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Document Cover Sheet

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Document Type:

National List Petition or Petition Update

A petition is a request to amend the USDA National Organic Program's National List of Allowed and Prohibited Substances (National List).

Any person may submit a petition to have a substance evaluated by the National Organic Standards Board (7 CFR 205.607(a)).

Guidelines for submitting a petition are available in the NOP Handbook as NOP 3011, National List Petition Guidelines.

Petitions are posted for the public on the NOP website for Petitioned Substances.

Technical Report

A technical report is developed in response to a petition to amend the National List. Reports are also developed to assist in the review of substances that are already on the National List.

Technical reports are completed by third-party contractors and are available to the public on the NOP website for Petitioned Substances.

Contractor names and dates completed are available in the report.

Magnesium Sulfate

Handling/Processing

Summary of Petitioned Use

This limited scope technical report provides updated information to the National Organic Standards Board (NOSB) to support the sunset review of magnesium sulfate, listed at 7 CFR 205.605(a)(18). Magnesium sulfate is currently listed as an allowed nonagricultural nonsynthetic substance for use in organic handling. This limited scope technical report focuses on the manufacturing processes used to generate magnesium sulfate, as well as the associated environmental impacts when used in organic processing and handling.

Magnesium sulfate was initially reviewed by the NOSB in 1995 (NOSB, 1995). It was included on the National List of Allowed and Prohibited Substances (hereafter referred to as the “National List”) with the first publication of the National Organic Program (NOP) Final Rule (65 FR 80548, December 21, 2000). The NOSB has continued to recommend the renewal of magnesium sulfate in 2005, 2010, 2015, and 2019 (NOSB, 2005, 2010, 2015, 2019).

Synthetic and nonsynthetic forms of magnesium sulfate exist. The placement of the substance at § 205.605(a)(18), and further reiteration within the annotation means that only nonsynthetic forms of magnesium sulfate are allowed in organic production and handling (under this listing). The annotation does not otherwise prescribe a specific use of the material. We do not evaluate magnesium sulfate, used as a synthetic nutrient mineral under § 205.605(b)(20) within this report.

Evaluation Questions for Substances to be used in Organic Handling

Evaluation Question #1: Describe the most prevalent processes used to manufacture or formulate the petitioned substance. Further, describe any chemical change that may occur during manufacture or formulation of the petitioned substance when this substance is extracted from naturally occurring plant, animal, or mineral sources [7 U.S.C. 6502 (21)].

Natural occurrence

The dissolved ions that form magnesium sulfate are naturally occurring in seawater and mineral springs (Rao & Kawamura, 2007; Seeger et al., 1990). In solid form, it is naturally occurring as the minerals kieserite and epsomite, hydrated salt rocks that precipitated from surface or near surface brines by solar evaporation (Rao & Kawamura, 2007; Seeger et al., 1990).

It may also form as a byproduct of *serpentinization* of magnesium rich mantle rocks (Debure et al., 2019; White et al., 2018). When seawater infiltrates fractures in the seafloor, it can reach high temperature and pressure. The supercritical seawater participates in the alteration of minerals in the Earth’s mantle, producing hydrated magnesium silicates and salt rich brines. These brines then migrate upward through fractures where they are rapidly cooled by cold seawater. This rapid cooling leads to precipitation of salt minerals (Debure et al., 2019; White et al., 2018).

Hypersaline brine bodies are found in arid to semi-arid climates and can be either marine or continental (Warren, 2006; White et al., 2018). Marine brines are a uniform mixture primarily composed of sodium and chloride, with lesser amounts of sulfate, magnesium, calcium, potassium, carbonate, and bicarbonate. Continental brines are less predictable, as they are deposits from rivers and groundwater, which are less uniform than seawater (White et al., 2018). Magnesium sulfate only forms in continental brine systems that contain dissolved dolomite ($\text{CaMg}[\text{CO}_3]_2$). The final brine is comprised of magnesium, sodium, calcium, sulfate, chloride ions; and water (White et al., 2018).

50 Magnesium sulfate hydration states form different minerals

51 A variety of magnesium sulfate minerals exist, each described by a different hydration state (see [Table 1](#),
52 below). A common challenge in isolating magnesium sulfate is limiting the potential creation of double
53 salts (as evidenced by the formation of distinct crystal lattice), usually with sodium and calcium, which
54 makes the isolation of most of these stages challenging and sometimes unfeasible (Lindström et al., 2016;
55 Sadan, 1994).

56
57 Manufacturers therefore use different sources, conditions, and methods to obtain magnesium sulfate in
58 varying hydration states. The most common paths to producing nonsynthetic magnesium sulfate are by:

- 59 • open-pit mining of salt efflorescence¹
- 60 • isolation of the material from salt ponds

61
62 Raw magnesium sulfate primarily appears in the form of (Balboni et al., 2011):

- 63 • magnesium sulfate monohydrate (kieserite)
- 64 • magnesium sulfate hexahydrate (hexahydrite)
- 65 • magnesium sulfate heptahydrate (epsomite)

66 Of these, kieserite and epsomite are the most commonly occurring crystalline phases (Kramer, 2001) as the
67 other forms are metastable (Lindström et al., 2016; Steiger et al., 2011).²

68
69 Other more rare hydration states are (Steiger et al., 2011; Vaniman et al., 2004):

- 70 • magnesium sulfate dihydrate (sanderite)
- 71 • magnesium sulfate tetrahydrate (starkeyite)
- 72 • magnesium sulfate pentahydrate (pentahydrite)

73
74 Different hydration states form due to environmental factors that affect the absorption of water by the
75 compound. The formation of the hydrates is dependent on the relative humidity and temperature during
76 the evaporation phase, and of the composition of the parent brine (Balboni et al., 2011; Lindström et al.,
77 2016; Linnow et al., 2014). Sadan et. al. (1994) describes applying a minimal amount of pressure to crystal
78 clusters as they form, resulting in the hexahydrate or lower hydrated crystals. Additionally, treating raw
79 material with higher temperatures and/or subjecting the raw material to longer periods of heating produce
80 lower hydration states. Lower hydration phases may be recrystallized to form higher purity products of
81 various hydration states (Sadan, 1994).

82
83 Magnesium sulfate heptahydrate will lose one mole of water on exposure to dry air at room temperature
84 (Merck Research Laboratories Division, 2001). Under dry conditions, the following water loss is observed

- 85 • Four moles are lost at 70-80 °C.
- 86 • Five moles are lost at 100 °C.
- 87 • Six moles are lost at 120 °C.
- 88 • Seven moles are lost at ~250 °C.

89 Conversely, the mineral rapidly absorbs water when exposed to moist air (Merck Research Laboratories
90 Division, 2001).

91

¹ Efflorescence: Salt deposit formed on a surface via evaporation.

² Metastable: A system with precarious stability that can easily be disturbed.

92 **Table 1. Naturally occurring magnesium sulfate hydrates and their stability. These crystalline phases precipitate**
 93 **from parent brines, namely rock formations, or salt ponds.**

Names	Chemical Formula	Stability	Mineral name(s)	CAS RN
Magnesium sulfate monohydrate	MgSO ₄ ·H ₂ O	Stable	Kieserite	14168-73-1
Magnesium sulfate dihydrate	MgSO ₄ ·2H ₂ O	Metastable	Sanderite	---
Magnesium sulfate tetrahydrate	MgSO ₄ ·4H ₂ O	Metastable	Starkeyite, Leonhardtite	---
Magnesium sulfate pentahydrate	MgSO ₄ ·5H ₂ O	Metastable	Pentahydrate	---
Magnesium sulfate hexahydrate	MgSO ₄ ·6H ₂ O	Stable*	Hexahydrate	17830-18-1
Magnesium sulfate heptahydrate	MgSO ₄ ·7H ₂ O	Stable	Epsomite, Epsom salt	10034-99-8
Magnesium sulfate undecahydrate	MgSO ₄ ·11H ₂ O	Stable below 2 °C	Meridianiite	---

94 **Sources:** (Balboni et al., 2011; Kramer, 2001; Lindström et al., 2016; National Center for Biotechnology Information,
 95 2023b; Steiger et al., 2011; Vaniman et al., 2004; Warren, 2006)

96 *Most sources state that this hydration state is stable; however, some declare this as a metastable phase that will
 97 quickly absorb an additional water molecule and become the more stable heptahydrate phase, at standard conditions
 98 (~50-55% relative humidity at 25 °C).
 99

100 Manufacturers produce magnesium sulfate from both liquid brines and solid minerals. These sources are
 101 discussed below.

102 **Production from kieserite (MgSO₄•H₂O)**

103 Magnesium sulfate monohydrate, also known as the mineral kieserite (Merck Research Laboratories
 104 Division, 2001), occurs in nature as a product of dried saline lake deposits (Deiseroth et al., 2008; Klein &
 105 Hurlbut, 1999). The mineral forms naturally in these marine deposits where seawater concentrates and is
 106 exposed to prolonged evaporation (Rao & Kawamura, 2007). These deposits are primarily found
 107 underground, near the surface and are accessed through open-pit mines (Wu et al., 2021). Although
 108 kieserite is mined in large quantities, most is between 89–93% pure (Sadan, 1994). Kieserite can contain the
 109 following impurities (Deiseroth et al., 2008):

- 110 • halite (NaCl)
- 111 • sylvite (KCl)
- 112 • polyhalite (K₂Ca₂Mg(SO₄)₄•2H₂O)
- 113 • langbeinite (K₂Mg₂(SO₄)₃)
- 114 • other salt-containing minerals

115
 116
 117 Crude salts are mined from these dried saline deposits, ground, and classified according to grain size
 118 (Deiseroth et al., 2008). The solid mixture of salts is treated with an organic conditioning agent, usually a
 119 fatty acid and/or an aromatic carboxylic acid, in order to exploit the differences in solubility and aid in a
 120 physical separation process (Deiseroth et al., 2008). To avoid dissolution, relative humidity is maintained at
 121 around 5–10%. The conditioning agent causes the crude kieserite fraction to separate from potassium
 122 chloride in a dry electrostatic separator (Deiseroth et al., 2008; Nilsen & Piasecki, 2007).³
 123

124 In another separation method, the conditioning agent creates one hydrophobic layer and one hydrophilic
 125 layer (Deiseroth et al., 2008). Air is bubbled through the mixture and the hydrophobic particles float to the
 126 surface where they accumulate as froth and are collected. Different variations of this method exist
 127 (Deiseroth et al., 2008). One variation uses conditioning agents to select and float potassium chloride,
 128 attaching the particles to small air bubbles and leaving a crude kieserite salt mixture as the hydrophilic
 129 layer.
 130

³ Electrostatic separation: Common chemical industry method where electromagnetic field generation within a liquid phase causes dispersed material to combine within the dispersant. The dispersed material can then be separated from liquid.

131 Regardless of the separation method, the crude kieserite fraction undergoes a water-based hot leaching
132 process where salt impurities are separated based on solubility differences. Once kieserite is isolated, it is
133 crystallized, centrifuged, dried, and sieved (Rao & Kawamura, 2007).
134

135 **Production from epsomite, Epsom salt ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$)**

136 Magnesium sulfate heptahydrate, also known as the mineral epsomite or Epsom salt, occurs in nature as
137 efflorescence on the rocks of cave walls from deposition from saline springs (Klein & Hurlbut, 1999;
138 Wahyudi & Agung, 2006) and in seawater brines (Sadan, 1994). Due to similarities in solubility, epsomite in
139 brine is commonly found in sodium (halite) and magnesium double salts (Sadan, 1994). Separating
140 epsomite and halite tends to be a costly and extremely complicated process due to the formation of these
141 double salts (Sadan, 1994). For this reason, most (but not all) commercial sourcing of natural epsomite is
142 from efflorescence. These efflorescence deposits come from saline springs in arid regions and in dry caves,
143 and from the deposition of sulfur and magnesium-rich waters in tunnels of sulfide mines (Wahyudi &
144 Agung, 2006). The dryness of the caves prevents double salt formation, which in turn keeps magnesium
145 sulfate from joining a mixture in solution.
146

147 Due to limited quantities of naturally-occurring epsomite, manufacturers also use a liquid brine epsomite-
148 halite separation method (Wahyudi & Agung, 2006). To separate the salts, steps are taken to avoid
149 formation of double salts in the first place. One common method is to evaporate salt brines to the bittern
150 salt stage (see [Figure 1](#), at the end of this question). From here, the brine is diluted with fresh water to
151 control the precipitation of halite (Bollinger et al., 2015). The remaining brine is cooled to below $-5\text{ }^\circ\text{C}$,
152 precipitating magnesium sulfate out of the solution. The magnesium sulfate is subsequently re-crystallized.
153 This refrigeration process requires a large amount of magnesium-containing brine to produce commercial
154 amounts of epsomite, and is not a major processing method (Sadan, 1994).
155

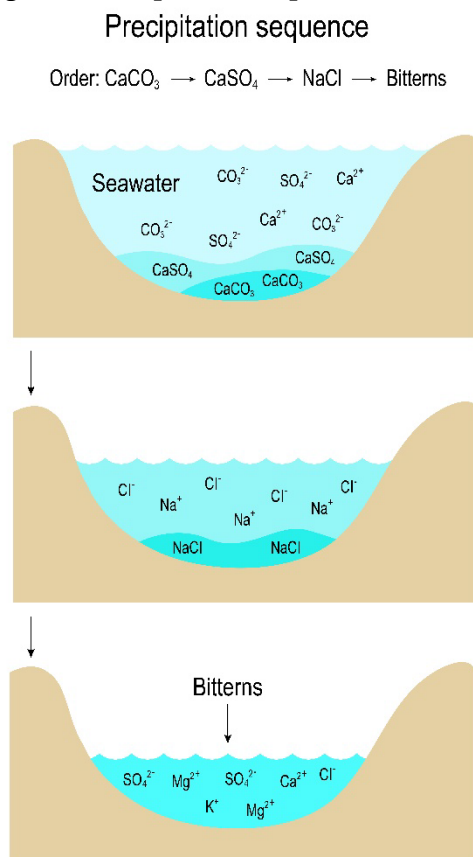
156 Epsomite is also manufactured through the dissolution of the monohydrate phase (kieserite) in hot water
157 followed by a crystallization process in cold water (Rao & Kawamura, 2007). Dissolving kieserite allows for
158 subsequent recrystallization of higher hydrated phases, mainly hexa- and heptahydrate forms (Lindström
159 et al., 2016). However, the reverse process does not occur. Both epsomite and hexahydrate do not easily
160 revert to kieserite upon desiccation in standard conditions (Balboni et al., 2011). The transition between
161 hexa- and heptahydrate is reversible and occurs at $\sim 50\text{--}55\%$ humidity at room temperature (Vaniman et al.,
162 2004).
163

164 **Production of magnesium sulfate from brine precipitation**

165 Manufacturers isolate magnesium sulfate by concentrating the hypersaline waters and precipitating the
166 dissolved salts (Loganathan et al., 2017; White et al., 2018). Differences in the solubility of different salts
167 cause the dissolved minerals to precipitate out of solution in stages (see [Figure 1](#), below) (White et al., 2018):

- 168 1) Calcium carbonate is the first to precipitate as water evaporates, at around twice the concentration
169 of the parent brine.
- 170 2) Calcium sulfate, then sodium chloride precipitate at ten to twelve times the concentration of the
171 parent brine.
- 172 3) The remaining solution, now at 70-90 times the concentration of the parent brine, is a mixture of
173 potassium or magnesium sulfates and chlorides (bittern salts).
- 174 4) Depending on the environmental factors and the desired product, magnesium sulfate is isolated
175 from this brine via different methods which are explored in more detail below.
176

177

Figure 1: Precipitation sequence of seawater

Sources: (Debure et al., 2019; Warren, 2006; White et al., 2018)

178

179

180

181 Production of synthetic magnesium sulfate

182 Magnesium sulfate can also be produced synthetically. Anhydrous magnesium sulfate is the most common
 183 synthetic form of magnesium sulfate (Rao & Kawamura, 2007; Zhang et al., 2015). Synthetic forms of
 184 magnesium sulfate are made by (Seeger et al., 1990; Wahyudi & Agung, 2006):

- 185 • Reacting magnesium oxide, magnesium hydroxide, or magnesium carbonate with sulfuric acid.
 186 The sulfuric acid used can be contaminated with organic compounds.
- 187 • Reacting dolomite, olivine, serpentine, or peridotite with sulfuric acid.
- 188 • Reacting magnesium oxide with pyrite during roasting, followed by extraction.
- 189 • Reacting waste serpentine from asbestos production with ammonium sulfate above 250 °C,
 190 followed by a water extraction.

191

192 **Evaluation Question #2: Discuss whether the petitioned substance is formulated or manufactured by a**
 193 **chemical process or created by naturally occurring biological processes [7 U.S.C. 6502(21)]. Discuss**
 194 **whether the petitioned substance is derived from an agricultural source.**

195

196 Food grade magnesium sulfate is commercially available in the heptahydrate form (Epsom salts) in both
 197 solid and liquid products (Food and Agriculture Organization of the United Nations & World Health
 198 Organization, 2007). According to the Joint FAO/WHO Expert Committee on Food Additives, anhydrous
 199 magnesium sulfate does not have any food uses. The committee also indicated that the heptahydrate form
 200 used as a food additive is manufactured by dissolving kieserite.

201

202 Synthetic/nonsynthetic classification

203 Evaluation of magnesium sulfate against Guidance NOP 5033-1 *Decision Tree for Classification of Materials as*
 204 *Synthetic or Nonsynthetic* (NOP, 2016a) is discussed below.

205

206 **1. Is the substance manufactured, produced, or extracted from a natural source?**

207

208 *Production from epsomite, kieserite, and brines*

209 The starting material for food grade magnesium sulfate is magnesium sulfate minerals in various states of
210 hydration. Magnesium sulfate's production processes start with magnesium sulfate-containing rocks or
211 from salt brines. Both sources are natural.

212

213 *Production from the reaction of magnesium containing materials with sulfuric acid*

214 When produced from the reaction of magnesium containing materials and sulfuric acid, the substance is
215 not manufactured, produced, or extracted from a natural source, and is therefore synthetic, according to
216 the decision tree.

217

218 2. *a. Has the substance undergone a chemical change so that it is chemically or structurally different*
219 *than how it naturally occurs in the source material?*

220

221 *b. At the end of the extraction process, does the substance meet all of the criteria described at 4.6 of*
222 *NOP 5033?*

223 • *At the end of the extraction process, the material has not been transformed into a different substance via*
224 *chemical change;*

225 • *The material has not been altered into a form that does not occur in nature; and*

226 • *Any synthetic materials used to separate, isolate, or extract the substance have been removed from the*
227 *final substance (e.g., via evaporation, distillation, precipitation, or other means) such that they have no*
228 *technical or functional effect in the final product.*

229

230 *Production from epsomite, kieserite, and brines*

231 Magnesium sulfate isolation occurs by exploiting the chemical properties of materials present in the source
232 material, without any alteration to the structure of the salt. One method of manufacturing involves using
233 conditioning agents to separate brine components by charge (Deiseroth et al., 2008). These conditioning
234 agents, though they may be synthetic themselves, do not chemically react with magnesium sulfate and
235 have no technical or functional effect in the final product. Instead, they physically interact with the
236 materials to reduce resistivity (i.e., condition them to accept electric flow) and are removed alongside
237 impurities.

238

239 Therefore, question 2b of the Decision Tree is yes and question 2 is therefore "no." Magnesium sulfate
240 derived from these methods is nonsynthetic.

241

242 *Production from the reaction of magnesium containing materials with sulfuric acid*

243 When produced from the reaction of magnesium containing materials and sulfuric acid, the substance has
244 undergone a change, such that it is a chemically different substance.

245

246 3. *Is the chemical change created by a naturally occurring biological process, such as composting,*
247 *fermentation, or enzymatic digestion; or by heating or burning biological matter?*

248

249 *Production from the reaction of magnesium containing materials with sulfuric acid*

250 When produced from the reaction of magnesium containing materials and sulfuric acid, the chemical
251 change is not created by a naturally occurring process. Therefore, magnesium sulfate derived from these
252 methods is synthetic.

253

254 **Agricultural/nonagricultural classification**

255 Evaluation of magnesium sulfate against Guidance NOP 5033-2 *Decision Tree for Classification of Agricultural*
256 *and Nonagricultural Materials for Organic Livestock Production or Handling* (NOP, 2016b) is discussed below.

257

258 1. *Is the substance a mineral or bacterial culture, as included in the definition of nonagricultural*
259 *substances at section 205.2 of the USDA organic regulations?*
260

261 When produced from epsomite, kieserite, or brines, magnesium sulfate is a mineral substance. Therefore,
262 magnesium sulfate from these sources is nonagricultural, according to the decision tree.
263

264 When produced from the reaction of magnesium containing material with sulfuric acid, magnesium sulfate
265 is also a mineral. Therefore, these sources are also nonagricultural.
266

267 **Evaluation Question #3: If the substance is a synthetic substance, provide a list of nonsynthetic or**
268 **natural source(s) of the petitioned substance [7 CFR 205.600(b)(1)].**
269

270 Magnesium sulfate occurs in both nonsynthetic and synthetic forms. As stated in [Evaluation Question #2](#),
271 food grade magnesium carbonate is produced from nonsynthetic sources. The most common commercial
272 forms of magnesium sulfate are as the nonsynthetic minerals epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) and kieserite
273 ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$) (Kramer, 2001, p. 9; Zhang et al., 2015). Steiger et. al. (2011) stated that kieserite is not
274 commercially available as a monohydrate, but rather, it is sold in the metastable range $\text{MgSO}_4 \cdot 1.20$ –
275 $1.27\text{H}_2\text{O}$. This is due to its difficult crystallization. Regardless of its true hydration state, kieserite is
276 commercially available from nonsynthetic sources. Magnesium sulfate also naturally occurs in seawater
277 and mineral springs (Rao & Kawamura, 2007).
278

279 **Evaluation Question #9: Discuss and summarize findings on whether the manufacture and use of the**
280 **petitioned substance may be harmful to the environment or biodiversity [7 U.S.C. 6517(c)(1)(A)(i) and**
281 **7 U.S.C. 6517(c)(2)(A)(i)].**
282

283 **Use**

284 The hydrated forms of magnesium sulfate are used in food as nutrient sources in salt substitutes and
285 dietary supplements, as firming agents, as coagulating agents in tofu production, as flavor enhancers in
286 bottled water products, and as fermentation aids in the processing of beer and malt beverages (Food and
287 Agriculture Organization of the United Nations & World Health Organization, 2007; Guan et al., 2021; Rao
288 & Kawamura, 2007). The quantity of magnesium sulfate used for these purposes is negligible compared to
289 other industrial uses. Environmental, chemical, agricultural, and deicing applications made up 75% of
290 magnesium compound consumption (including magnesium sulfate) in the U.S. in 2023 (USGS, 2023). The
291 U.S. Geological Survey's Mineral Commodity Summary did not cite food processing in the remaining
292 industrial uses. Though these uses are not noted as being specific to one type of food production, it is
293 reasonable to expect that magnesium sulfate would be used similarly in organic processing.
294

295 Given the small quantities of magnesium sulfate used as food additives and the ubiquitous nature of
296 magnesium and sulfate ions in the environment, food processing applications do not present an area of
297 environmental concern. The National Library of Medicine does not list any food uses as sources of artificial
298 (human caused) magnesium sulfate pollution (National Center for Biotechnology Information, 2023a).
299 Similarly, the EPA (2003) reported on anthropogenic sources of environmental sulfur pollution, noting the
300 burning of sulfur-containing fossil fuels, household wastes such as detergents, and effluents coming from
301 industries such as steel mills, tanneries, sulfate-pulp mills, and textile plants, but did not cite the use of
302 magnesium sulfate in food processing as a source of sulfur pollution (U.S. EPA, 2003).
303

304 **Manufacturing**

305 The environmental impacts related to the food additive, magnesium sulfate, come primarily from its
306 sourcing and manufacturing.
307

308 Magnesium sulfate deposits exist in the Western United States; however, the material is not mined from
309 domestic sources and is instead imported primarily from China, India, Germany, and Canada (Kramer,
310 2001; Merrill, 2022). Currently, the largest importing source of the material for the United States is China
311 (Merrill, 2022). China is currently the largest producer and exporter of magnesium compounds in the
312 world, including magnesium sulfate (Wu et al., 2021). Most of this magnesium sulfate comes from salt

313 lakes in the northern part of the Tibet Autonomous Region and Qaidam Basin of the Qinghai Province.
314 Because magnesium sulfate is not as readily available as other magnesium compounds, literature about
315 mining activities for this specific material is limited. Wu et. al. (2021) notes that magnesium mining
316 activities in China are not well-managed, resulting in heavy damage to surface vegetation through large-
317 scale open-pit mining. The equipment itself also causes serious water and air pollution (Wu et al., 2021).
318

319 International studies primarily in Australia have also identified a need for more research and data
320 regarding the effects (if any) of magnesium sulfate contamination stemming from mining operations
321 (Canham et al., 2020; van Dam et al., 2010). The focus of existing studies shows that low-hardness waters
322 (i.e., soft waters with low concentrations of Ca^{2+} and/or Mg^{2+}) are susceptible to adverse effects stemming
323 from discharges from mining operations.
324

325 Although van Dam et al. (2010) report magnesium sulfate to be of generally low toxicity and low
326 significance as an environmental contaminant, it is potentially toxic to aquatic life. Its main toxic effect on
327 aquatic life is cellular damage caused by osmo-regulatory stress due to elevated ion concentrations
328 (Kleinhenz et al., 2019). Sulfate contributes slightly to toxicity; it is the magnesium ion that primarily causes
329 toxicity to invertebrate organisms (van Dam et al., 2010). Magnesium sulfate's potential for aquatic toxicity
330 comes from its high solubility and its role as a physiologic calcium blocker. (National Center for
331 Biotechnology Information, 2023b; van Dam et al., 2010). An ionic compound, magnesium sulfate is highly
332 soluble in water (710 mg of the compound will solubilize in 1000 mL of water) (National Center for
333 Biotechnology Information, 2023b). Magnesium ions compete with (and inhibit) the uptake of calcium ions
334 in biological systems (van Dam et al., 2010).
335

336 Direct toxicity through non-osmoregulatory mechanisms can also occur. Magnesium ions are also a known
337 disrupter of numerous calcium-dependent processes. One study showed that organisms in surface waters
338 with low calcium concentrations are more susceptible to small elevations of magnesium concentration (van
339 Dam et al., 2010). When elevated magnesium concentrations accompany elevated calcium concentrations,
340 there is a reduction of risk effects to certain aquatic species. The same researchers also observed two plant
341 species, one with a high calcium requirements and one with low requirements. The researchers showed
342 that the magnesium toxicity to algae species (*Chlorella spp.*) is extremely low (LC_{50} = 6014 mg/L), as this
343 algal species has fewer calcium-dependent mechanisms. However, some species are at a higher risk of
344 toxicity and may not be protected by calcium amelioration (Kleinhenz et al., 2019).
345

346 Kleinhenz et. al (2019) focused on the tropical freshwater mussel *Velesunio sp.* and discussed the effects of
347 high magnesium ion environments during a critical life stage. This species occurs in naturally low-
348 hardness waterways throughout the northern Australian tropics. The researchers observed the species'
349 growth and survival, first from larvae to juvenile, and then the first two weeks of the juvenile stage when
350 an adult shell begins forming. The researchers found that *Velesunio sp.* is moderately sensitive to
351 magnesium toxicity when compared to other freshwater species such as:

- 352 • the crayfish *Austropotamobius palippes spp.* and *Orconectes limosus*
- 353 • the water flea *Daphna magna*
- 354 • the worm *Caenorhabditis elegans*
- 355

356 Of these, the mussels response to magnesium sulfate were more comparable to *A. palippes*, with an LC_{50}
357 range of 270–480 mg/L. *C. elegans* was the least sensitive species mentioned in the study, with an LC_{50} of
358 4389 mg/L.
359

Report Authorship

361 The following individuals were involved in research, data collection, writing, editing, and/or final
362 approval of this report:
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370 All individuals are in compliance with Federal Acquisition Regulations (FAR) Subpart 3.11 – Preventing
371 Personal Conflicts of Interest for Contractor Employees Performing Acquisition Functions.
372

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