.A. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch Environ Contam Toxicol 2(4):331-341
Sodium sulfate	Myriophyllum spicatum	Eurasian watermilfoil	EC50	GRO	32	S	902.84	AQUIRE	Stanley, R.A. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch Environ Contam Toxicol 2(4):331-341
Sodium sulfate	Myriophyllum spicatum	Eurasian watermilfoil	EC50	POP	32	S	1558.84	AQUIRE	Stanley, R.A. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch Environ Contam Toxicol 2(4):331-341
Sodium sulfate	Myriophyllum spicatum	Eurasian watermilfoil	EC50	POP	32	S	1428.99	AQUIRE	Stanley, R.A. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch Environ Contam Toxicol 2(4):331-341
Sodium sulfate	Myriophyllum spicatum	Eurasian watermilfoil	EC50	POP	32	S	2240.53	AQUIRE	Stanley, R.A. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch Environ Contam Toxicol 2(4):331-341
Sodium sulfate	Myriophyllum spicatum	Eurasian watermilfoil	EC50	POP	32	S	2053.88	AQUIRE	Stanley, R.A. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch Environ Contam Toxicol 2(4):331-341

Note:

*=Source other than AQUIRE and HSDB indicate AQUIRE value replaced by the original data source

POP= Population

GRO= Growth

S= Static

TABLE 3
GEOMETRIC MEAN OF ACUTE VALUES

Scientific Name	Common Name	Number of Data Points	Geometric Mean Acute Value (GMAV) (mg/L)
Poecilia latipinna	Sailfin molly	2	12108
Culex sp.	Mosquito	2	8354
Lepomis macrochirus	Bluegill	13	6207
Gambusia affinis	Western mosquitofish	16	5524
Polycelis nigra	Planarian	1	4611
Lymnaea sp.	Pond snail	8	4351
Pimephales promelas	Fathead minnow	12	3690
Daphnia magna	Water flea	18	1970
Ceriodaphnia dubia	Water flea	7	1592
Morone saxatilis	Striped bass	8	1064
Amphipoda	Scud	4	809
Oryzias latipes	Medaka, high-eyes	6	798
Tricorythus sp.	Mayfly	1	446

TABLE 1
ACUTE TOXICITY OF SULFATE

Chemical Name	Scientific Name	Common Name	Endpoint	Effect	Test Duration (Hour)	Exposure Type	Sulfate Concentration (mg/L)	Source*	References
Sodium sulfate	Daphnia magna	Water flea	LC50	MOR	48	S	1733.94	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Daphnia magna	Water flea (Young)	LC50	MOR	48	S	4125.33	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Daphnia magna	Water flea	LC50	MOR	72	S	490.30	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Daphnia magna	Water flea (Adult)	LC50	MOR	96	S	3075.00	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Calcium sulfate	Daphnia magna	Water flea	LC50	MOR	24	S	1390.02	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Magnesium sulfate	Daphnia magna	Water flea	LC50	MOR	24	S	1883.44	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Magnesium sulfate	Daphnia magna	Water flea	LC50	MOR	48	S	1452.48	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Magnesium sulfate	Daphnia magna	Water flea	LC50	MOR	24	S	768.54	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Magnesium sulfate	Daphnia magna	Water flea	LC50	MOR	48	S	741.40	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Magnesium sulfate	Daphnia magna	Water flea	LC50	MOR	72	S	687.14	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Magnesium sulfate	Daphnia magna	Water flea	LC50	MOR	96	S	628.87	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Magnesium sulfate	Daphnia magna	Water flea	LC50	MOR	96	S	3035.00	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Daphnia magna		LC50	MOR	96		3075.07	HSDB	Environment Canada 1985. . HSDB
Sodium sulfate	Culex	Mosquito	LC50	MOR	24	S	7729.90	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Culex	Mosquito	LC50	MOR	48	S	9028.00	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Tricorythus	Mayfly	LC50	MOR	96	R	446.35	AQUIRE	Goetsch, P.A. and C.G. Palmer 1997. Salinity Tolerances of Selected Macroinvertebrates of the Sabie River, Kruger National Park, South Africa. Arch Environ Contam Toxicol 32(1):32-41
Sodium sulfate	Lymnaea	Pond snail	EC50	MOR	24	S	3652.60	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Lymnaea	Pond snail	EC50	MOR	48	S	3651.90	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Lymnaea	Pond snail	EC50	MOR	72	S	3651.90	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Lymnaea	Pond snail	EC50	MOR	96	S	2402.84	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316

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Chemical Name	Scientific Name	Common Name	Endpoint	Effect	Test Duration (Hour)	Exposure Type	Sulfate Concentration (mg/L)	Source*	References
Magnesium sulfate	Lymnaea	Pond snail	EC50	MOR	24	S	8403.66	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Magnesium sulfate	Lymnaea	Pond snail	EC50	MOR	48	S	5207.40	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Magnesium sulfate	Lymnaea	Pond snail	EC50	MOR	72	S	5027.83	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Magnesium sulfate	Lymnaea	Pond snail	EC50	MOR	96	S	4987.93	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	24	S	3651.94	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Sodium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	24	S	5275.02	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Sodium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	48	S	2664.56	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Sodium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	48	S	3834.54	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Sodium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	144	S	1487.83	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Sodium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	144	S	2164.11	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Sodium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	96	S	2509.02	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Sodium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	96	S	3618.13	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
	Gambusia affinis	Western mosquitofish	LC50	MOR	48	CF	11834.99	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711 (WPCRS)
Calcium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	24	S	39513.15	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Calcium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	48	S	39513.15	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Calcium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	96	S	39513.15	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Magnesium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	24	S	2474.01	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711

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Chemical Name	Scientific Name	Common Name	Endpoint	Effect	Test Duration (Hour)	Exposure Type	Sulfate Concentration (mg/L)	Source*	References
Magnesium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	48	S	2474.01	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Magnesium sulfate	Gambusia affinis	Western mosquitofish	LC50	MOR	96	S	2474.01	AQUIRE	Wallen, I.E., W.C. Greer, and R. Lasater 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind Wastes 29(6):695-711
Sodium sulfate		Mosquito fish	LC50	MOR	48		11834.99	HSDB	Environment Canada 1985. . HSDB
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	8791.71	AQUIRE	Cairns, J.C.J. and A. Scheier 1959. The Relationship of Bluegill Sunfish Body Size to its Tolerance for Some Common Chemicals. Proc 13th Ind Waste Conf , Purdue Univ Eng Bull 96:243-252
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	8622.63	AQUIRE	Cairns, J.C.J. and A. Scheier 1959. The Relationship of Bluegill Sunfish Body Size to its Tolerance for Some Common Chemicals. Proc 13th Ind Waste Conf , Purdue Univ Eng Bull 96:243-252
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	8453.56	AQUIRE	Cairns, J.C.J. and A. Scheier 1959. The Relationship of Bluegill Sunfish Body Size to its Tolerance for Some Common Chemicals. Proc 13th Ind Waste Conf , Purdue Univ Eng Bull 96:243-252
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	9129.85	AQUIRE	Academy of, N.S. 1960. The Sensitivity of Aquatic Life to Certain Chemicals Commonly Found in Industrial Wastes. Final Report No RG-3965(C2R1), U S Public Health Service Grant, Academy of Natural Sciences, Philadelphia, P A:89
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	24	S	11834.99	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	9129.85	AQUIRE	Patrick, R., J. Cairns, J, and A. Scheier 1968. The Relative Sensitivity of Diatoms, Snails, and Fish to Twenty Common Constituents of Industrial Wastes. Prog Fish-Cult 30(3):137-140 (Author Communication Used) (Publ in Part As 2406) :
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	2962.13	AQUIRE	Trama, F.B. 1954. The Acute Toxicity of Some Common Salts of Sodium, Potassium and Calcium to the Common Bluegill. Proc Acad Nat Sci Philadelphia 106:185-205
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	2055.91	AQUIRE	Trama, F.B. 1954. The Acute Toxicity of Some Common Salts of Sodium, Potassium and Calcium to the Common Bluegill. Proc Acad Nat Sci Philadelphia 106:185-205
Sodium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	9129.85	AQUIRE	Trama, F.B. 1954. The Acute Toxicity of Some Common Salts of Sodium, Potassium and Calcium to the Common Bluegill. Proc Acad Nat Sci Philadelphia 106:185-205 (WPCRS)
Calcium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	2102.66	AQUIRE	Academy of, N.S. 1960. The Sensitivity of Aquatic Life to Certain Chemicals Commonly Found in Industrial Wastes. Final Report No RG-3965(C2R1), U S Public Health Service Grant, Academy of Natural Sciences, Philadelphia, P A:89
Calcium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	96	S	2102.66	AQUIRE	Patrick, R., J. Cairns, J, and A. Scheier 1968. The Relative Sensitivity of Diatoms, Snails, and Fish to Twenty Common Constituents of Industrial Wastes. Prog Fish-Cult 30(3):137-140 (Author Communication Used) (Publ in Part As 2406) :
Magnesium sulfate	Lepomis macrochirus	Bluegill	LC50	MOR	24	S	15163.30	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate		Bluegill	LC50	MOR	96		8622.63	HSDB	NIH/EPA; OHM/TADS 1986. . HSDB
Sodium sulfate	Morone saxatilis	Striped bass (fry)	LC50	MOR	24	S	1352.00	Hughes, 1975	Hughes, J.S. 1975. Striped Bass, *Morone saxatilis* (Walbaum), Culture Investigations in Louisiana with notes on Sensitivity of Fry and Fingerlings to Various Chemicals. La Dep Wildl Fish Fisheries Bulletin No. 13

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Sodium sulfate	Morone saxatilis	Striped bass (fingerling)	LC50	MOR	24	S	2367.00	Hughes, 1975	Hughes, J.S. 1975. Striped Bass, *Morone saxatilis* (Walbaum), Culture Investigations in Louisiana with notes on Sensitivity of Fry and Fingerlings to Various Chemicals. La Dep Wildl Fish Fisheries Bulletin No. 13
Sodium sulfate	Morone saxatilis	Striped bass (fry)	LC50	MOR	48	S	676.00	Hughes, 1975	Hughes, J.S. 1975. Striped Bass, *Morone saxatilis* (Walbaum), Culture Investigations in Louisiana with notes on Sensitivity of Fry and Fingerlings to Various Chemicals. La Dep Wildl Fish Fisheries Bulletin No. 13
Sodium sulfate	Morone saxatilis	Striped bass (fingerling)	LC50	MOR	48	S	2367.00	Hughes, 1975	Hughes, J.S. 1975. Striped Bass, *Morone saxatilis* (Walbaum), Culture Investigations in Louisiana with notes on Sensitivity of Fry and Fingerlings to Various Chemicals. La Dep Wildl Fish Fisheries Bulletin No. 13
Sodium sulfate	Morone saxatilis	Striped bass (fry)	LC50	MOR	72	S	338.00	Hughes, 1975	Hughes, J.S. 1975. Striped Bass, *Morone saxatilis* (Walbaum), Culture Investigations in Louisiana with notes on Sensitivity of Fry and Fingerlings to Various Chemicals. La Dep Wildl Fish Fisheries Bulletin No. 13
Sodium sulfate	Morone saxatilis	Striped bass (fingerling)	LC50	MOR	72	S	2367.00	Hughes, 1975	Hughes, J.S. 1975. Striped Bass, *Morone saxatilis* (Walbaum), Culture Investigations in Louisiana with notes on Sensitivity of Fry and Fingerlings to Various Chemicals. La Dep Wildl Fish Fisheries Bulletin No. 13
Sodium sulfate	Morone saxatilis	Striped bass (fry)	LC50	MOR	96	S	169.00	Hughes, 1975	Hughes, J.S. 1975. Striped Bass, *Morone saxatilis* (Walbaum), Culture Investigations in Louisiana with notes on Sensitivity of Fry and Fingerlings to Various Chemicals. La Dep Wildl Fish Fisheries Bulletin No. 13
Sodium sulfate	Morone saxatilis	Striped bass (fingerling)	LC50	MOR	96	S	2367.00	Hughes, 1975	Hughes, J.S. 1975. Striped Bass, *Morone saxatilis* (Walbaum), Culture Investigations in Louisiana with notes on Sensitivity of Fry and Fingerlings to Various Chemicals. La Dep Wildl Fish Fisheries Bulletin No. 13
Sodium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	24	S	5464.38	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Sodium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	48	S	5383.23	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Sodium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	96	S	5383.23	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Sodium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	24-96	S	7439.14	AQUIRE	Henderson, C., Q.H. Pickering, and C.M. Tarzwellet.al 1960. The toxicity of organic phosphorus and chlorinated hydrocarbon insecticides to fish. In: C.M. Tarzwell (comp.), Biological Problems in Water Pollution, Cincinnati, Ohio, Robt. A. Taft San. Eng.
Sodium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	24-96	S	9298.92	AQUIRE	Henderson, C., Q.H. Pickering, and C.M. Tarzwellet.al 1960. The toxicity of organic phosphorus and chlorinated hydrocarbon insecticides to fish. In: C.M. Tarzwell (comp.), Biological Problems in Water Pollution, Cincinnati, Ohio, Robt. A. Taft San. Eng.
Calcium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	24	S	1390.02	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Calcium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	48	S	1390.02	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Calcium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	96	S	1390.02	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019

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Chemical Name	Scientific Name	Common Name	Endpoint	Effect	Test Duration (Hour)	Exposure Type	Sulfate Concentration (mg/L)	Source*	References
Magnesium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	24	S	3695.06	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Magnesium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	48	S	2801.22	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Magnesium sulfate	Pimephales promelas	Fathead minnow	LC50	MOR	96	S	2250.55	AQUIRE	Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans 1997. Statistical Models to Predict the Toxicity of Major Ions to Ceriodaphnia dubia, Daphnia magna and Pimephales promelas (Fathead Minnows). Environ Toxicol Chem 16(10):2009-2019
Sodium sulfate		Fathead minnow	LC50	MOR	24-96		9298.92	HSDB	Environment Canada 1985. . HSDB
Sodium sulfate	Poecilia latipinna	Sailfin molly	LC50	MOR	24	S	13552.75	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Sodium sulfate	Poecilia latipinna	Sailfin molly	LC50	MOR	48	S	10817.85	Dowden & Bennett, 1965	Dowden, B.F. and H.J. Bennett 1965. Toxicity of Selected Chemicals to Certain Animals. J Water Pollut Control Fed 37(9):1308-1316
Magnesium sulfate	Oryzias latipes	Medaka, high-eyes	LC50	MOR	24	S	798.07	AQUIRE	Tsuji, S., Y. Tonogai, Y. Ito, and S. Kanoh 1986. The Influence of Rearing Temperatures on the Toxicity of Various Environmental Pollutants for Killifish (Oryzias latipes). J Hyg Chem /Eisei Kagaku 32(1):46-53 (JPN) (ENG ABS) :
Magnesium sulfate	Oryzias latipes	Medaka, high-eyes	LC50	MOR	24	S	798.07	AQUIRE	Tsuji, S., Y. Tonogai, Y. Ito, and S. Kanoh 1986. The Influence of Rearing Temperatures on the Toxicity of Various Environmental Pollutants for Killifish (Oryzias latipes). J Hyg Chem /Eisei Kagaku 32(1):46-53 (JPN) (ENG ABS) :
Magnesium sulfate	Oryzias latipes	Medaka, high-eyes	LC50	MOR	24	S	798.07	AQUIRE	Tsuji, S., Y. Tonogai, Y. Ito, and S. Kanoh 1986. The Influence of Rearing Temperatures on the Toxicity of Various Environmental Pollutants for Killifish (Oryzias latipes). J Hyg Chem /Eisei Kagaku 32(1):46-53 (JPN) (ENG ABS) :
Magnesium sulfate	Oryzias latipes	Medaka, high-eyes	LC50	MOR	48	S	798.07	AQUIRE	Tsuji, S., Y. Tonogai, Y. Ito, and S. Kanoh 1986. The Influence of Rearing Temperatures on the Toxicity of Various Environmental Pollutants for Killifish (Oryzias latipes). J Hyg Chem /Eisei Kagaku 32(1):46-53 (JPN) (ENG ABS) :
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Note:
*=Source other than AQUIRE and HSDB indicate AQUIRE value replaced by the original data source
MOR= Mortality
S= Static
R= Renewal
CF= continuous flowthrough